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Aims and Scope

Korean Journal of Interventional Radiology, the official English-language journal of the *Korean Society of Interventional Radiology (KSIR)*, is an international peer-reviewed academic journal dedicated to interventional radiology. *KJIR* will publish cutting-edge and impactful scientific research articles in the field of interventional radiology.

KJIR will feature peer-reviewed original articles, authoritative reviews, systematic reviews and meta-analysis, case reports, and expert opinion on novel techniques and technologies.

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Interventional radiologist's guide to the latest trends in pulmonary arteriovenous malformation management

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Pulmonary arteriovenous malformations (PAVMs) are rare congenital vascular anomalies characterized by a direct connection between pulmonary arteries and veins, resulting in right-to-left shunting, arterial hypoxemia, and an increased risk of paradoxical embolic events. Endovascular embolization has become the standard of care for the treatment of PAVMs, significantly reducing the risk of neurologic and hemorrhagic complications. However, optimal patient selection, choice of embolic materials, procedural strategies, and post-treatment surveillance remain areas of active evolution. This review provides an interventional radiologist–focused overview of contemporary practice in PAVM management. Key topics include the clinical relevance of hereditary hemorrhagic telangiectasia, current indications for treatment in adult and pediatric populations, and periprocedural strategies to minimize complications such as air embolism and catheter-related thrombosis. Advances in embolic materials, including detachable coils, venous sac embolization techniques, and vascular plugs, are discussed with an emphasis on their relative efficacy and impact on recanalization and reperfusion rates. Procedure-related complications and their management are reviewed, highlighting both common self-limiting events and rare but serious adverse outcomes. Finally, current approaches to post-embolization surveillance are summarized, with a focus on the role of computed tomography, metal artifact reduction techniques, and emerging dynamic imaging modalities such as time-resolved magnetic resonance angiography for detecting treatment failure. By integrating recent evidence and practical procedural considerations, this review aims to support interventional radiologists in optimizing the safety, durability, and long-term outcomes of PAVM embolization.

Keywords: Pulmonary arteriovenous fistulas; Embolization; Magnetic resonance angiography; Surveillance; Endovascular

Introduction

Pulmonary arteriovenous malformations (PAVMs) are rare congenital vascular anomalies of the lung characterized by direct communication between a pulmonary artery and vein without an intervening capillary bed [1]. This leads to the direct passage of arterial blood into the venous system, resulting in arterial hypoxemia and an increased risk of paradoxical embolism. Such paradoxical embolism can lead to complications like brain infarction, brain abscess, transient ischemic attack, or even myocardial infarction [2-5]. Additionally, PAVMs carry a risk of rupture and hemorrhage, which can lead to significant complications for the patient [6]. As an interventional radiologist specializing in the embolization of PAVMs, it is essential to understand the clinical implications of the associated hereditary hemorrhagic telangiectasia (HHT), as well as the advantages and limitations of current embolic materials. Furthermore, a comprehensive evaluation

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of the various embolization techniques and the appropriate post-procedural follow-up is crucial. This review article aims to provide a thorough synthesis of these aspects, thereby enhancing clinical practice and patient outcomes.

Hereditary Hemorrhagic Telangiectasia

HHT is an autosomal dominant disease with an estimated prevalence of 1 in 5,000 [7]. It is characterized by clinically significant vascular lesions involving the skin and mucosa (nasal and gastrointestinal), as well as the brain, lungs, and liver. It is underdiagnosed, and a long diagnostic delay is common [8]. A diagnosis of HHT allows appropriate screening and preventive treatment to be undertaken in a patient and their affected family members. The most common symptom of HHT, epistaxis, has an age-related expression, as does the appearance of the typical telangiectasia (Fig. 1). The diagnosis of HHT is well described in Curaçao criteria (Table 1). In patients with symptoms or signs of a PAVM by history and/or physical examination, contrast-enhanced or agitated saline bubble echocardiography remains the best initial screening tool because of its high sensitivity and negative predictive value approaching 100% (Fig. 1) [9]. According to the expert panel, if HHT is confirmed or suspected, a workup for PAVMs is necessary, and for this workup, contrast-enhanced echocardiography is recommended [10].

Treatment Indications

To prevent paradoxical embolism or life-threatening bleeding, all detected PAVMs should be treated in adult patients. Historically, a feeding artery diameter of '3 mm' was considered the minimal diameter criterion for treatment of PAVMs [2]. However, with advances in embolic devices and catheter systems, less than 3 mm feeding arteries ≥2 mm can now be embolized (Fig. 2) [11]. Pregnancy is a special risk factor in

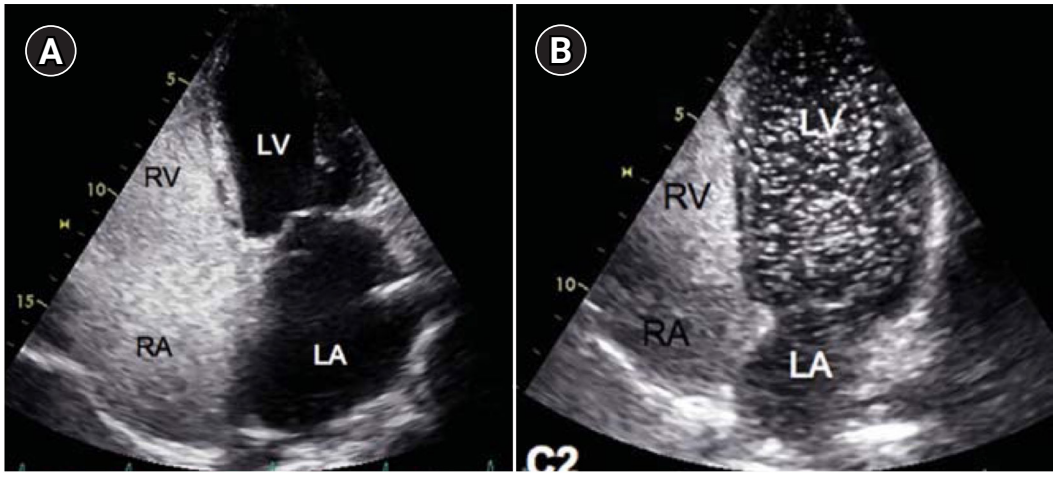

Fig. 1. Agitated saline bubble echocardiography images. (A) After injection of agitated saline bubbles into a peripheral vein, echogenic bubbles are seen filling the right heart. Under normal conditions, the bubbles are completely filtered by the pulmonary capillary bed, and no bubbles appear in the left cardiac chambers. (B) After the appearance of bubbles in the right cardiac chambers, bubbles are subsequently observed in the left cardiac chambers after three cardiac cycles, indicating the presence of an extracardiac shunt (pulmonary arteriovenous malformation). RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle.

Table 1. Curaçao criteria for clinical diagnosis of HHT

Criteria	Description
Epistaxis	Spontaneous and recurrent
Telangiectasias	Multiple, at characteristic sites: lips, oral cavity, fingers, nose
Visceral lesions	Gastrointestinal telangiectasia, pulmonary, hepatic, cerebral or spinal arteriovenous malformations
Family history	A first-degree relative with HHT according to these criteria

A diagnosis of hereditary hemorrhagic telangiectasia (HHT) is considered 'definite' if three or more Curaçao criteria are present, 'possible or suspected' if two criteria are present, and 'unlikely' if 0 or 1 criterion is present.

patients with PAVM, especially in the second and third trimesters due to a decrease in peripheral vascular resistance and an increase in cardiac output by nearly 50% [12]. A recent study in 244 pregnant women with HHT showed major complications in 13%, all in patients who had not been screened or treated for PAVMs prior to pregnancy [13]. Thus, all women with HHT considering pregnancy should be screened for PAVM with computed tomography (CT) and eventually treated prior to conception.

For pediatric patients with PAVMs, it is recommended to treat only if they have symptoms, and if they are asymptomatic or have associated complex anomalies, the approach should be considered on a case-by-case basis [14]. According to recent studies [15,16], PAVMs treated in pediatric patients before puberty show a high recurrence rate because PAVMs may enlarge and evolve with somatic growth, making it difficult to determine the optimal timing for intervention. However, experts suggest that if there are symptoms or if the risk level increases—for instance, when a PAVM is large enough to risk rupture or causes significant hypoxemia—then, it is advisable to treat regardless of age. Otherwise, for asymptomatic PAVMs detected through screening, treatment is recommended after puberty [10,11].

Periprocedural Care and Strategies to Minimize Air Embolism

Although the evidence regarding the necessity of intravenous sedation or general anesthesia for the procedure is unclear, in the case of pediatric patients, the procedure typically requires general anesthesia. For PAVM embolization, the right common femoral vein is generally used for access, and intravenous heparin (60–80 units/kg or 3,000–5,000 units) is administered after sheath insertion to prevent catheter-related

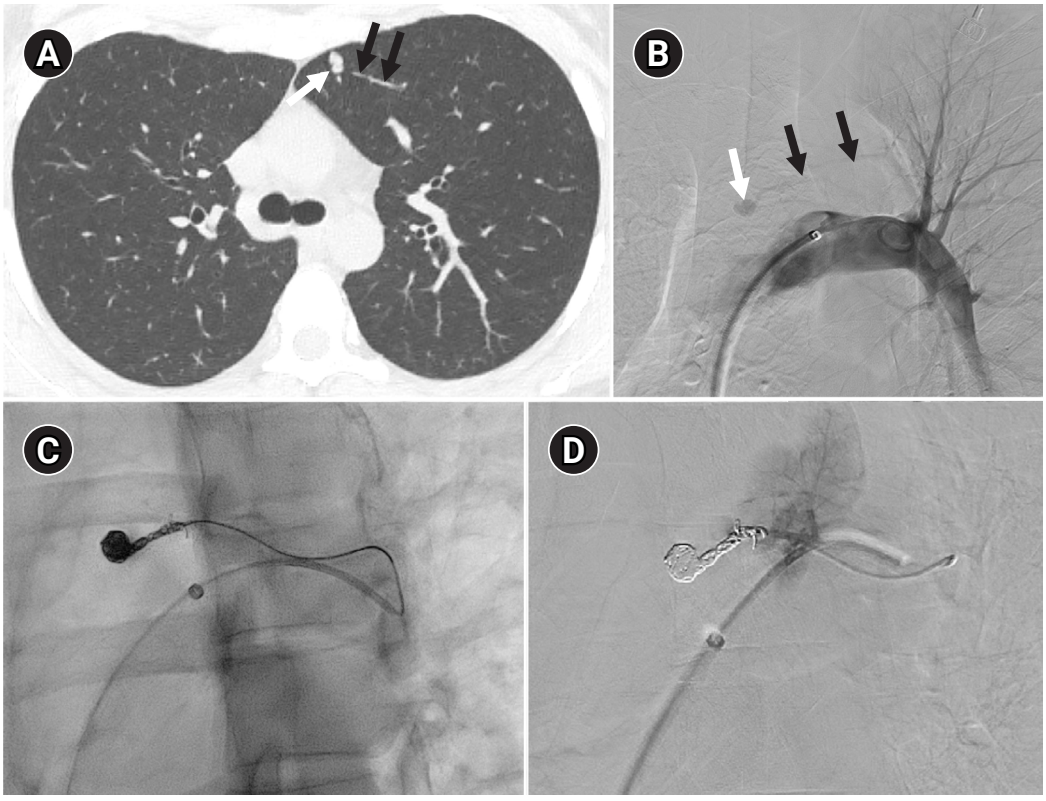

Fig. 2. Embolization of a 1.5-mm feeding artery associated with an arteriovenous malformation in the left upper lobe of a 36-year-old female patient. (A) On the computed tomography (CT), a slender 1.5 mm feeding artery to the left upper lobe (black arrows) and a dilated venous sac (white arrow) are visible. (B) On angiography, the same finding as on the CT is observed (black arrows and white arrow), and the angulated course makes plug embolization difficult. (C, D) A scene of coil embolization (C) and a post-embolization angiography image (D). In panel (D), the tri-axial system was utilized, including a 6-Fr Shuttle guiding catheter, a 5-Fr angled catheter, and a 1.9-Fr microcatheter, to access the feeding artery. Coil embolization was performed using Concerto 3D and Helix coils.

thrombosis. After sheath insertion, a 7- to 8-Fr vascular sheath is typically used, and long guiding catheters of about 80–90 cm, as well as diagnostic catheters, are employed to access the pulmonary artery via the right atrium. The reason for using a sufficiently long guiding catheter is to reduce catheter exchanges, thereby minimizing arrhythmias and reducing the risk of air embolism. Additionally, it provides more stable support during the embolization procedure, helping to ensure precise placement and control. There is no evidence supporting the use of prophylactic antibiotics for this procedure.

In PAVM embolization, the selection and catheterization of the target feeding artery can be challenging. It is important to analyze the detailed anatomy and branching patterns using pre-procedural CT scans. If fusion imaging is available, incorporating those fused images is also recommended [17]. In cases such as the right middle lobe or the lingular division of the left upper lobe, where there is a sharp angulation of about 90 degrees, it is important to choose a diagnostic catheter shape that corresponds appropriately. If the feeding artery is identified, a guidewire or microcatheter can be used to approach the feeding artery more closely. This allows advancement of a 4- or 5-Fr catheter or guiding sheath deeper into the feeding artery, improving stability during embolization. Special caution is required to prevent air embolism and intraprocedural thrombus formation. To minimize the risk of thromboembolism, meticulous heparinized saline flushing using a rotating Y-connector is essential. At the author's institution, two separate heparinized saline flushing systems (5,000 U of heparin mixed with 500 mL of saline) are routinely prepared: one for the 6-Fr guiding sheath and another for flushing 4- or 5-Fr catheters. These systems can be connected between the diagnostic catheter and the microcatheter or the Amplatzer vascular plug adaptor to ensure continuous flushing and reduce the risk of air or thrombus introduction. Special caution is required to prevent air embolism. To prevent air embolism, it is important to use a heparinized saline flushing technique with a rotating Y-connector. Additionally, performing guidewire or coil insertion and exchanges under a water seal, essentially submerged in fluid, can also be helpful (Fig. 3). During the procedure, when injecting contrast material—particularly into the feeding artery—it is essential to aspirate blood and confirm that all air has been completely removed from the catheter. This is especially important when accessing small-caliber feeding arteries, as the catheter tip may become wedged within the vessel lumen, increasing the risk of air being introduced or trapped inside the catheter. When air embolism occurs, issues can arise mainly if the air enters the coronary arteries or the cerebral circulation. If an air embolism occurs in the heart, the patient may experience sudden-onset chest discomfort and difficulty breathing, which usually improves with conservative management such as providing oxygen.

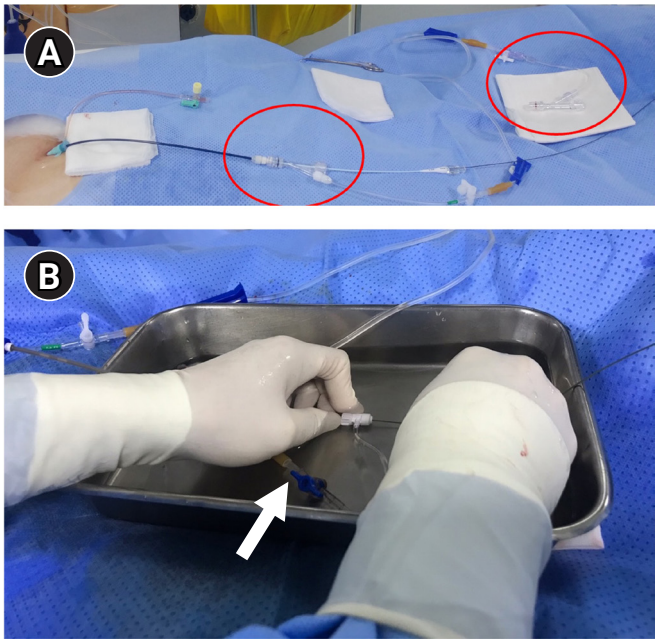

Fig. 3. Techniques to prevent air embolism and intracatheter thrombosis during pulmonary arteriovenous malformation procedures. The illustration demonstrates the use of two rotating Y-connectors (red circles) with heparinized saline flushing (A) one for guiding catheter and another for 5-Fr catheter, as well as underwater insertion techniques (B) to minimize the risk of air embolism and catheter-related thrombosis. Note, second flushing line is connected to vascular plug adaptor (arrow).

Embolic Materials and Techniques

Historically, detachable balloons were used as an embolization material; however, they are no longer utilized in current practice [18]. In the context of PAVM embolization, the use of coils, vascular plugs, or a combination of both is now standard practice [19-21]. Since the development of detachable coils, they have offered advantages over pushable coils, particularly in terms of repositioning during the procedure. They can even be fully retrieved and redeployed if necessary, enhancing procedural safety and control. It is crucial to prioritize minimizing the recanalization rate while ensuring the

overall safety of the procedure when selecting the appropriate embolic materials and techniques. Feeding artery coil embolization was historically regarded as the standard approach, whereas venous sac embolization was discouraged because of the perceived risk of rupture [22]. However, with the introduction of newer venous sac embolization techniques, recent findings now indicate that tightly packing the venous sac with coils can achieve a higher success rate than the traditional feeding artery approach (Fig. 2) [22-25]. Additionally, vascular plugs, including micro-vascular plugs (Medtronic, Minneapolis, MN, USA) and Amplatzer vascular plugs (Abbott Vascular, Saint Paul, MN, USA) have also demonstrated a higher success rate compared to feeding artery coil embolization (Fig. 4) [26-28]. In the case of vascular plugs, the risk of device migration is relatively low. Moreover, an additional advantage is that the device can be repositioned if the sizing is not ideal or if it is not deployed in the exact desired location. This flexibility enhances the precision of the procedure (Fig. 5). In a recent European guideline, there is also a recommendation to consider vascular plug embolization as a first-line option whenever possible, rather than coil embolization [11]. Additionally, a recent meta-analysis recommended vascular plugs or venous sac coil embolization, noting that vascular plugs had a recanalization rate of 13.6% compared to 32.7% for coil-only embolization. Similarly, venous sac embolization showed a 3.8% recanalization rate, while feeding artery embolization had a rate of 24.3%. Additionally, a recent meta-analysis has recommended the use of vascular plug or venous sac coil embolization, as these techniques have demonstrated a lower persistence rate compared to other methods [21]. This shift is

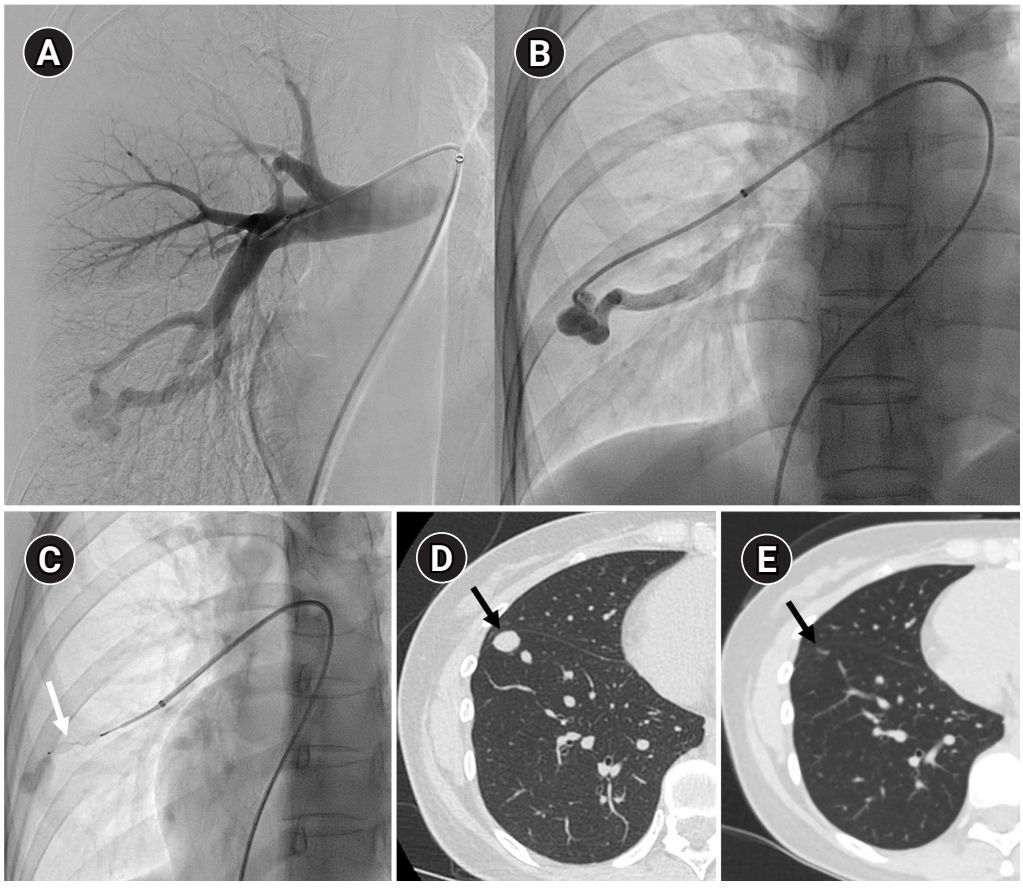

Fig. 4. The images show a 38-year-old female patient undergoing pulmonary arteriovenous malformation embolization using an Amplatzer vascular plug. (A) A simple pulmonary arteriovenous malformation is observed in the right pulmonary angiography, and the feeding artery diameter is measured at 3.7 mm. (B) An 8-Fr, 80-cm guiding catheter and a 5-Fr Berenstein angled catheter were used to advance to the distal end of the feeding artery. (C) A 7-mm Amplatzer vascular plug type IV (arrow) was deployed at the distal portion of the feeding artery with a 100% oversizing. (D, E) The large venous sac (arrow) that was visible on the pre-procedure non-enhanced chest computed tomography (CT) (D) had only a trace remaining (arrow) on the CT performed 6 months later (E).

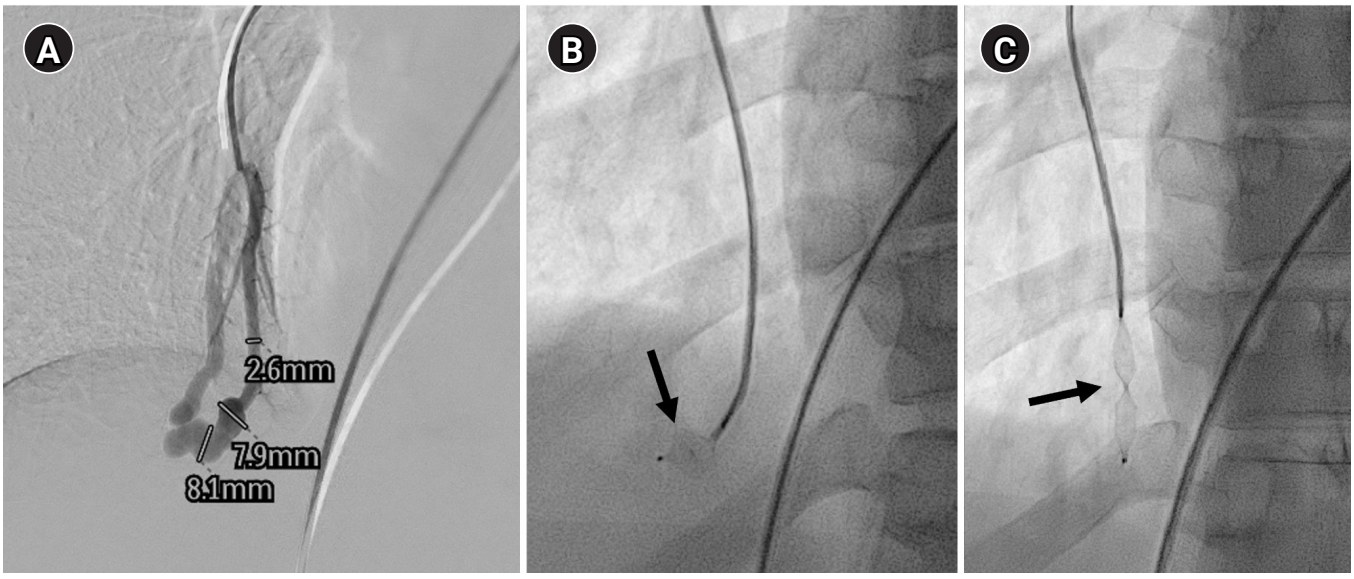

Fig. 5. Embolization procedure in a patient with a feeding artery diameter of 2.6 mm and a venous sac diameter of 8 mm in the right lower lobe. (A) Selective angiography of the right lower lobe pulmonary arteriovenous malformation. (B) A 7 mm Amplatzer vascular plug type IV (arrow) was deployed into an approximately 8 mm venous sac, and it was determined that this would not provide adequate embolization effect. (C) By repositioning the Amplatzer plug and deploying it at the distal part of the feeding artery (arrow), it becomes clear that an Amplatzer vascular plug sufficiently larger than the feeding artery's size is needed to effectively achieve embolization.

largely in response to the relatively high recanalization rate associated with feeding coil embolization. In the case of embolization using vascular plugs, the plug should be deployed at the most distal segment of the feeding artery just before the venous sac in order to preserve the normal pulmonary artery. Since the pulmonary artery contains less elastin and has a thinner wall compared to systemic arteries, it is more distensible [29]. Therefore, in the author's experience, oversizing by about 50% to 100% has been effective in reducing the recanalization rate. When performing venous sac coil embolization, it is important to use coils large enough to create a stable framing coil larger than the draining vein diameter, thereby preventing coil migration. After establishing this frame, the venous sac and the proximal feeding artery should be carefully packed to achieve complete occlusion.

Procedure-Related Complications

The most common complication during PAVM embolization is pleuritic chest pain [1]. In addition, transient arrhythmias may occur due to intracardiac catheter manipulation, although these are typically self-limiting. A small amount of air may also be inadvertently introduced during the procedure, potentially leading to acute chest discomfort or dyspnea. Such symptoms are usually transient and can be managed with intravenous nitroglycerin or atropine, resolving spontaneously as the air is absorbed. Additionally, patients may experience arrhythmias caused by intracardiac catheterization during the procedure, but these are typically self-limiting. A small volume of air can be introduced during the procedure, which typically enters the coronary arteries and may cause sudden-onset chest discomfort or dyspnea. In such cases, this can be managed with intravenous nitroglycerin or atropine, and it generally resolves once the air is absorbed without significant issues [30]. In contrast, device-related complications primarily include migration of embolic materials into the pulmonary vein. Given that the pulmonary vein generally has a larger diameter than the corresponding pulmonary artery, appropriate device sizing is essential. The use of a framing coil larger than the draining vein diameter or an adequately oversized vascular plug is recommended to minimize the risk of device migration. In addition, continuous flushing with heparinized saline helps prevent thrombus formation within the catheter. To prevent these complications, it is advisable to use the framing coil or an appropriately oversized plug to prevent device migration into the pulmonary vein. Additionally, flushing through a heparinized saline line can help prevent thrombus formation within the catheter.

Pulmonary parenchymal hemorrhage can occur due to the device or catheter, and it is usually self-limiting, often accompanied by mild hemoptysis. In cases where the device causes pulmonary artery perforation, quickly occluding the feeding artery with an appropriate embolic material can reduce further complications such as hemothorax [31].

Surveillance after Embolization

Long-term follow-up after treating PAVMs is needed to detect newly developed PAVMs and to identify persistence or recurrent flow [10,11]. Treatment failure in PAVMs can be classified as recanalization and reperfusion. Recanalization refers to the reopening of blood flow through spaces between the previously placed embolic material (Fig. 6). Reperfusion, on the other hand, occurs when blood flow from an adjacent pulmonary artery reopens the previously embolized distal vein or venous sac (Fig. 7) [32]. As the primary follow-up modality, CT is recommended, but there are currently no specific guidelines on whether or not to use contrast enhancement [33]. It is recommended to perform an initial evaluation by CT about 6 months after PAVM embolization, and then follow-up with CT every 3–5 years thereafter (Fig. 8). In CT follow-up, the evaluation is based on the reduction rate of the venous sac or the draining vein, and the traditional criterion is that there should be at least a 70% reduction in the size of the venous sac or draining vein [34,35]. In recent studies, there have been opinions that this 70% size reduction criterion is too strict. In response, some research using angiographic-confirmed cases or time-resolved magnetic resonance angiography (TR-MRA) has proposed a 50%–60% guideline [36,37]. When using CT, repeated radiation exposure and metal artifacts from the coils can be problematic. By using metal artifact reduction techniques, it is possible to obtain clear images of the surrounding

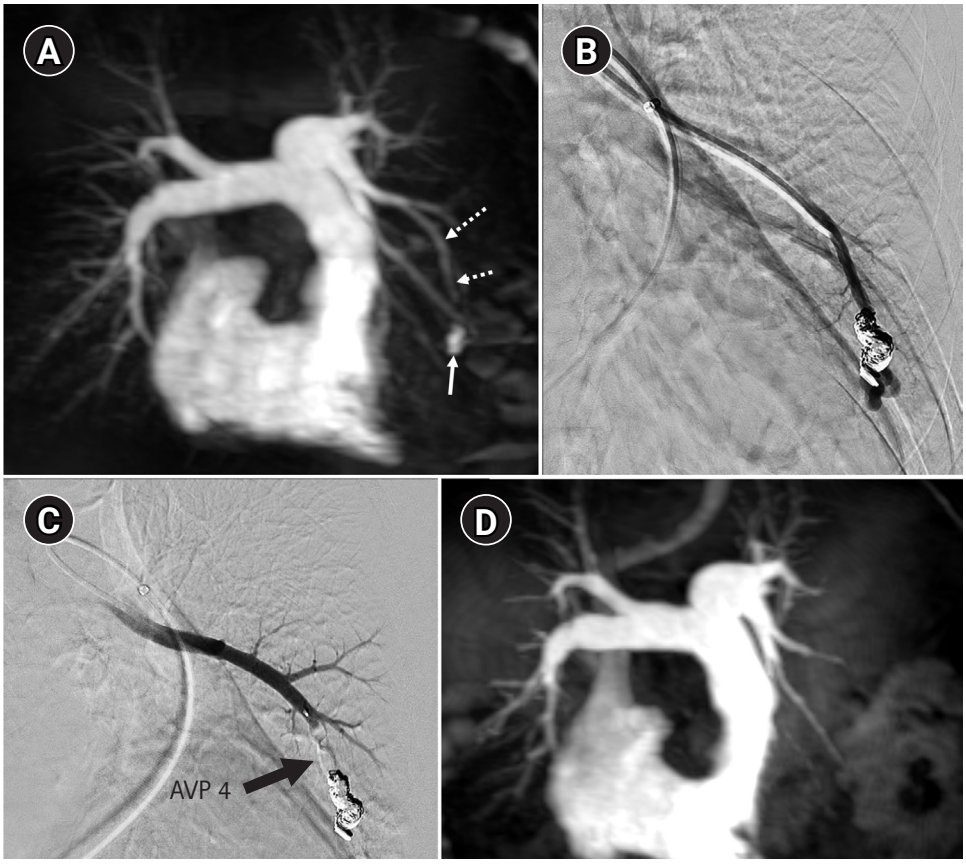

Fig. 6. Time-resolved magnetic resonance angiography (TR-MRA) and procedural images of a pulmonary arteriovenous malformation showing recanalization. (A) In the TR-MRA performed before the procedure, a venous sac (arrow) is observed concurrently with the feeding artery (dashed arrows). (B) Recanalization was confirmed in the selective angiography. (C) Utilizing additional coils and an 8 mm Amplatzer vascular plug type IV (AVP 4) (arrow), the feeding artery embolization was carried out. (D) On the 6-month follow-up TR-MRA, the feeding artery is no longer visible, and the venous sac is also not observed.

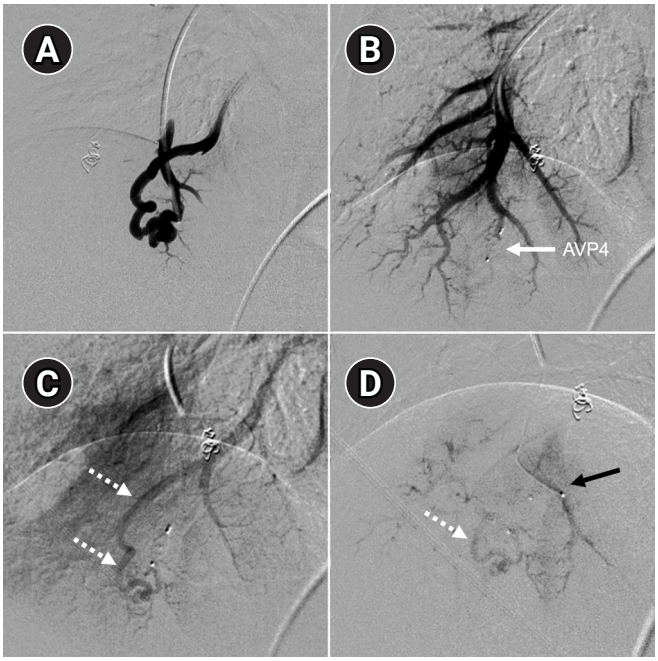

Fig. 7. Example of a patient showing reperfusion after pulmonary arteriovenous malformation (PAVM) embolization using an Amplatzer vascular plug type IV (AVP 4). (A) Angiography of a simple-type PAVM in the right lower lobe accessed with a 5-Fr catheter. (B) Early pulmonary arterial phase image from a diagnostic angiography performed three years later due to suspected reperfusion on follow-up computed tomography, showing that the pulmonary vein is not visible distal to the AVP 4 (indicated by the arrow). (C) Delayed phase image confirming the pulmonary vein, marked by dashed arrows, which corresponds to the venous sac and draining vein seen in (A), now reduced in size. (D) A typical example of reperfusion shown on angiography using a microcatheter in an adjacent pulmonary artery, illustrating multiple newly formed tortuous collaterals leading to the draining vein (marked by dashed arrow). In this patient, additional AVP 4 embolization was performed at the tip of microcatheter (black arrow). However, draining vein size persisted even after additional treatment (not shown).

parenchyma, and this also helps in assessing parameters like the draining vein diameter reduction rate (Fig. 9) [38]. Furthermore, low-dose CT protocols may help reduce cumulative radiation exposure during repeated follow-up imaging.

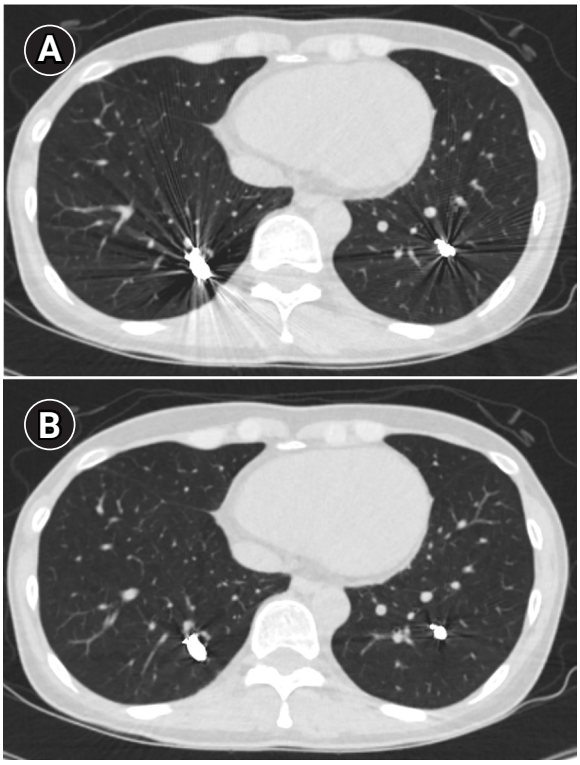

Fig. 9. Computed tomographic images of a patient with bilateral lower lobe pulmonary arteriovenous malformations treated with coil embolization. (A) Image without metal artifact reduction, showing prominent beam-hardening artifacts that obscure the evaluation of surrounding vessels and parenchyma. (B) Image with metal artifact reduction technique applied, significantly reducing beam-hardening artifacts and allowing for better evaluation of the adjacent vessels and parenchyma.

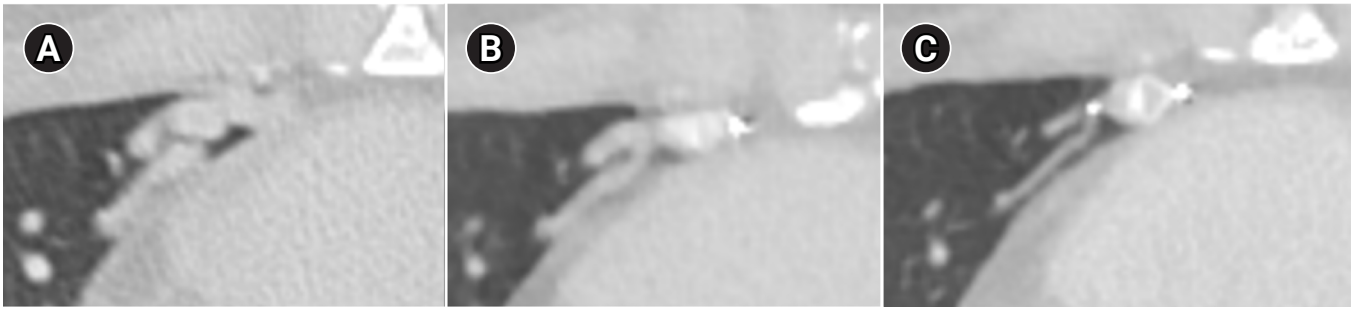

Fig. 8. Computed tomographic (CT) images of a pulmonary arteriovenous malformation before the procedure (A), 20 days after embolization (B), and at the 6-month follow-up (C). After the procedure, at both 20 days and 6 months, the diameter of the feeding artery and the draining vein is gradually reduced. In this case, the embolization was performed using an Amplatzer vascular plug type IV. Notably, the Amplatzer vascular plug produces minimal beam-hardening artifacts on CT, aiding in the evaluation of vessel diameter and the surrounding parenchyma.

In parallel, increasing attention has been directed toward the role of dynamic imaging modalities, particularly TR-MRA [39-42]. Reperfusion can be confirmed if the draining vein is observed simultaneously with the pulmonary artery on TR-MRA. Because TR-MRA can clearly distinguish between the pulmonary arterial and pulmonary venous phases, and because it is less affected by coil artifacts, it allows for a more reliable differentiation between residual arteriovenous malformation and residual sac filling caused by normal pulmonary vein drainage (Fig. 10) [41].

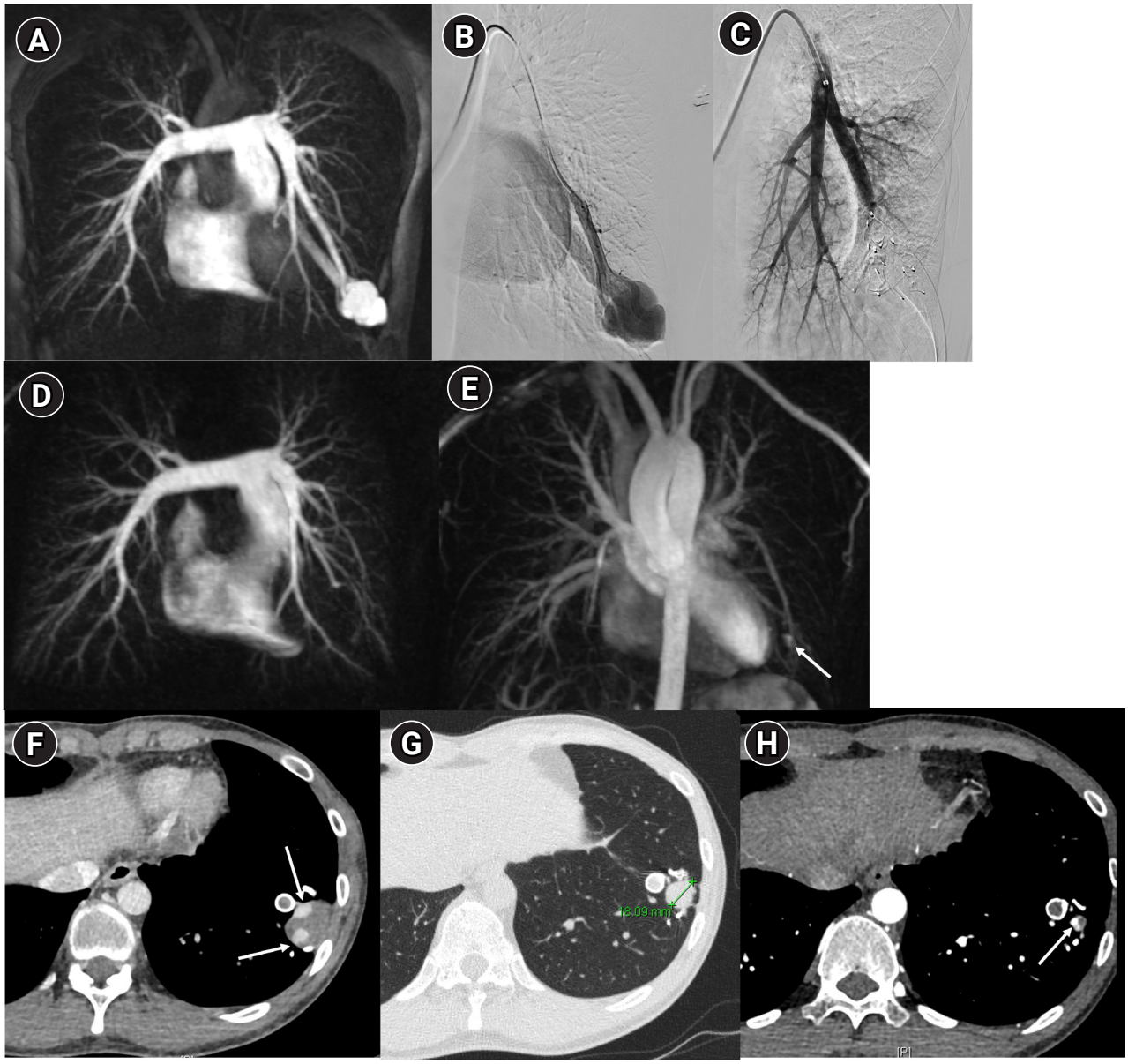

Fig. 10. Images before and after embolization using a vascular plugs in a patient with a large pulmonary arteriovenous malformation (PAVM) in the left lower lobe. (A) In the time-resolved magnetic resonance (MR) angiography, a PAVM in the left lower lobe exhibiting an early draining vein is observed. (B, C) The pulmonary arteriography also shows the same findings, and feeding artery embolization was performed using one Amplatzer vascular plug type II and six Amplatzer vascular plugs type IV devices. (D, E) In the 6-month follow-up time-resolved MR angiography, no rapidly appearing vein is observed in the arterial phase, and in the delayed phase, there is enhancement within the venous sac (arrow), which is considered part of the normal draining vein. (F–H) In the computed tomographic images taken at 1 month (F), 6 months (G), and 18 months (H) post-treatment, the thrombosed venous sac gradually diminishes, leaving only the normal draining vein (arrows) inside.

Conclusion

Endovascular embolization remains the cornerstone of treatment for PAVMs, offering effective prevention of paradoxical embolism and hemorrhagic complications when appropriately performed. Ongoing advances in embolic materials and techniques—particularly the use of vascular plugs and venous sac embolization—have significantly improved treatment durability by reducing recanalization and persistence rates.

A thorough understanding of PAVM anatomy, careful procedural planning, and meticulous attention to periprocedural techniques are essential to minimize complications such as air embolism, device migration, and vascular injury. Long-term surveillance is equally critical, as treatment failure may occur through either recanalization or reperfusion. In this context, evolving imaging strategies, including metal artifact–reduced CT and TR-MRA, provide valuable tools for accurate post-treatment assessment while mitigating limitations of conventional imaging.

As evidence continues to evolve, individualized treatment strategies that balance procedural safety with long-term efficacy are paramount. An interventional radiologist–centered, evidence-based approach is essential for optimizing outcomes in patients with PAVMs, particularly those with HHT who require lifelong surveillance and management.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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None.

Author contributions

The author conducted all aspects of the study.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

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Review Article

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Strategic integration of radioembolization and chemoembolization for the management of hepatocellular carcinoma in Korea

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Transarterial chemoembolization (TACE) has long been the standard locoregional therapy for unresectable hepatocellular carcinoma, while transarterial radioembolization (TARE) using yttrium-90 microspheres has emerged as a promising alternative driven by advances in dosimetry and improved outcomes. TARE offers high complete response rates, durable local control, and minimal post-embolization syndrome, particularly in patients with localized or large tumors and preserved hepatic function. However, its broader use is limited by radiation-related toxicity, technical challenges, and socioeconomic factors, including high cost and limited repeatability. In contrast, TACE remains widely applicable, repeatable, and cost-effective, achieving excellent tumor control through refined superselective techniques, especially in Korea. Rather than competing modalities, TARE and TACE should be integrated within a tailored treatment strategy, with the choice determined by tumor characteristics, hepatic reserve, and institutional expertise.

Keywords: Hepatocellular carcinoma; Therapeutic radioembolization; Therapeutic chemoembolization

Introduction

Hepatocellular carcinoma (HCC) is a hypervascular malignancy that arises predominantly in cirrhotic livers, and its arterial vascularity makes transarterial therapy a key component of disease management [1-5]. Since the 1980s, transarterial chemoembolization (TACE) has been established as the cornerstone of locoregional therapy for unresectable HCC, with its efficacy in improving tumor response and survival confirmed by pivotal randomized controlled trials, large-scale Japanese cohort studies, and subsequent meta-analyses [6-10]. Building on this robust evidence, TACE remains the most widely recommended treatment for patients with large or multifocal HCC and is also extensively employed both as an initial therapy and as a salvage option for post-treatment recurrence [3-5].

In recent years, transarterial radioembolization (TARE) using yttrium-90 (Y-90) microspheres has shown a rapid increase in clinical use, driven by advances in personalized dosimetry, improved treatment planning, and accumulating evidence of favorable tumor control and survival outcomes [11,12]. In Korea, the expansion of National Health Insurance coverage for TARE since December 2020 has accelerated its clinical adoption, especially in patients with larger tumor burdens or in those considered unsuitable for surgical resection or other locoregional therapy [13].

This review is based on two recent publications in the Korean Journal of Radiology: the 2023 Korean Liver Cancer Association expert consensus on TACE and the 2025 review on opti-

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mizing Y-90 TARE dosimetry for HCC [13,14]. Building on the core principles discussed in these works, this article provides a comparative overview of TACE and TARE, focusing on their therapeutic mechanisms, advantages, limitations, and optimal indications within Korean clinical practice. This context inevitably leads to a central clinical question: Can TARE realistically replace TACE in the management of HCC?

TARE Compared with TACE: Treatment Mechanisms

TACE achieves tumor necrosis through ischemic injury and cytotoxic effects induced by transarterial infusion of chemoembolic materials [14,15]. To enhance tumor response and minimize injury to non-tumorous parenchyma, superselective catheterization is crucial. In conventional TACE, chemotherapeutic agents are mixed with lipiodol, an iodized poppy seed oil that has been used for more than a century as an oil-based contrast agent in radiology (e.g., lymphangiography and myelography), to form a radiopaque emulsion that allows real-time fluoroscopic visualization of the chemoembolic material distribution [14].

TARE, also known as selective internal radiation therapy, delivers Y-90 labeled microspheres into the hepatic artery [13]. These particles lodge in the tumor microvasculature and emit β-radiation, producing tumoricidal effects without causing complete arterial occlusion. In the aspect of treatment mechanism, TARE more closely resembles external beam radiation therapy (EBRT) than TACE. However, EBRT delivers homogeneous, calibrated doses to a defined target, whereas TARE distributes radiation heterogeneously according to tumor vascularity and microsphere deposition, even with advances in predictive dosimetry modeling. Two types of Y-90 microspheres are commercially available in Korea: glass microspheres and resin microspheres. In glass microspheres, Y-90 is embedded within a glass matrix, resulting in higher density and a high specific activity of approximately 4,000 Bq per particle, producing minimal embolic effect. In contrast, resin microspheres consist of Y-90 coated onto a resin core, with lower specific gravity and specific activity of around 50 Bq per particle, leading to a relatively greater embolic effect and a more uniform distribution within the tumor vascular bed.

The dose–response relationship in Y-90 TARE is a critical determinant of therapeutic efficacy. Because glass and resin microspheres differ in their physical and radiologic characteristics, they exhibit distinct dose–response thresholds. Glass microspheres generally require a higher tumor-absorbed dose to achieve comparable treatment outcomes, whereas resin microspheres, with their lower specific activity and larger particle number, can exert a stronger radiobiologic effect even at lower absorbed doses [16]. For HCC, the tumoricidal absorbed dose is generally considered to be approximately in the range of >205–260 Gy for glass microspheres and >100–157 Gy for resin microspheres [13]. Increasing evidence supports a strong positive correlation between tumor-absorbed dose and tumor response, emphasizing the importance of personalized dosimetry to achieve adequate tumor irradiation while minimizing radiation injury to non-tumorous liver parenchyma [11,17].

TARE Compared with TACE: Pros

Recent advances in dosimetry optimization have markedly improved the therapeutic outcomes of TARE. Radiation segmentectomy and radiation lobectomy have expanded the role of TARE from a palliative treatment to a potentially curative modality. In early or localized HCC, radiation segmentectomy can achieve complete necrosis by delivering ablative radiation doses confined to one or two hepatic segments (Fig. 1). In the LEGACY study, which included patients with solitary HCCs (median diameter, 2.7 cm; range, 1.0 to 8.1 cm), radiation segmentectomy achieved a 2-year complete response (CR) rate of 84% [12]. In the RASER trial, a single-center prospective study conducted in patients with solitary HCCs ≤ 3 cm, the initial objective response rate was 100 % [18]. This outcome was superior to that reported in a Korean retrospective study (2-year CR rates in 1–10 cm HCCs: 66.2% with conventional TACE and 30.5% with drug-eluting bead TACE [DEB-TACE]) and a Japanese randomized controlled trial (3-month CR rates in 1–5 cm HCCs: 75.2% with conventional TACE and 27.6% with DEB-TACE) [19,20]. Several studies have further demonstrated that radiation segmentectomy can achieve local tumor control rates comparable to those of surgical resection or local ablation, when appropriate dosimetry is achieved [21]. Even for multifocal or bulky tumors, Korean investigators have expanded this principle beyond segmentectomy into a

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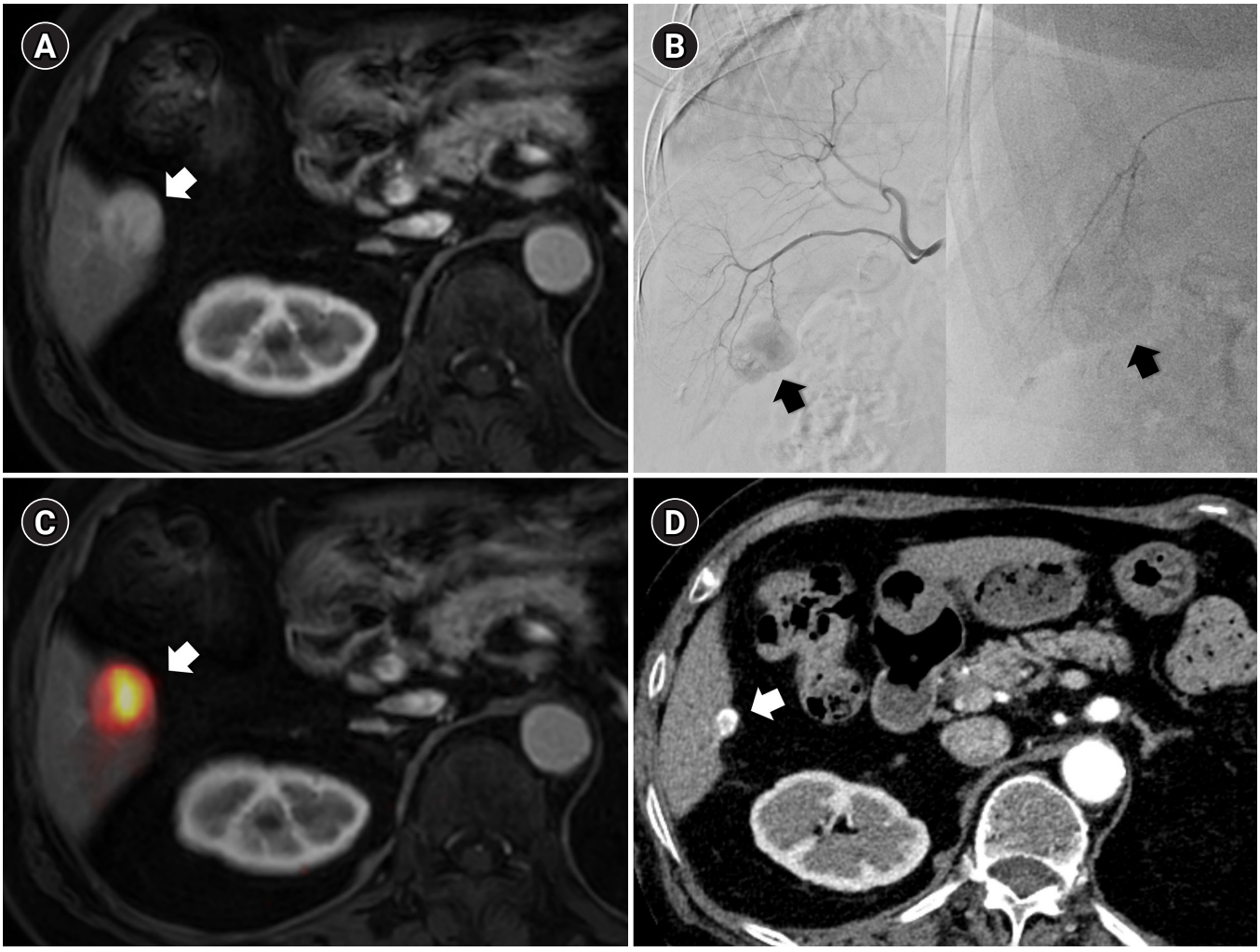

Fig. 1. Radiation subsegmentectomy in an 86-year-old man with a single nodular hepatocellular carcinoma. (A) Liver magnetic resonance imaging shows a 2.2-cm hypervascular tumor (arrow) with exophytic growth in segment 6. (B) Hepatic arteriography shows a hypervascular tumor (arrows), and the microcatheter was advanced into a subsegmental branch of A6 (right side image). A total activity of 0.35 GBq of glass microspheres was infused. (C) Post-treatment Y-90 positron emission tomography shows intense uptake at the tumor (arrow), confirming a perfused liver dose of 508.7 Gy and a tumor dose of 1,794.7 Gy. Voxel-based dosimetry showed a D95 of 625 Gy and a V200 of 100% (D95: the minimum dose delivered to 95% of the target volume, V200: the percentage of target volume receiving ≥200 Gy). (D) Twenty-month follow-up computed tomography shows complete response with dystrophic calcification (arrow).

broader concept of radiation "major hepatectomy," applying ablative doses to larger anatomical territories when disease remains confined and hepatic reserve is adequate (Fig. 2). A Korean study reported a median time to progression of 17.1 months in patients with tumors averaging 11.4 cm in size treated at mean absorbed doses of 418.8 Gy [22]. Radiation lobectomy can also be used when resection is technically feasible but unsafe because the future liver remnant (FLR) is insufficient [23]. By intentionally delivering sufficient radiation dose to non-tumorous parenchyma in the target lobe, contralateral hypertrophy can be induced while simultaneously suppressing tumor progression in the treated lobe [24]. Taken together, these results indicate that territory-based TARE with high radiation dose can serve as a reasonable alternative in patients who are technically resectable but medically inoperable, or in those initially considered for resection who later become unsuitable because of comorbidities or limited hepatic reserve [25].

Because the therapeutic effect of TARE is driven by radiation-induced cytotoxicity rather than ischemic injury, the incidence of post-embolization syndrome, which presents with abdominal pain, fever, and transient elevation of liver en-

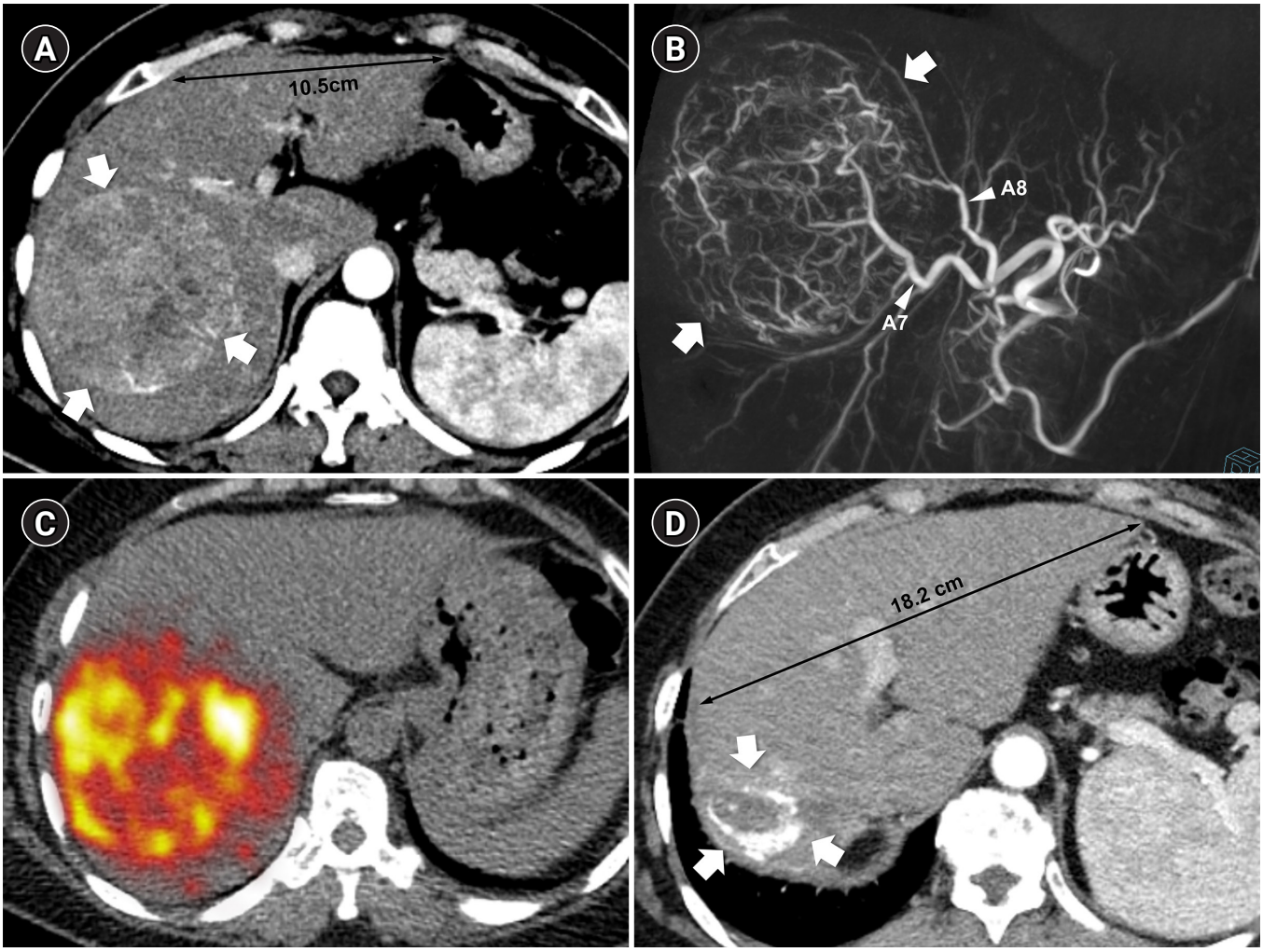

Fig. 2. Radiation major hepatectomy in a 60-year-old woman with hepatocellular carcinoma. (A) Contrast-enhanced computed tomography (CT) shows a 9.0-cm hypervascular tumor (arrows) with two satellite nodules (not shown) in segments 7 and 8. (B) Cone-beam CT hepatic arteriography shows tumor staining (arrows) supplied by A7 and A8 (arrowheads). A total of 9.11 GBq of glass microspheres was infused via A7 and A8. (C) Post-treatment Y-90 positron emission tomography shows intense uptake throughout the tumor, consistent with complete microsphere coverage, with a perfused liver dose of 355.3 Gy and a tumor dose of 609.9 Gy. (D) Fifty-month follow-up CT shows complete response with dystrophic calcification (arrows), atrophy of segments 7 and 8, and compensatory hypertrophy of the left hepatic lobe (double arrowheads).

zymes, is lower than that observed after TACE [26]. As a result, patients experience faster recovery, shorter hospitalization, and better overall tolerance. In Western countries, TARE is frequently performed on an outpatient basis, whereas in Korea it is typically carried out during a short-term hospital stay, reflecting differences in healthcare systems, reimbursement policies, and institutional practice patterns.

The minimal ischemic insult associated with TARE also translates into improved quality of life after treatment [27]. Patients generally experience fewer postprocedural symptoms and require less analgesic or supportive care. Furthermore, because radiation segmentectomy achieves high CR rates, TARE provides durable tumor control that often reduces the need for repeated transarterial sessions. This decreased frequency of retreatment lowers the cumulative treatment burden and enhances long-term patient convenience and satisfaction. Collectively, these features make TARE a well-tolerated and patient-friendly therapeutic option, particularly for individuals who may not tolerate the ischemic and systemic stress associated with TACE.

TARE Compared with TACE: Cons

TARE carries several radiation-related and technical limita-

tions that restrict its broader clinical application. Radiation pneumonitis is one of the significant complications of TARE, resulting from inadvertent shunting of Y-90 microspheres into the pulmonary circulation [28]. To minimize this risk, Western guidelines typically recommend limiting the lung dose to <30 Gy per TARE session and <50 Gy cumulatively over a lifetime. However, Korean cohort data indicate that clinically significant radiation pneumonitis has occurred even at lung doses below these Western thresholds, which may be related to smaller lung mass and higher effective radiation exposure per unit dose [29]. Therefore, a more conservative lung dose limit is advisable in Korean practice, particularly for patients with preexisting pulmonary disease or advanced liver cirrhosis [13]. For example, modified thresholds are generally applied in my clinical practice; <25 Gy for males and <20 Gy for females when using glass microspheres, and <15 Gy for resin microspheres, assuming a lung mass of approximately 1 kg. Because of this cumulative radiation constraint, patients who have undergone prior TARE often become ineligible for repeat treatment, even when intrahepatic recurrence later develops. This inherent limitation contrasts with TACE, which can be safely repeated multiple times as long as hepatic function is preserved, thereby allowing more flexible long-term disease control.

Another significant complication is radioembolization-induced liver disease (REILD), caused by radiation injury to non-tumorous liver parenchyma. REILD typically manifests as jaundice, ascites, and hepatic failure in the absence of tumor progression, and histologically corresponds to sinusoidal obstruction and veno-occlusive injury [30]. Because the absorbed radiation dose to normal liver correlates directly with hepatotoxicity, adequate hepatic reserve and a sufficient FLR are critical prerequisites for safe treatment. Patients with Child-Pugh class B or C liver function or marginal FLR are at markedly increased risk of hepatic decompensation. In practice, the safety threshold for TARE should approximate that of hepatic resection, with an FLR of at least 30% of total liver volume while preserving two contiguous Couinaud segments considered essential [5,13]. Given the higher prevalence of cirrhosis and smaller baseline liver volumes in Korean patients, a more conservative approach is often warranted. In my clinical practice, the irradiated liver volume should not exceed approximately 50% of the total normal parenchyma, and treatment should be limited to Child-Pugh class A patients with clearly demarcated arterial territories, such as localized HCCs. These precautions are crucial to minimize the risk of REILD and to preserve post-treatment hepatic function, especially when repeat or sequential therapy is anticipated, as most HCC patients ultimately require additional treatments during their lifetime. Although TARE often achieves higher CR rates, this does not necessarily translate into longer survival. There have been no large-scale randomized controlled trials comparing TARE with TACE. According to three small comparative studies and subsequent meta-analyses published before 2020, there were no significant differences in overall survival or safety outcomes between the two treatments [31].

From a procedural standpoint, TARE also presents inherent technical challenges. Unlike conventional TACE, in which chemoembolic materials are radiopaque and their distribution can be continuously observed under fluoroscopy, Y-90 microspheres are invisible during infusion, making real-time monitoring impossible [13]. Although a technetium-99m–labeled macroaggregated albumin (99mTc-MAA) scan is performed pre-procedurally to simulate microsphere distribution, actual flow dynamics during treatment may differ, often resulting in a wider-than-anticipated infusion territory and unintended radiation exposure to non-tumorous liver parenchyma. This unpredictability can contribute to hepatotoxicity or even REILD, particularly when the functional liver reserve is marginal. In addition, for central or hilar lesions, the inability to monitor microsphere flow raises another critical concern. When excessive embolic effect occurs in fine caudate or peribiliary arteries, flow stasis cannot be detected in real time, leading to prolonged high-dose radiation exposure to the peribiliary plexus and subsequent central bile duct injury [32] (Fig. 3). Therefore, achieving a truly selective and controlled infusion is technically more challenging with TARE than with TACE, where the infusion of chemoembolic materials can be directly visualized and adjusted during the procedure. These limitations underscore a fundamental difference between the two modalities: whereas TACE allows dynamic control and immediate correction of reflux or over-embolization, TARE relies entirely on pre-procedural planning and hemodynamic prediction, making the actual treatment field less predictable and inherently less selective.

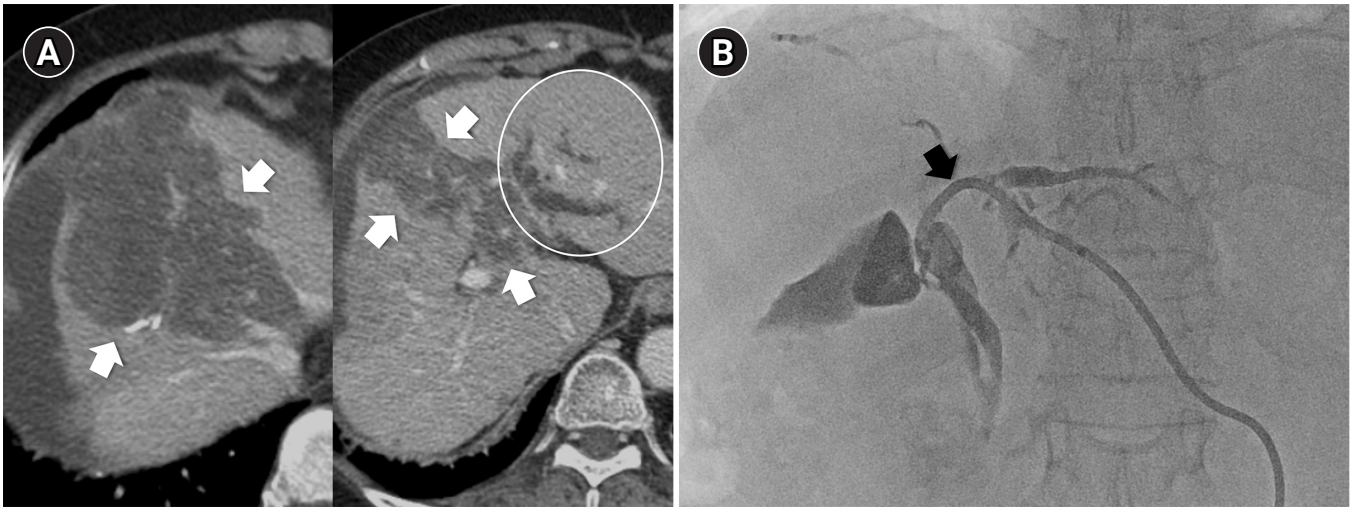

Fig. 3. Central bile duct injury after transarterial radioembolization in an 80-year-old woman with ruptured hepatocellular carcinoma. (A) Computed tomography obtained 5 months after selective infusion of Y-90 microspheres via A1, A4, and A8 shows extensive radiation necrosis (arrows) in segments 4 and 8, with dilatation of the intrahepatic bile ducts (circle) in the left lateral segments. (B) Because of progressive jaundice and pruritus, percutaneous transhepatic biliary drainage was performed, and cholangiography showed segmental occlusion of the left main bile duct (arrow), suggesting radiation-induced ductal injury.

TARE is also resource-intensive and logistically demanding. It requires close coordination among interventional radiology, nuclear medicine, and radiation safety teams. The Y-90 microspheres must be imported and used within a limited calibration window, complicating scheduling and procedural timing [13]. Comprehensive pre-treatment work-up, including mapping angiography, prophylactic embolization, and MAA scanning is mandatory, followed by post-treatment Y-90 positron emission tomography for dose verification. Furthermore, the procedure demands substantial expertise and experience. Mastery of radiation physics, dosimetry modeling, and complex hepatic flow dynamics requires a long learning curve, and the actual procedure often takes longer than conventional TACE due to detailed dose planning and safety verification. In the Korean healthcare environment, the cost of a single TARE session remains several times higher than that of TACE. As TARE use expands, its impact on the National Health Insurance expenditures is expected to increase although there are some clinical scenarios the need for fewer repeat treatments may partially offset the overall cost. These technical, educational, and socioeconomic challenges collectively limit the accessibility and scalability of TARE despite its proven therapeutic potential.

Comparative Indications and Clinical Applications

Given the advantages and limitations discussed above, it is evident that TARE cannot fully replace TACE in the treatment of HCC. Instead, these two modalities should be considered complementary tools that can be selectively applied according to tumor characteristics, liver function, and patient condition (Table 1). The therapeutic goal should not be to choose one modality over the other, but rather to combine them in a way that maximizes efficacy while minimizing hepatic injury.

TARE is particularly advantageous in early or localized HCC where curative-intent therapy is feasible, but surgery or ablation is not possible. Radiation segmentectomy can achieve high CR rates and durable local control, making it a reasonable alternative for patients who are technically resectable but medically inoperable. Because it induces minimal ischemic injury and has a low incidence of post-embolization syndrome, TARE is also suitable for elderly patients, those with comorbidities, or individuals with poor performance status who may not tolerate TACE. In addition, for patients with large tumor burden, TARE can be used as an initial debulking strategy to reduce tumor volume before subsequent TACE or systemic treatments.

Conversely, TACE remains the backbone of transarterial

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Table 1. Comparison of TARE and cTACE in key clinical domains

Domain	TARE	cTACE
Treatment mechanism	Radiation-induced cytotoxicity	Ischemia and intra-arterial chemotherapy
Local tumor control/CR rates	Higher and more durable in localized tumors (radiation segmentectomy)	Slightly lower, operator-dependent
Overall survival	Comparable	Comparable
Contralateral hypertrophy induction	Effective (radiation lobectomy)	Less effective
Superselective delivery	Limited (invisible microsphere delivery)	Excellent (real-time Lipiodol visualization under fluoroscopy)
Repeatability	Limited by cumulative lung dose and hepatic reserve	Repeatable as long as liver function preserved
Post-embolization syndrome	Less frequent	More frequent
Hospital stay	Shorter	Longer
Cost/reimbursement burden	Higher	Lower
Medical resource requirement	Higher (multidisciplinary, complex scheduling)	Lower

TARE, transarterial radioembolization; cTACE, conventional transarterial chemoembolization; CR, complete response.

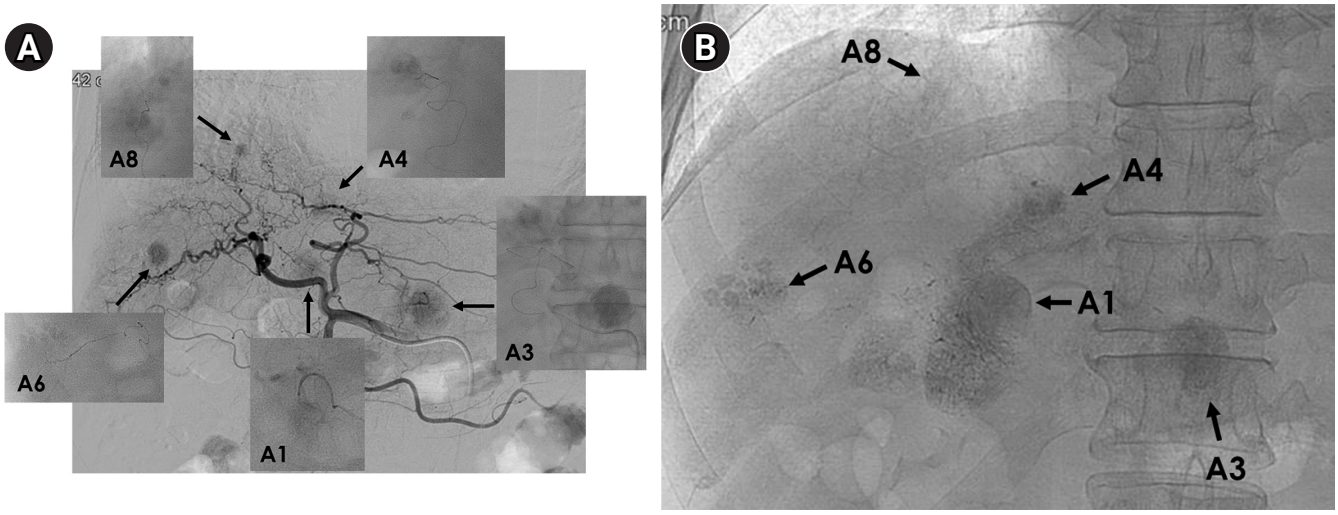

Fig. 4. Superselective transarterial chemoembolization (TACE) for five nodular tumors in a 60-year-old man. (A) Common hepatic arteriography shows five nodular tumors. Superselective TACE was performed through tumor-feeding arteries including A1, A3, A4, A6, and A8. (B) Post-TACE fluoroscopy shows dense lipiodol uptake within the tumors without significant parenchymal deposition.

therapy due to its broad applicability, repeatability, and controllability. It can be safely performed in a wide range of clinical settings as long as hepatic function is preserved. The National Cancer Center–Korean Liver Cancer Association guidelines continue to recommend TACE as the best or alternative treatment option across most stages of HCCs, underscoring its versatility and reliability [5]. Moreover, the ability to visualize lipiodol-based emulsions under fluoroscopy allows for real-time monitoring and precise control, enabling superselective embolization that maximizes tumor necrosis while sparing functional parenchyma [14] (Fig. 4). There is a report that superselective TACE yielded survival outcomes similar with early HCC for patients beyond Milan but within up-to-seven criteria [33]. Korean interventional radiologists, in particular, have achieved remarkable tumor control through refined superselective techniques, even in anatomically complex or high-risk cases where other modalities may not be feasible. The technical sophistication developed in East Asia, especially in Korea and Japan, has produced outcomes that often exceed those reported in Western studies [6]. Using meticulous microcatheter techniques, embolization can be performed safely even in patients with marginal hepatic reserve or tumors near critical structures, minimizing non-target injury while maintaining high tumor response rates. In Korea, TACE is not only technically advanced but also widely accessible and cost-effective, supported by a national

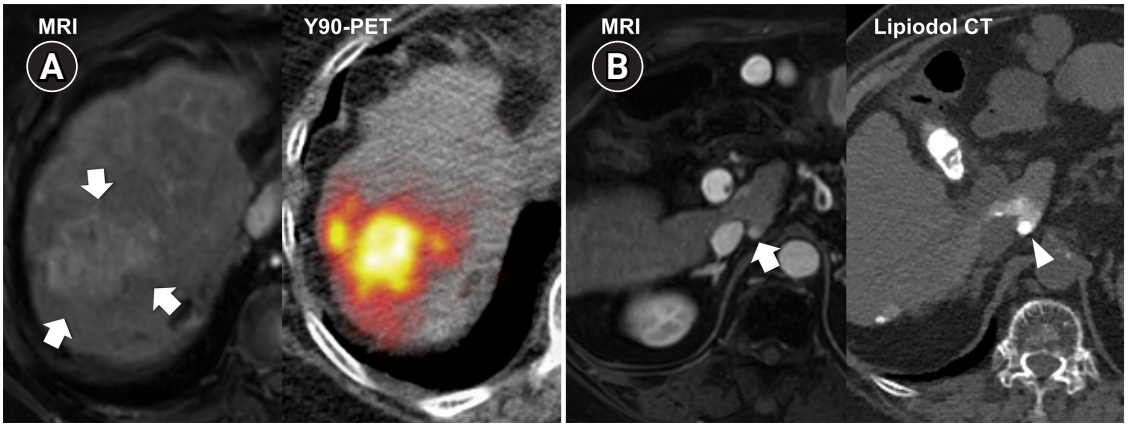

Fig. 5. Combined transarterial radioembolization and superselective transarterial chemoembolization (TACE) performed during planning angiography in a 78-year-old man with multifocal hepatocellular carcinoma (two lesions). (A) Liver magnetic resonance imaging (MRI) shows a recurrent 4.7-cm lobulating tumor (arrows) at the previous TACE-treated site. To change the treatment mechanism from chemoembolization to radiation-based therapy, radiation segmentectomy was performed with 1.18 GBq of glass microspheres via A7 and A8. (B) Liver MRI also shows a new 0.6-cm nodule (arrow) in the Spiegel lobe. During planning angiography, superselective TACE was performed for this lesion to avoid excessive radiation exposure to the central liver. Lipiodol computed tomography (CT), obtained immediately after chemoembolization, shows dense lipiodol uptake (arrowhead) confined to the tumor. Y-90 PET, yttrium-90 positron emission tomography.

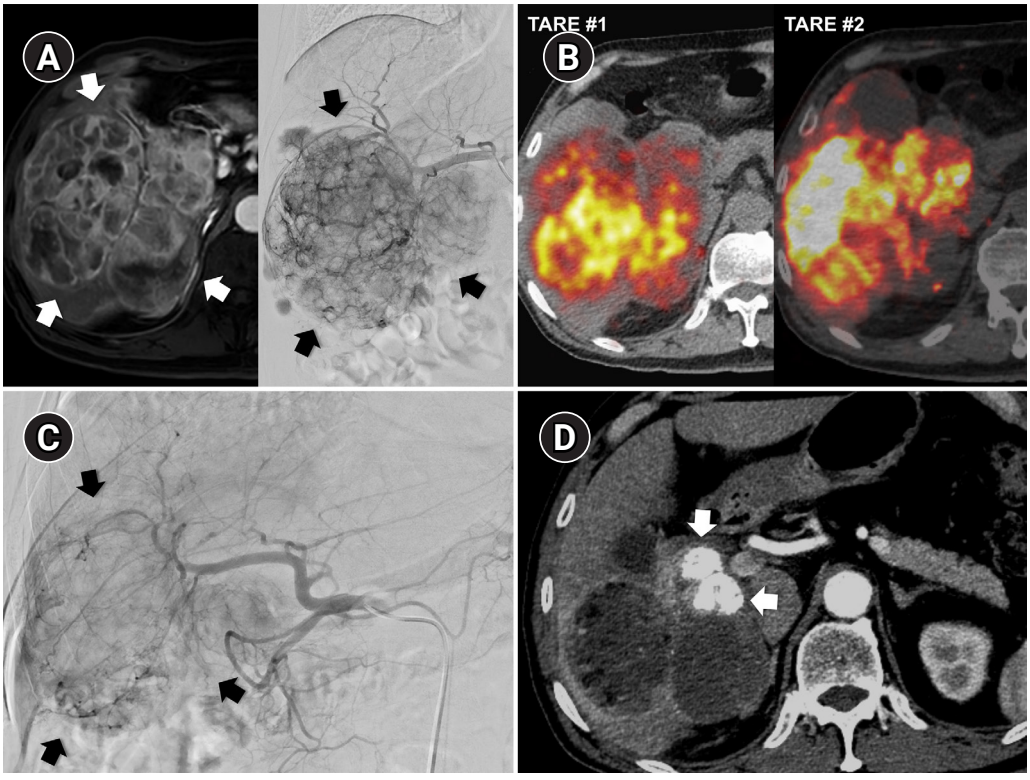

Fig. 6. Sequential transarterial radioembolization (TARE) followed by transarterial chemoembolization (TACE) in a 77-year-old man with large hepatocellular carcinoma. (A) Magnetic resonance imaging and angiography show a 12.5-cm conglomerated mass (arrows) with multiple satellite nodules in segments 5, 6, and 7. (B) Sequential TARE was planned because a single session could not achieve sufficient tumor dose owing to lung dose limitation. In TARE #1 (5.0 GBq resin microspheres), perfused liver dose was 178 Gy and lung dose was 9.6 Gy. In TARE #2 (5.5 GBq resin microspheres), perfused liver dose was 255 Gy and lung dose was 12.2 Gy. Post-treatment Y-90 positron emission tomography/computed tomography demonstrates heterogeneous intratumoral Y-90 activity in the tumors. (C) Angiography 5 months after TARE #2 shows decreased tumor staining (arrows) in the right lobe. TACE was performed through multiple subsegmental branches supplying residual tumor. (D) After two additional TACE sessions (not shown), the computed tomography obtained 2 years after the initial TARE showed decreased tumor size, near-complete disappearance of arterial enhancement, and partial lipiodol uptake (arrows) in the tumor.

insurance system that enables most tertiary and regional hospitals to perform the procedure. In my opinion, perhaps half in jest, no other country can offer such highly selective TACE at such an affordable cost, which reflects both the skill of Korean interventional radiologists and the efficiency of the healthcare system.

Conclusion

TARE and TACE should not be regarded as competing procedures but as complementary components of a personalized treatment strategy for HCC. TARE offers durable local control and better tolerability, making it suitable for localized or large tumors in patients with preserved hepatic function or limited procedural tolerance. In contrast, TACE provides procedural precision, broad applicability, and repeatability, maintaining its role as the backbone of transarterial therapy across most clinical stages. In clinical practice, sequential or combined use may achieve a better balance between efficacy and safety (Figs. 5, 6) [34]. Ultimately, the choice between TARE and TACE should be individualized according to tumor characteristics, hepatic reserve, and institutional expertise, and that optimal HCC management depends on integration rather than substitution.

Conflict of interest

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Author contributions

The author conducted all aspects of the study.

Data availability statement

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

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Review Article

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Clinical challenges and transjugular intrahepatic portosystemic shunt strategies for pyrrolizidine alkaloid-induced hepatic sinusoidal obstruction syndrome: an Asian perspective

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Pyrrolizidine alkaloid–induced hepatic sinusoidal obstruction syndrome (PA-HSOS) is highly prevalent in Asia, primarily due to the widespread use of traditional herbal medicines containing hepatotoxic pyrrolizidine alkaloids. This condition poses significant clinical challenges, including diagnostic difficulties and limited therapeutic options, frequently leading to severe liver damage and portal hypertension. Transjugular intrahepatic portosystemic shunt (TIPS) treatment has emerged as a key intervention for managing complications associated with PA-HSOS, such as refractory ascites and variceal bleeding, by reducing portal pressure and supporting liver function recovery. However, TIPS has not been widely accepted as a salvage therapy for severe PA-HSOS unresponsive to anticoagulation therapy, mainly due to concerns about post-TIPS complications, particularly hepatic encephalopathy. Consequently, careful patient selection and risk stratification are critical. This review synthesizes the current evidence on PA-HSOS in Asia, evaluates the clinical utility of TIPS, and discusses strategies to optimize outcomes while minimizing adverse effects. Specifically, we review the epidemiology, pathophysiology, and diagnostic advancement of PA-HSOS, with a particular focus on the evolving role of TIPS in its management.

Keywords: Hepatic sinusoidal obstruction syndrome; Pyrrolizidine alkaloids; Portal hypertension; Transjugular intrahepatic portosystemic shunt; Treatment

Introduction

Hepatic sinusoidal obstruction syndrome (HSOS) is a vascular liver disorder characterized by damage to hepatic sinusoidal endothelial cells, resulting in sinusoidal congestion, portal hypertension (PH), and potential liver failure [1-3]. In Western countries, HSOS is predominantly associated with hematopoietic stem cell transplantation (HSCT) or certain chemotherapeutic agents [4,5]. On the other hand, pyrrolizidine alkaloid (PA)–induced HSOS (PA-HSOS) in Asia is primarily induced by the consumption of traditional herbal medicines containing PAs, such as *Gynura japonica* [1,6]. There are notable clinical and histopathological differences between the two entities. Clinically, PA-HSOS typically pres-

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ents with abdominal pain, ascites, jaundice, and liver dysfunction, whereas HSCT-related HSOS is more frequently associated with rapid weight gain and renal impairment [7]. Histopathologically, PA-HSOS is characterized by prominent sinusoidal congestion and hepatocyte necrosis, whereas HSCT-related HSOS lacks these specific damage mechanisms inherent to PA exposure [8]. Despite growing clinical recognition, PA-HSOS remains a diagnostic challenge due to overlapping features with other causes of acute liver injury and PH [9]. Histopathologically, PA-HSOS is characterized by sinusoidal dilation, erythrocyte extravasation, and fibrosis, which can be confirmed by liver biopsy [10,11].

PA-HSOS constitutes a substantial health burden in several Asian countries, particularly China, South Korea, and India, where the use of traditional herbal medicines is widespread [12-15]. The market size and diversity of herbal products vary across these countries [16,17]. South Korea shows a clear preference for traditional herbal products, particularly with a growing trend in dietary supplements. A survey of 1,134 Korean respondents revealed that 726 individuals had used herbal products, indicating a high prevalence rate [16]. Notably, Socheongryongtang is the most commonly used herbal formula for treating allergic rhinitis [18]. Similarly, India, often referred to as the 'World's Medicinal Plant Garden,' possesses approximately 8,000 medicinal plant species and provides an estimated 25,000 effective herbal formulations [19,20]. In China, PA-HSOS accounts for a substantial proportion (50.0%–88.6%) of all HSOS cases, frequently linked to herbal products like *Gynura japonica* [21]. Retrospective studies from China have identified PA-HSOS as a leading cause of drug-induced liver injury (DILI) [11,22]. The condition is closely associated with unregulated herbal products, which underscores the need for greater public awareness and regulatory control [10,23]. Socioeconomic factors, including reliance on folk remedies in rural populations, further increase the risk of PA-HSOS [24]. The condition predominantly affects older individuals and those with chronic exposure to herbal substances, emphasizing the need for targeted preventive strategies [10,25].

Clinical management of PA-HSOS differs notably from Western HSOS, reflecting distinct etiologies and pathophysiology. In PA-HSOS, early anticoagulation or transjugular intrahepatic portosystemic shunt (TIPS) is commonly pursued, especially in severe cases, to reduce portal pressure and improve hepatic perfusion. Liver transplantation is considered for refractory PA-HSOS. By contrast, Western guidelines emphasize defibrotide prophylaxis and broader supportive care as central strategies, with liver transplantation reserved for refractory cases. TIPS appears to show superior outcomes over conservative therapy specifically in PA-HSOS but is rarely used and less favored in Western HSOS. These differences underscore the need for region-specific, tailored management algorithms that account for exposure patterns, resource availability, and clinical trajectories.

This review highlights the key clinical challenges of PA-HSOS, including delayed diagnosis due to nonspecific manifestations such as ascites and hepatomegaly, as well as the lack of reliable biomarkers. We evaluate the current evidence supporting the use of TIPS as a therapeutic option, noting its efficacy in reducing portal pressure despite variable post-procedural outcomes. Management strategies for PA-HSOS are compared with Western HSOS protocols, with a focus on region-specific considerations in Asia. The review also explores emerging treatments, including anticoagulation therapy (AT) with rivaroxaban and gut microbiota modulation. Finally, we advocate for the adoption of standardized diagnostic frameworks, such as the Drum Tower Severity Scoring (DTSS) system, to improve diagnostic accuracy and consistency in PA-HSOS management.

Epidemiology and Etiology

Epidemiology

PA-HSOS is a significant public health concern in Asia, primarily attributed to the widespread use of herbal medicines and dietary supplements containing PAs. In China, PA-HSOS has emerged as the leading cause of DILI, with PA-rich herb products, such as *Gynura japonica*, playing a central role in its etiology [26]. A systematic review based on 2,156 reported cases of HSOS related to *Gynura japonica* from 1980 to 2019 indicated that HSOS caused by this herb accounts for over 50% of DILI cases [26]. The cultural reliance on traditional herbal remedies, often consumed without adequate awareness of their hepatotoxic potential, further contributes to the high prevalence of PA-HSOS (Table 1). However, despite its clinical relevance, comprehensive epidemiological data on

Table 1. Common plants causing PA-HSOS (Asia region)

Plant family	Common genera/species	Notes
Asteraceae (Compositae)	*Gynura japonica* (Tusanqi)	Leading cause of PA-HSOS in China; roots/herbs used in traditional medicine
	Gynura segetum	Widely used herbal plant containing PAs; linked to HSOS in China
	Senecio spp.	PAs (e.g., retrorsine) damage sinusoidal endothelial cells
	Tussilago farfara (coltsfoot)	Traditional herb with PAs; potential HSOS risk
Boraginaceae	*Heliotropium* spp.	Plants containing hepatotoxic PAs; implicated in HSOS cases
	Symphytum spp. (comfrey)	Traditional medicinal herb; PAs cause HSOS and chronic liver damage
	Echium spp.	PA-containing plants associated with liver injury
Fabaceae (Leguminosae)	*Crotalaria* spp.	Plants containing monocrotaline, a PA that induces sinusoidal obstruction in animal models

PA-HSOS, pyrrolizidine alkaloid–induced hepatic sinusoidal obstruction syndrome; PAs, pyrrolizidine alkaloids; HSOS, hepatic sinusoidal obstruction syndrome.

PA-HSOS remain limited, as the majority of existing studies are retrospective and involve small cohorts. This highlights a critical gap in systematic surveillance and standardized reporting in the region [1,27].

Etiology

The hepatotoxicity of PAs is primarily mediated by metabolic conversion into reactive intermediates, such as dehydro-PAs, which directly damage liver sinusoidal endothelial cells (LSECs) [26,28]. This injury disrupts the sinusoidal architecture, leading to the characteristic features of HSOS, including hepatomegaly, hyperbilirubinemia, and ascites [3,26]. LSECs are particularly vulnerable to PA-induced damage due to their fenestrated structure and high exposure to circulating toxins. The resulting injury to LSECs triggers a cascade of pathological events, including sinusoidal capillarization, perisinusoidal matrix deposition, and impaired vascular exchange, which are key hallmarks of HSOS [29,30]. Additionally, PAs are known to disrupt bile acid homeostasis, aggravating liver injury. The imbalance in bile acid metabolism leads to heightened oxidative stress and hepatocellular damage, contributing to the progression of HSOS [31,32].

Emerging evidence further implicates gut microbiota dysbiosis in PA-HSOS pathogenesis. Experimental models have shown that fecal microbiota transplantation can modulate disease severity, suggesting a role for the gut-liver axis in PA-HSOS development [33,34]. Additionally, macrophage activation and subsequent inflammatory responses amplify sinusoidal injury, creating a pro-fibrogenic microenvironment [29,34]. Over time, PA-HSOS may progress to chronic liver disease, with the development of hepatic fibrosis; however, the precise mechanisms underlying this transition remain incompletely understood [30,35].

High-Risk Populations

Middle-aged and elderly individuals with prolonged exposure to PA-containing herbal products are the highest-risk group for developing PA-HSOS [27,36]. The early mortality rate in this population is approximately 10.3% to 14%, and the 3-year cumulative mortality ranges from 24% to 30.8% [37,38]. Notably, in patients receiving only supportive care, mortality can reach as high as 43.9% [39]. This high mortality rate is concerning, as these individuals often rely on traditional remedies for chronic conditions, typically without awareness of their potential hepatotoxic effects. For instance, *Gynura japonica*, a popular herb used for treating blood stasis or traumatic injuries, has been strongly associated with numerous cases of HSOS due to its high PAs content [36]. Inadequate regulation of herbal products in many Asian countries exacerbates the risk, as contamination or misidentification of PA-producing plants is not uncommon [32,40]. Reducing the burden of PA-HSOS in these populations requires a multifaceted approach, including enhanced public education, stricter regulatory oversight, and improved strategies for early diagnosis. Additionally, the effects of PAs on individuals are stochastic, characterized by significant variability [41]. Evidence indicates that individual differences in metabolism, species sensitivity, and chemical structure lead to diverse toxic responses, underscoring the non-deterministic nature of these effects rather than a uniform response across all individuals [42].

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Diagnosis

The diagnosis of PA-HSOS relies on a comprehensive assessment that includes clinical features, imaging findings, and histopathological evaluation [15]. Patients typically present with the hallmark triad of abdominal distension, hepatic region pain, and ascites, often accompanied by jaundice and hepatomegaly (Fig. 1). The widely adopted "Nanjing criteria" for PA-HSOS diagnosis require a confirmed history of exposure to PA-containing plants, such as *Gynura segetum*, along with at least one of the following: abdominal or hepatic symptoms, elevated serum bilirubin or abnormal liver function tests, imaging evidence of hepatic vascular changes, or compatible pathological findings after excluding other liver injuries [15].

In addition to these criteria, the validated DTSS system has proven useful in stratifying disease severity and guiding therapeutic decisions [27,43]. Imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) play an important non-invasive role in the diagnostic process, often revealing characteristic signs such as hepatic sinusoidal congestion, hepatic vein narrowing, and a "clover-like" enhancement pattern [3,44] (Fig. 1). Enhanced CT typically shows heterogeneous low-density areas in the liver, which is the most common manifestation, alongside hepatomegaly, ascites, and thickening of the gallbladder wall. During the arterial or portal venous phase, patchy liver enhancement reflects abnormal perfusion [45]. On MRI, gadolinium ethoxybenzyl diethylenetriamine pentaacetic acid (Gd-EOB-DTPA) enhanced imaging during the hepatobiliary phase consistently shows low signal intensity in PA-HSOS patients, correlating positively with prothrombin time (PT) and international normalized ratio, thus serving as an independent mortality risk factor. Additionally, susceptibility-weighted imaging and T2-weighted imaging reveal low signal areas associated with hemosiderin deposition [46]. Nevertheless, liver biopsy remains the diagnostic gold standard, allowing for the identification of characteristic histopathological lesions. Differentiating PA-HSOS from other vascular liver diseases, including Budd-Chiari syndrome and cirrhotic PH, continues to present

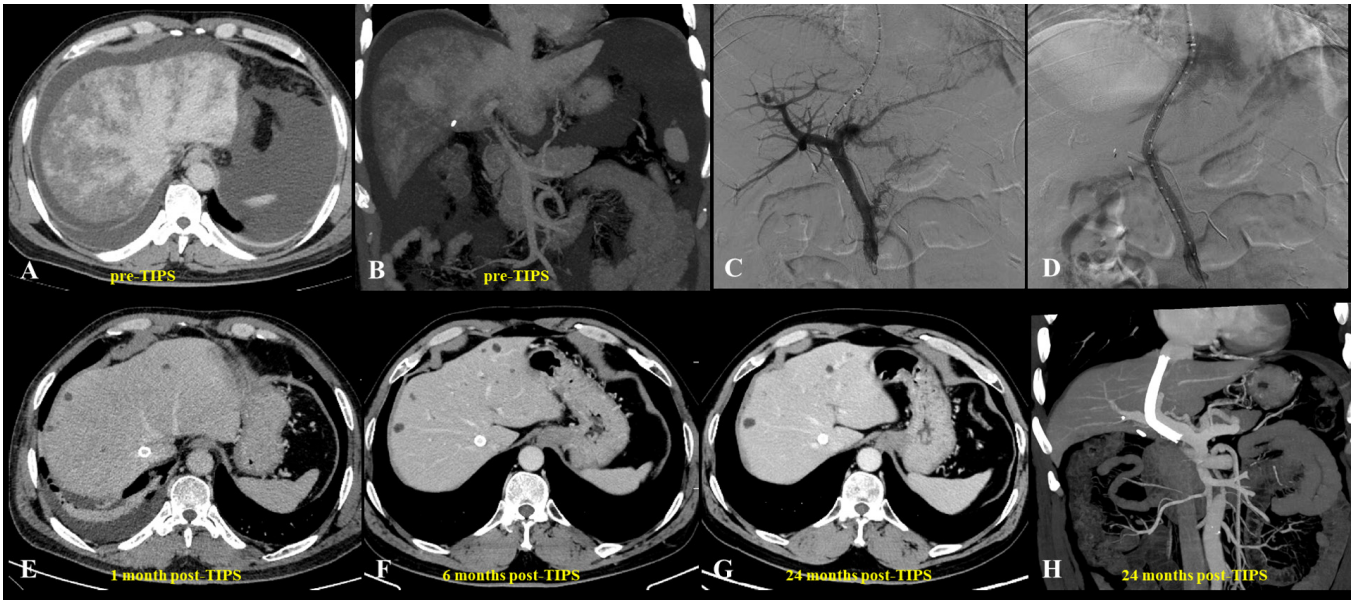

Fig. 1. A 62-year-old man diagnosed with hepatic sinusoidal obstruction syndrome 4 months after ingestion of *Gynura segetum*. (A) Abdominal computed tomography (CT) during the hepatic venous phase demonstrated patchy parenchymal enhancement with characteristic clover-like enhancement around the hepatic veins. Significant ascites and bilateral pleural effusions were also observed. (B) Coronal CT revealed patchy liver enhancement and narrowing (thinning) of the portal vein, accompanied by abundant ascites. (C, D) Portography before and after transjugular intrahepatic portosystemic shunt (TIPS) creation. A guidewire, introduced via the right hepatic artery, was used to provide real-time guidance during the procedure. (E–H) Post-TIPS abdominal CT showed well-defined opacification of hepatic veins with substantial resolution of both ascites and pleural effusions. Long-term follow-up CT, extending up to 24 months, confirmed homogeneous enhancement of the liver parenchyma and sustained patency of the TIPS shunt.

a significant clinical challenge (Table 2) [47,48]. Future research should prioritize the validation of non-invasive biomarkers and the refinement of scoring systems such as DTSS to enhance diagnostic accuracy and allow timely intervention, particularly in high-prevalence regions.

Treatment Strategies

Medical Management

The treatment of PA-HSOS remains challenging due to the lack of specific therapeutic options. AT, including low-molecular-weight heparin (LMWH) and rivaroxaban, is often employed as an initial treatment. Specifically, LMWH is dosed at 4,000 IU subcutaneously twice daily [39]. In a study involving five PA-HSOS patients treated with LMWH for 8–21 days, ascites resolved, symptoms improved, and hepatic venous blood flow was restored [49]. However, in severe cases, AT alone appears limited in efficacy. Another study reported a mortality rate of 34.1% with AT versus 0% with TIPS [50]. A multicenter study involving 249 PA-HSOS patients indicated that AT improved survival in some cases; however, the benefits were inconsistent, highlighting the need for better patient stratification [39]. Defibrotide, which has proven effective for managing HSOS after HSCT, has also been studied in PA-HSOS [51]. In HSCT-associated HSOS, defibrotide is dosed at 6.25 mg/kg intravenously every 6 hours (equivalent to 25 mg/kg per day) and continued for at least 3 weeks until total bilirubin (TBIL) levels normalize. However, its efficacy may be constrained by the unique pathogenesis of PA-HSOS, and its limited availability in China raises uncertainties about its effectiveness in treating PA-induced HSOS. A study assessing defibrotide effectiveness in monocrotaline-induced rat HSOS found that it improved outcomes, suggesting that defibrotide may be a preferable option to LMWH in clinical practice [8].

Transjugular Intrahepatic Portosystemic Shunt

TIPS has emerged as an important therapeutic option for PA-HSOS patients with refractory PH or ascites, and although it has no specific contraindications for treatment, guidelines recommend considering it for patients with ineffective medical therapy, highlighting the importance of individualized assessment [15]. Studies have shown that ascites and pleural effusions can markedly improve within a short period after TIPS placement, with previously obstructed hepatic veins often regaining patency in the short term when combined with AT (Figs. 1, 2) [10,52]. Various studies have confirmed the safety and efficacy of TIPS in managing PA-HSOS (Table 3) [50,52-57]. A retrospective study involving 30 PA-HSOS patients demonstrated that TIPS significantly reduced portal pressure, alleviated ascites, and improved clinical symptoms [52]. The

Table 2. Key features for differential diagnosis of PA-HSOS, Budd-Chiari syndrome, and typical cirrhotic decompensation

Feature	PA-HSOS	Budd-Chiari syndrome	Typical cirrhotic decompensation
Etiology	Exposure to PAs	Thrombosis of large hepatic veins or inferior vena cava	Chronic liver disease (e.g., viral hepatitis, alcohol)
Onset	Acute/subacute	Acute or subacute	Chronic, with acute exacerbations
Portal hypertension	Yes, post-sinusoidal portal hypertension due to hepatic outflow obstruction	Yes, due to obstruction of major veins	Yes, due to cirrhosis
Imaging findings	Patchy parenchymal enhancement on CT/MRI	Hepatic vein occlusion, collateral circulation	Nodular liver surface, ascites, and splenomegaly on imaging
Ascites	Common, often refractory to diuretics	Common, often with significant fluid accumulation	Common, usually associated with other signs of cirrhosis
Clinical presentation	Ascites, hepatomegaly, jaundice	Acute liver failure, abdominal pain, ascites	Varices, jaundice, hepatic encephalopathy
Histopathology	Sinusoidal dilatation, necrosis, fibrosis	Thrombosis-related changes in the liver	Fibrosis, cirrhosis, regenerative nodules
Coagulation status	Often coagulopathy present	Prothrombotic states common	Coagulopathy may be present due to liver dysfunction
Risk factors	Herbal medicine use, exposure to specific plants	Myeloproliferative disorders, pregnancy, oral contraceptives	Alcohol use, viral hepatitis, metabolic disorders
Management	Supportive care, TIPS for refractory cases	Anticoagulation, TIPS for severe cases	Management of underlying liver disease, TIPS for refractory ascites

PA-HSOS, pyrrolizidine alkaloid–induced hepatic sinusoidal obstruction syndrome; PAs, pyrrolizidine alkaloids; CT, computed tomography; MRI, magnetic resonance imaging; TIPS, transjugular intrahepatic portosystemic shunt.

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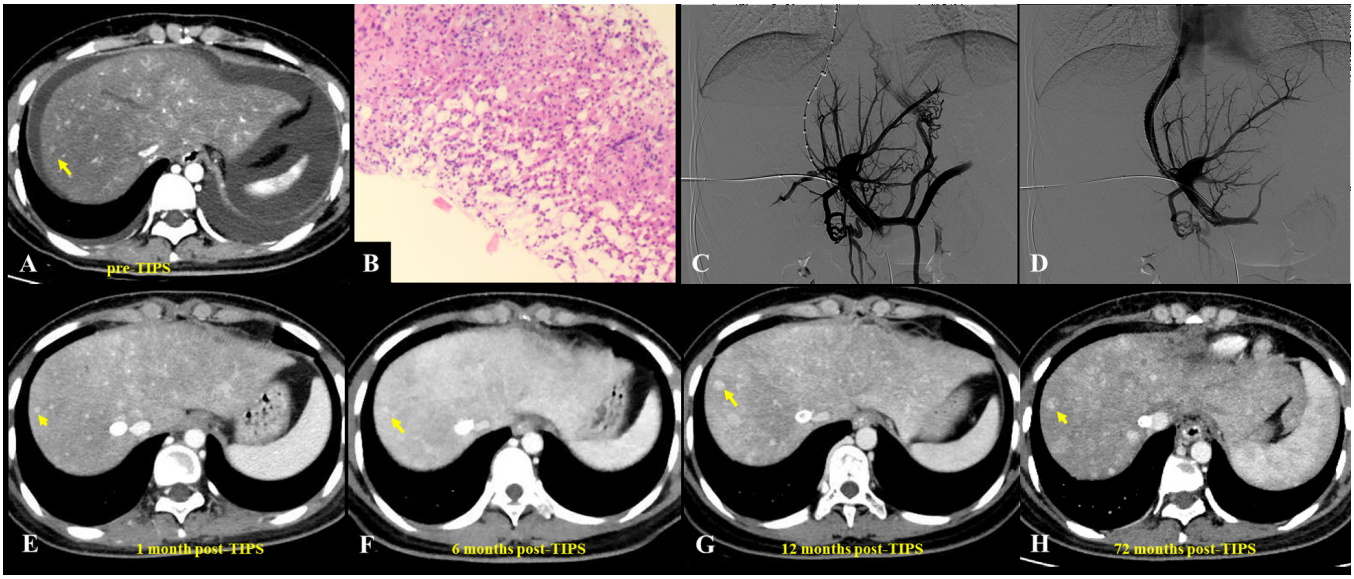

Fig. 2. A 23-year-old woman presented with pyrrolizidine alkaloid–induced hepatic sinusoidal obstruction syndrome following ingestion of oral weight-loss medications. (A) Pre–transjugular intrahepatic portosystemic shunt (TIPS) computed tomography (CT) (portal venous phase) demonstrated heterogeneous, patchy hepatic enhancement with multiple regenerative nodules (yellow arrow), accompanied by massive ascites and bilateral pleural effusions. (B) Histopathological analysis from a transjugular liver biopsy revealed focal hepatic atrophy, marked sinusoidal dilatation, and hepatocellular cholestasis, consistent with hepatic venous outflow obstruction. Immunohistochemical staining was negative for hepatitis B surface antigen, hepatitis B core antigen, diastase-periodic acid-Schiff, and periodic acid-Schiff, while showing positivity for cytokeratin 7 (biliary epithelium), reticulin, and Masson's trichrome (indicating underlying fibrosis) (H&E, ×400). (C) Due to the diminished caliber (slenderness) of the portal vein, percutaneous transhepatic balloon-assisted TIPS placement was performed. Initial portal venography confirmed narrowing of the intrahepatic portal branches, stagnant portal flow, and the presence of prominent esophagogastric varices. (D) Post-TIPS venography demonstrated a widely patent shunt with unobstructed portal venous return and successful decompression of the varices. (E-H) Follow-up contrast-enhanced CT scans (venous phase) obtained at 1 month (E), 6 months (F), 12 months (G), and up to 72 months (H) post-TIPS demonstrated persistent heterogeneous enhancement and intrahepatic nodules (yellow arrows).

median time to complete ascites remission was 52 days, while the median recovery time for liver CT radiological manifestations was 196.5 days. However, the timing of the procedure is critical, with preoperative TBIL levels identified as a key prognostic factor. Early intervention, when TBIL levels are below 10 mg/dL, is associated with improved recovery [53].

In the context of treatment strategy selection, a multicenter study comparing the efficacy between TIPS and AT in 164 PA-HSOS patients revealed that TIPS conferred significantly better mid- to long-term survival rates compared with those of AT, particularly in patients with moderate to severe PA-HSOS [54]. This suggests that TIPS should be considered a viable initial treatment option for this patient cohort [50]. Similarly, another retrospective study involving 69 patients in the TIPS group and 95 patients in the supportive treatment group confirmed that TIPS placement significantly improved survival rates and effectively alleviated PH-related clinical symptoms in PA-HSOS patients [54].

Despite its promising efficacy, the use of TIPS in Asian populations faces several challenges. Research indicates that a significant proportion of PA-HSOS patients present at advanced stages of the disease, complicating the identification of appropriate candidates for TIPS [58]. Additionally, postoperative anticoagulation management protocols vary widely among medical institutions, and there is currently no standardized approach for preventing shunt thrombosis or disease progression [59]. To address these challenges, a research team developed the DTSS system, which incorporates prognostic factors such as liver function and imaging findings to guide treatment strategy selection, including TIPS candidacy [11,27].

Regarding prognostic assessment, several studies have explored predictive factors that may influence the effectiveness of TIPS treatment. One study found that prolonged baseline PT and elevated serum TBIL levels 5 days post-TIPS are independent risk factors predicting mortality in PA-HSOS patients following TIPS placement [55]. Another study suggested that preoperative measurement of the hepatic venous pressure

Table 3. Summary of major studies on TIPS for PA-HSOS in Asia

Country	Author (Year)	Sample size	Type of study	Aim of study	Outcomes
China	Dai et al. (2025) [52]	30 Patients	Retrospective analysis	Evaluated safety/efficacy of TIPS	The PPG significantly decreased post-TIPS, with ascites remission occurring in 52 days (median) and liver CT showing recovery in 196.5 days. Disease severity and ALBI grade were key recovery time predictors.
China	Huang et al. (2023) [50]	20 Patients (TIPS) and 41 patients (AT)	Comparative study	Compared mid-long-term outcomes of TIPS vs. AT as initial treatment	TIPS demonstrated superior mid- to long-term outcomes compared to anticoagulation therapy, particularly for patients with severe or very severe PA-induced HSOS.
China	Wu et al. (2021) [53]	4 in 10 PA-HSOS patients received TIPS	Retrospective analysis	Evaluated TIPS timing using TBIL as a measure	TIPS timing based on TBIL levels affected efficacy.
China	Huang et al. (2023) [57]	12 Patients (TIPS) and 10 patients (conservative treatment)	Retrospective cohort	Investigated efficacy and safety of TIPS in PA-HSOS	TIPS may be a safe and effective therapeutic strategy for PA-HSOS patients who do not respond to conservative treatment.
China	Zhou et al. (2020) [56]	37 Patients (TIPS) and 17 patients (conservative treatment)	Retrospective analysis	Evaluated TIPS as treatment for PA-HSOS	Better outcomes may be achieved with TIPS compared with conventional symptomatic treatment in patients with PA-HSOS.
China	Wang et al. (2024) [54]	164 Patients (69 in TIPS group vs. 95 in supportive group)	Retrospective analysis	Compared clinical outcomes and liver histology between TIPS and supportive treatment	In comparison with supportive treatment, TIPS treatment improved clinical outcomes and liver histology.
China	Xiao et al. (2021) [55]	116 Patients	Retrospective analysis	Evaluated predictors of poor outcomes in PA-HSOS patients receiving TIPS	Prolonged prothrombin time at baseline and increased serum TBIL levels 5 days after TIPS were independent risk factors for predicting death after TIPS treatment in PA-HSOS patients.

TIPS, transjugular intrahepatic portosystemic shunt; PA-HSOS, pyrrolizidine alkaloid–induced hepatic sinusoidal obstruction syndrome; PPG, portal pressure gradient; CT, computed tomography; ALBI, albumin-bilirubin; AT, anticoagulation therapy; PA, pyrrolizidine alkaloid; HSOS, hepatic sinusoidal obstruction syndrome; TBIL, total bilirubin.

gradient may assist in assessing disease severity and predicting TIPS treatment efficacy [60]. Notably, the response to TIPS may vary depending on the underlying cause of PA-HSOS. For example, a study involving nine patients with HSOS related to *Gynura segetum* found that TIPS treatment significantly improved clinical symptoms; nevertheless, further research is needed to determine the optimal timing for intervention [61]. Additionally, pathological studies have shown that TIPS placement can lead to significant improvements in pathological features, such as hepatic congestion and hepatocyte swelling, over time [56].

Despite the promising outcomes of TIPS, its long-term efficacy in PA-HSOS requires further validation. A multicenter study involving 117 PA-HSOS patients emphasized the importance of establishing a reliable prognostic assessment system to better guide treatment decisions [38]. Additionally, for some advanced PA-HSOS patients, TIPS may serve primarily as a bridge to liver transplantation [25,62]. In PA-HSOS patients without severe underlying cirrhosis, post-TIPS complications, such as hepatic encephalopathy (HE), are less common than in cirrhotic cohorts [52,63]. A systematic review included 19 studies and 465 HSOS patients, reported an overall HE incidence of 13.2% post-TIPS; however, this data encompasses all types of HSOS and is not limited to the PA-HSOS subgroup [64]. Conversely, a retrospective review of 30 PA-HSOS patients who underwent TIPS found no post-procedure HE cases [52]. By comparison, the pooled HE incidence among cirrhotic patients ranges from 33.2% to 58% [65,66]. The absence of advanced liver disease likely reduces the risks associated with portosystemic shunting, including hyperammonemia and HE, making TIPS a relatively safer option for these patients [10,25]. Overall, existing evidence suggests that TIPS may be an effective means of managing PA-HSOS associated with PH; however, careful consideration of patient-specific factors is essential to determine the appropriate indications and timing for intervention. Future research should focus on establishing standardized preoperative assessment systems and postoperative management protocols to further

enhance treatment outcomes [7,45,67].

Liver Transplantation

For end-stage PA-HSOS patients who do not respond to medical and TIPS therapies, liver transplantation is the last resort. However, data on transplantation outcomes in PA-HSOS are limited, as most cases are managed conservatively or with TIPS [25]. Although the high mortality rate and rapid disease progression highlight the importance of early referral to transplant centers, organ availability and patient selection criteria complicate the transplantation process, particularly in Asia [38]. Future studies should aim to optimize the timing of liver transplantation and refine post-transplant management strategies to improve survival outcomes in this critically ill population.

Conclusion

Recent studies have advanced our understanding of PA-HSOS, particularly regarding the underlying toxicity pathways and the role of the gut-liver axis in disease progression. Emerging evidence suggests that the PU.1 signaling pathway plays a vital role in mediating PA-induced hepatotoxicity, primarily by driving damage to sinusoidal endothelial cells [68]. Additionally, the gut microbiota has been implicated in PA-HSOS pathogenesis, with studies on fecal microbiota transplantation revealing that dysbiosis exacerbates liver injury through macrophage activation [33,34]. Experimental models of monocrotaline-induced HSOS have demonstrated the potential therapeutic benefits of modulating the gut microbiota [34,69], further underscoring the importance of investigating specific microbial taxa and their interactions with host immune pathways.

The lack of standardized diagnostic criteria for PA-HSOS in Asia highlights the urgent need for multicenter collaborative efforts to establish region-specific guidelines. Current diagnostic challenges include the overlap of PA-HSOS with other liver diseases and the variable sensitivity of non-invasive diagnostic tools [70]. Furthermore, although TIPS is crucial for managing severe PA-HSOS, its clinical efficacy is often hampered by complications and inconsistent outcomes [55]. The development of enhanced TIPS techniques and public education on the risks associated with the unregulated use of herbal medicines are essential for prevention and improved patient care [71].

Conflict of interest

No potential conflicts of interest relevant to this article were reported.

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Conceptualization, investigation, and manuscript writing: TYZ. Conceptualization and investigation: HLW, ZCJ. All aspects of the work: BX, JHS.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

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Impact of embolic agents on outcomes of renal angiomyolipoma embolization: a dual-center retrospective cohort study

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Purpose: Transcatheter arterial embolization (TAE) is widely used for managing renal angiomyolipoma (AML) to prevent hemorrhage and control symptoms while preserving renal function. However, the optimal embolic material remains undetermined due to limited comparative data. This study aimed to compare the effectiveness of ethanol-based embolization versus polyvinyl alcohol (PVA) and to evaluate additional benefits of microcoil use in ethanol-based treatments.

Materials and Methods: We retrospectively analyzed 119 patients with single renal AML who underwent TAE at two tertiary centers between 2005 and 2023. Patients were grouped into ethanol-based (ethanol alone or ethanol plus microcoil, n = 93) and PVA (n = 26) cohorts. Subgroup analysis compared ethanol alone (n = 24) versus ethanol plus microcoil (n = 69). Inverse probability treatment weighting and linear mixed-effects models were used to assess tumor volume reduction and treatment response (≥ 50% volume reduction).

Results: After adjustment, the ethanol group demonstrated significantly greater tumor volume reduction than the PVA group at 6 and 12 months (adjusted mean difference = –23.9%, p = 0.002; –23.1%, p = 0.001) and a higher response rate (92.1% vs. 78.4%, p = 0.043). In the subgroup analysis, ethanol plus microcoil achieved higher response (91.3% vs. 73.8%; odds ratio [OR], 3.73; p = 0.038) and lower recurrence (7.1% vs. 30.2%; OR, 0.18; p = 0.008) compared with ethanol alone.

Conclusion: Ethanol-based embolization provides superior tumor control compared to PVA in renal AML, and the addition of microcoils enhances early volume reduction and reduces recurrence, supporting its use as an effective treatment strategy.

Keywords: Angiomyolipoma; Therapeutic embolization; Ethanol; Polyvinyl alcohol; Microcoil

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Introduction

Renal angiomyolipoma (AML) is a benign mesenchymal tumor characterized by a composite structure of dysmorphic blood vessels, smooth muscle cells, and mature adipose tissue [1-3]. These tumors can manifest sporadically or in association with tuberous sclerosis complex, displaying a higher prevalence in women in sporadic cases [2-4]. Although AML

typically shows subtle clinical manifestations, large tumors exceeding 4 cm or containing aneurysms larger than 5 mm pose a risk for severe complications such as rupture, hemorrhage, or renal failure [4].

Transcatheter arterial embolization (TAE) is currently the favored nephron-sparing approach for AML treatment, utilized both prophylactically and emergently, particularly in high-risk bleeding situations [2,5-7]. Various embolic agents have been employed, including particulate materials such as polyvinyl alcohol (PVA), liquid embolics (ethanol), and coils, aiming to reduce tumor vascularity and size while preserving renal function. Previous studies using liquid or particulate embolic agents reported various tumor reduction percentages, ranging from 55% to 77% [8-10]. However, no embolic agent has consistently demonstrated superior clinical outcomes, and comparative studies focusing on embolization materials remain scarce [11-15].

Therefore, we aimed to compare clinical outcomes of TAE using ethanol-based embolization (ethanol alone or ethanol plus microcoil) versus PVA particles in patients with single renal AML.

Materials and Methods

Patient

This study was approved by the Institutional Review Board (B-2412-944-104), and the need for consent was waived. From 2005 to 2023, electronic medical records of two tertiary academic hospitals (Seoul National University Bundang Hospital, Seongnam, Korea, and Jeonbuk University Hospital, Jeonju, Korea) were reviewed for patients who underwent TAE for renal AML. Inclusion criteria were adult (>18 years old), a single renal AML with maximal diameter ≥4 cm or symptomatic lesion with any size, preprocedural computed tomography (CT)/magnetic resonance imaging (MRI) within 3 months before TAE. Exclusion criteria were patients with ruptured AML before TAE, previous history of TAE for the lesion, multiple/bilateral lesions, contrast allergy or impaired renal function (estimated glomerular filtration rate < 30 mL/min/1.73 m^2), lost to follow-up within 1 month after TAE. Baseline characteristics of enrolled patients, including age, sex, presence of a symptom, the date of preprocedural and follow-up cross-sectional image studies including CT or MRI, TAE-procedure date, and any occurrence or change of symptom after an embolization, were identified.

Transarterial Embolization

During the study period, seven interventional radiologists performed TAE for renal AML, and embolic materials were chosen based on the operator's preference. The procedure began with 5-Fr sheath inserted via right common femoral artery access under local anesthesia, followed by renal arteriography to evaluate tumor location and feeding arteries. A 2.0-Fr microcatheter (Progreat alpha, Terumo, Tokyo, Japan) was then advanced into the feeding artery, ensuring the preservation of normal renal parenchyma. In the PVA group, embolization was performed with 355–500 μm PVA particles (Contour, Boston Scientific, Marlborough, MA, USA). In the ethanol group, 99% absolute ethanol (Daihan Pharma, Seoul, Korea) was infused to ablate the vascular endothelium of the feeding arteries. In both groups, the embolization endpoint was the cessation of inflow to the target feeding arteries. In ethanol with microcoil group, 99% absolute ethanol embolization was first performed in a manner similar to the ethanol group. After confirming occlusion, one or two microcoils (2–3 mm; Concerto, Medtronic, Minneapolis, MN, USA; Tornado, Cook Medical, Bloomington, IN, USA) were placed in the proximal portion of the target vessels to prevent recanalization and achieve durable embolization. Final angiography confirmed the devascularization of the tumors in all groups.

Follow-up and Image Analysis

Follow-up was performed at 6 and 12 months after embolization and then at 1-year intervals thereafter, with CT or MRI. Two radiologists with more than 10 years of clinical experience reviewed the patients' preprocedural and follow-up CT/MRI images in consensus. The date of the cross-sectional imaging, the long and short diameters on the axial image, and the z-axis diameter on the coronal image of the target lesion were acquired. Tumor volume at each time point was calculated using the ellipse volume formula (long diameter × short diameter × z-axis diameter × 0.52). Tumor volume reduction was assessed using pre- and post-TAE imaging. A positive treatment response was defined as a volume reduction of the tumor by 50% or more after TAE [16].

Outcome Assessment

Technical success was defined as the successful cannulation of all feeding arteries and complete embolization of the targeted vascular network. Tumor volume changes were evaluated at each follow-up to assess therapeutic efficacy, and long-term efficacy was determined by tumor volume reduction at the 24-month follow-up. Multivariable logistic regression analysis was performed to identify independent predictors of achieving this response. Tumor recurrence was defined as an increase in tumor volume compared to the preceding follow-up, assessing the durability of embolization effects over time [7].

Statistical Analysis

Continuous variables were summarized using means ± standard deviation and categorical variables as frequencies and percentages. Differences between groups were compared with Student's t-test or Wilcoxon rank-sum test for continuous data, and chi-square or Fisher's exact test for categorical variables.

Missing follow-up data were addressed by multiple imputation using chained equations. Propensity scores were calculated using multivariable logistic regression incorporating age, sex, and baseline tumor volume to balance baseline differences. Inverse probability of treatment weighting (IPTW) based on these propensity scores was performed to adjust for confounding factors in the main comparison between ethanol and PVA groups. After IPTW, standardized mean differences <0.1 were considered indicative of adequate balance.

Linear mixed-effects modeling was used to assess longitudinal tumor volume changes over the follow-up periods. The models included random intercepts for subjects and fixed effects for treatment group, follow-up time, and their interactions. Additionally, within the ethanol group, subgroup analyses comparing Ethanol alone and Ethanol plus microcoil were conducted following the same statistical methodology.

Multivariable logistic regression analysis identified independent predictors of achieving treatment response, defined as a tumor volume reduction greater than 50%. A p-value <0.05 was considered statistically significant. All analyses were performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA) and R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Patient Demographics

A total of 119 patients (mean age, 48.6 ± 13.3 years; 70.6% female) were enrolled (Fig. 1). The mean follow-up period was 33.1 ± 26.5 months (median, 27.8 months), with group-specific means of 43.6 ± 37.2 months (PVA), 22.9 ± 14.2 months (ethanol), and 32.6 ± 23.4 months (ethanol with microcoil). Patients were categorized into two groups based on embolization agents: the ethanol group (n = 93, including ethanol alone (n = 24) and ethanol plus microcoil (n = 69) and the PVA group (n = 26). No significant differences in age or sex were observed between groups. However, baseline tumor volume tended to be larger in the PVA group compared to the ethanol group (262.8 ± 334.2 cm^3 vs. 118.1 ± 158.6 cm^3, p = 0.098). After IPTW adjustment, baseline characteristics including age, sex, and tumor volume were balanced (Table 1).

Technical Success and Safety

Technical success was achieved in all cases, with complete embolization confirmed by final angiography. The embolization endpoints—cessation of inflow to target feeding arteries in the PVA and ethanol groups—were consistently reached in all groups. No immediate post-procedural complications were recorded.

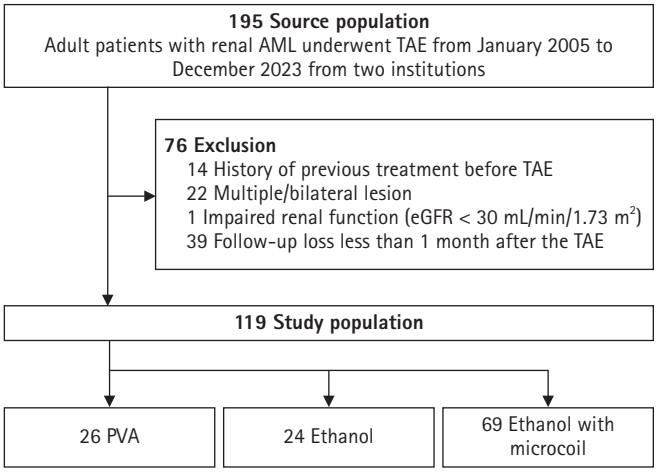

Fig. 1. Flow diagram of patient selection and inclusion in the study. AML, angiomyolipoma; TAE, transcatheter arterial embolization; eGFR, estimated glomerular filtration rate; PVA, polyvinyl alcohol.

Table 1. Patient demographics before and after IPTW

Parameter	Before IPTW			p-value	SMD	After IPTW			p-value	SMD
	Ethanol	Ethanol + microcoil	PVA			Ethanol	Ethanol + microcoil	PVA		
No.	24	69	26		–	47	42	30	–	–
Women (%)	41.7	52.5	65.4	0.333	0.23	–	–	–	–	–
Age (years)	47.6 ± 12.8	50.9 ± 14.5	52.0 ± 16.5	0.334	0.18	–	–	–	–	–
Baseline long diameter (mm)	53.4 ± 19.6	61.9 ± 25.7	77.2 ± 27.2	0.001	1.02	63.5 ± 23.6	65.4 ± 28.6	66.0 ± 20.7	0.85	0.05
Baseline volume (cm^3)	93.5 ± 133.8	132.4 ± 172.6	281.1 ± 315.9	0.001	1.15	136.8 ± 184.9	159.5 ± 202.7	169.8 ± 217.1	0.72	0.04

IPTW, inverse probability of treatment weighting; PVA, polyvinyl alcohol; SMD, standardized mean difference.

Treatment Response and Recurrence

After IPTW adjustment, ethanol-based embolization achieved significantly greater tumor volume reduction compared with PVA embolization at 6 and 12 months (adjusted mean difference = –23.9%, p = 0.002; –23.1%, p = 0.001, respectively), whereas the difference was not significant at 24 months (p = 0.266). The ≥50% response rate was higher in the ethanol group than in the PVA group (92.1% vs. 78.4%; odds ratio [OR], 2.86; p = 0.043), with no difference in recurrence (p = 0.844) (Table 2). In the subgroup analysis, ethanol + microcoil achieved a higher response rate (91.3% vs. 73.8%; OR, 3.73; p = 0.038) and lower recurrence (7.1% vs. 30.2%; OR, 0.18; p = 0.008) compared with ethanol alone, indicating improved treatment durability without significant differences in overall volume reduction (Table 3).

Predictor for Favorable Treatment Response

Table 4 highlights the results of univariable and multivariable logistic regression analyses. The type of embolic material was an independent predictor of favorable treatment response. Patients treated with the ethanol with microcoil approach were significantly more likely to achieve ≥50% tumor volume reduction (adjusted odds ratio, 4.667; p = 0.011).

Discussion

This study demonstrated that embolization using ethanol with microcoil outperformed single-agent embolization with either PVA or ethanol in terms of treatment response and recurrence rate. Technical success was achieved in all cases, and the ethanol with microcoil group exhibited the highest treatment response rate (91.3%) and tumor volume reduction. These findings highlight the efficacy and durability of this ethanol with microcoil approach for managing renal AML.

Historically, embolization with PVA is one of the earliest embolic agents, with modest therapeutic effects and relatively higher recurrence rates attributed to incomplete vessel occlusion [17,18]. In contrast, ethanol-based embolization has yielded more favorable outcomes [10,12,17,18]. A recent meta-analysis of 13 studies (478 patients) reported that ethanol embolization produced the greatest tumor shrinkage (95.8%) and the lowest re-intervention rate (3.4%) [18]. Theoretically, ethanol offers distinct advantages over particulate agents: as a liquid, it penetrates the distal microvasculature, produces endothelial destruction and tumor necrosis, and provides permanent occlusion at the arteriolar and capillary level.

However, ethanol-only embolization may result in incomplete occlusion due to rapid washout in high-flow vessels, increasing the risk of recanalization and recurrence [13,15]. The low viscosity of ethanol makes it difficult to control high-flow vessels, potentially compromising durable occlusion and necessitating adjunctive devices such as micro-balloons or coils.

In our study, these issues were addressed by combining ethanol with microcoil. Our study demonstrated superior outcomes with this combined ethanol and microcoil approach, achieving ≥50% tumor volume reduction in 91.3% of cases and the lowest recurrence rate of 7.1%, compared to ethanol-only or PVA-only treatments.

The enhanced efficacy of the ethanol with microcoil method likely stems from its mechanism of action. Ethanol initiates endothelial injury and thrombus formation, while the microcoil acts as a physical barrier to stabilize the thrombus and prevent washout, allowing for better contact time between ethanol and endothelium [19]. This synergy ensures complete and durable vessel occlusion, a key factor in its superior outcomes. The significantly greater tumor volume reduction ob-

Table 2. Tumor volume reduction between ethanol (ethanol and ethanol plus microcoil) and PVA before and after IPTW adjustment

Parameter	Before IPTW			After IPTW			
	PVA	Ethanol	p-value	PVA	Ethanol	Adjusted mean difference (ethanol – PVA)	p-value
Tumor volume (% of baseline)							
6-Month follow-up	70.0	43.8	0.003	68.7	44.8	–23.9	0.002
12-Month follow-up	49.2	25.1	0.018	48.9	25.8	–23.1	0.001
24-Month follow-up	41.2	25.6	0.200	40.1	26.1	–14.0	0.266
≥ 50% Tumor reduction (response rate, %)	69.2	87.1	0.031	78.4	92.1	OR, 2.86	0.043
Recurrence rate (%)	15.4	12.9	0.743	14.8	13.3	OR, 0.88	0.844

PVA, polyvinyl alcohol; IPTW, inverse probability of treatment weighting; OR, odds ratio.

Table 3. Tumor volume reduction between ethanol and ethanol plus microcoil before and after IPTW adjustment

Parameter	Before IPTW			After IPTW			
	Ethanol only	Ethanol + microcoil	p-value	Ethanol only	Ethanol + microcoil	Effect (microcoil vs. ethanol only)	p-value
Tumor volume (% of baseline)							
6-Month follow-up	46.6	42.8	0.621	47.3	42.1	–5.2	0.510
12-Month follow-up	25.4	25.0	0.936	27.2	24.7	–2.5	0.669
24-Month follow-up	23.5	26.3	0.736	25.9	26.3	0.4	0.977
≥ 50% Tumor reduction (response rate, %)	75.0	91.3	0.040	73.8	91.3	OR, 3.73	0.038
Recurrence rate (%)	29.2	7.2	0.006	30.2	7.1	OR, 0.18	0.008

IPTW, inverse probability of treatment weighting.

Table 4. Univariable and multivariable analyses of predictors for favorable treatment response

Parameter	Univariable analysis		Multivariable analysis	
	OR (95% CI)	p-value	aOR (95% CI)	p-value
Embolic material type				
PVA		0.026		0.026
Ethanol	1.333 (0.384–4.625)	0.650	1.333 (0.384–4.625)	0.650
Ethanol with microcoil	4.667 (1.433–15.203)	0.011	4.667 (1.433–15.203)	0.011
Age (years)	0.974 (0.939–1.010)	0.148	-	-
Female sex	0.406 (0.111–1.489)	0.174	-	-
Initial tumor size				
Long diameter (mm)	0.990 (0.973–1.007)	0.256	-	-
Short diameter (mm)	0.984 (0.960–1.008)	0.196	-	-
Z-axis diameter (mm)	0.989 (0.975–1.004)	0.146	-	-
Tumor volume (cm^3)	1.000 (1.000–1.000)	0.474	-	-

aOR, adjusted odds ratio; CI, confidence interval; PVA, polyvinyl alcohol.

served in the ethanol with microcoil group, even before IPTW adjustment, supports this mechanism. These findings are consistent with prior observations of embolization approaches that emphasize the importance of stable vessel closure [3,12].

Treatment response analysis revealed that the ethanol with microcoil strategy achieved 91.3% favorable outcomes, surpassing those of the PVA (69.2%) and ethanol (75%) groups. This is a promising result compared to the treatment response rates reported in earlier studies, which ranged from 60% to 80% with single-agent embolization [12,15,17]. These findings highlight the potential of the ethanol with microcoil approach, offering enhanced efficacy and reduced recurrence risks.

The ethanol with microcoil group demonstrated the lowest recurrence rate, likely due to the combined effect of ethanol's distal embolization, inducing endothelial injury and thrombosis, and microcoils' proximal embolization, ensuring stable vascular occlusion. This dual strategy minimizes the risk of

recanalization, offering superior long-term efficacy compared to single-modality approaches.

Multivariable analysis further reinforces the robustness of our results. After adjusting for confounding variables, the type of embolic material emerged as an independent predictor of favorable treatment response (≥50% tumor volume reduction). Specifically, patients treated with the ethanol with microcoil approach demonstrated significantly higher odds of achieving a positive treatment response than those in the PVA or ethanol groups.

Despite these results, this study's limitations should be acknowledged. As a retrospective analysis, inherent biases such as operator variability and loss to follow-up may affect the outcomes. However, this real-world setting reflects diverse operator expertise, enhancing the generalizability of the findings. Furthermore, variations in baseline tumor volume across groups were adjusted using IPTW, mitigating confounding effects. The study lacked long-term follow-up, leaving questions about the durability of outcomes unaddressed. Additionally, this study did not evaluate variations in tumor composition or preprocedural CT and angiographic findings—such as hypervascularity, aneurysm formation, or arteriovenous shunts—that may influence embolization strategy and outcomes. Minor complications, including post-embolization syndrome, were also not systematically recorded, which may underestimate their incidence. These factors should be considered when interpreting our results and warrant further prospective investigation.

In conclusion, ethanol with microcoil embolization is an effective and durable treatment for renal AML, achieving superior tumor volume reduction and treatment response compared to single-agent embolization. These findings highlight the effectiveness of this combination of embolic materials, supporting its use as the preferred approach for treating large or symptomatic AML.

Conflict of interest

Kun Yung Kim and Jae Hwan Lee, contributing editors of the *Korean Journal of Interventional Radiology*, were not involved in the editorial evaluation or decision to publish this article. All remaining authors have declared no conflicts of interest.

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Author contributions

Conceptualization: KYK, YMH, JHL. Methodology: KYK, Minuk Kim, CJY, JHL. Investigation: KYK, MK, SHY, YMH, JHL. Data curation: KYK, MK. Formal analysis: KYK, MK. Supervision: CJY, CHL, YMH, JHL. Writing—original draft: KYK. Writing—review & editing: all authors. All authors read and approved the final manuscript.

Data availability statement

The datasets generated and/or analyzed during the current study are not publicly available due to institutional and privacy restrictions but are available from the corresponding authors upon reasonable request.

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How I Do It

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Catheter-directed sclerotherapy for ovarian endometriomas

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Introduction

Ovarian endometriomas are common cystic lesions that can cause chronic pelvic pain and infertility. While laparoscopic cystectomy is the standard surgical treatment, it often leads to a significant decline in ovarian reserve due to the removal of healthy ovarian tissue and excessive electrocoagulation. Catheter-directed sclerotherapy (CDS) with ethanol has emerged as an effective, minimally invasive alternative that achieves high technical success while preserving ovarian function [1,2].

Indications and Patient Selection

CDS is particularly indicated for patients with a reduced ovarian reserve, typically indicated by anti-Müllerian hormone (AMH) levels < 2 ng/mL. It is also highly recommended for patients with recurrent endometriomas following previous surgery [1]. Cysts ≥ 3 cm in diameter are ideal to facilitate smoother guidewire insertion and catheter placement [2]. Contraindications include suspected gynecologic malignancy, active pelvic infection, or abnormal coagulation profiles.

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Access Strategies

Transvaginal Access

While recent literature suggested that transvaginal access may be a risk factor for technical failure due to the inherent complexity of deep-seated lesions and the operator's learning curve [3], we still prefer this route as the primary approach. Its proximity to the pelvic floor and superior image resolution allow for precise targeting, provided the operator is sufficiently experienced in endocavitary procedures [1,4].

Transabdominal Access

This alternative is considered if high-risk structures like blood vessels lie between the endometrioma and the vaginal probe, or if the patient prefers it for personal reasons (e.g., preservation of virginity). However, this route may be technically challenging or contraindicated if there is no safe window; for instance, when the bowel or other vital organs are positioned along the needle path, increasing the risk of peritoneal or visceral injury.

Technical Procedures (Video 1)

Intravenous sedoanalgesia is administered using 25 mg pethidine hydrochloride (Hana Pharm. Co. Ltd., Seoul, Korea) and 50 μg fentanyl (Hanlim Pharmaceutical Co. Ltd., Seoul, Korea). Following placement in the lithotomy position, the vagina is disinfected with 0.5% chlorhexidine gluconate solution (Hexitane 0.5%, Firson, Cheonan, Korea). Following the insertion of a vaginal speculum, an ultrasound probe equipped with an in-plane endocavitary needle guide (EVN4-

9, Aspen Surgical, Caledonia, MI, USA) is inserted to facilitate precise targeting. The use of a 7-F or 8.5-F catheter (Dawson-Mueller Drainage Catheter, Cook Medical, Bloomington, IN, USA) is crucial, as it provides a lumen cross-sectional area significantly larger than conventional needles, allowing for the effective aspiration of thick, highly viscous "chocolate" contents often found in these cysts [1,2]. To further optimize the drainage efficiency, the existing side holes of the catheter are occasionally enlarged using surgical scissors prior to insertion. For example, in cases showing T2 dark signal intensity on pre-procedural magnetic resonance imaging, which is a significant risk factor for technical failure due to extremely high viscosity [3], this technical modification is combined with repeated saline irrigation to dilute the thick chocolate content, eventually allowing for the complete aspiration of even the most tenacious materials.

1. Puncture and catheterization: Under ultrasound guidance, the cyst is punctured with an 18-gauge Chiba needle (≥ 20 cm, Cook Medical). A 0.035-inch hydrophilic guidewire (Terumo, Tokyo, Japan) is then advanced into the lesion [2]. To minimize resistance, the metal inner stylet is first advanced alone over the guidewire to pre-dilate the track through the tough vaginal wall or adherent tissues. Its superior stiffness ensures more effective penetration than plastic dilators. The pigtail catheter is then assembled with the stylet and introduced as a unit, preventing kinking and ensuring seamless placement despite significant tissue resistance. Notably, CDS enables the mechanical breakdown of internal septa via guidewire manipulation, converting multiloculated cysts into a single cavity. This maneuver maximizes ethanol contact, thereby enhancing the efficacy of sclerotherapy for complex, multiseptated lesions [4].

2. Aspiration and irrigation: The content is completely aspirated, followed by saline irrigation until the return is clear [1].

3. Contrast injection: Before injecting the sclerosant, 5–20 mL of a nonionic contrast medium is instilled under fluoroscopy to rule out any leakage into the pelvic cavity [1,2].

4. Ethanol sclerotherapy: 99% ethanol (Taiwan Biotech Co., Ltd., Taoyuan, Taiwan) is instilled, typically 50% of the aspirated volume. While conventional protocols often suggest a maximum of 100 mL for safety, there is no strictly defined upper limit, and up to 150 mL can be administered without significant complications based on the operator's experience and cyst size. The patient changes position every 5 minutes for 20 minutes to maximize ethanol contact with the cyst wall. After the dwell time, the ethanol must be completely re-aspirated [2].

5. Two-session protocol: Although not a universal standard, a two-session protocol can be performed to minimize recurrence, particularly for large cysts (e.g., ≥10 cm) or those with internal septa where a single session may be insufficient. In this approach, the catheter is clamped and left in situ overnight after the first session. The same sclerotherapy procedure (ethanol instillation, positioning, and re-aspiration) is repeated the following day. The catheter is finally removed under fluoroscopic guidance to prevent catheter kinking only after the completion of the last re-aspiration in the final session [1,2].

Clinical Outcomes

- Volume reduction: CDS demonstrates a high-volume reduction ratio, reaching an average of 96.4% at 6 months post-procedure [2].
- Ovarian reserve preservation: Studies have shown that post-procedural AMH levels remain stable without significant decline, confirming that CDS spares the healthy ovarian cortex [2,5].
- Low recurrence: While needle-directed sclerotherapy has a reported recurrence rate of around 13.8%, CDS has achieved recurrence rates as low as 0% in prospective cohorts [1,2].

Conclusion

CDS with ethanol is a safe and effective treatment for ovarian endometriomas. Its ability to provide superior cyst drainage and prolonged ethanol contact makes it highly effective in reducing recurrence while successfully preserving the ovarian reserve.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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None.

Author contributions

Conceptualization, investigation, and manuscript writing: BSI, JHS. All aspects of the work were performed by the corresponding author.

Data availability statement

All data generated or analyzed during this study are included in this published article and its supplementary information files (Video 1).

Supplementary material

The supplementary data are available with this article at https://doi.org/10.64961/kjir.2026.00017.

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Instructions for authors

KJIR
Korean Journal of
Interventional Radiology

These guidelines outline the requirements for submitting manuscripts to the Korean Journal of Interventional Radiology (KJIR). Authors should ensure their submissions meet the formatting standards, article type specifications, ethical requirements, and follow the proper submission process.

Table of Contents

Aims and scope

Korean Journal of Interventional Radiology, the official English-language journal of the Korean Society of Interventional Radiology (KSIR), is an international peer-reviewed academic journal dedicated to interventional radiology. *KJIR* will publish cutting-edge and impactful scientific research articles in the field of interventional radiology.

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Author A has received research grants from [Company Name]. Author B serves as a consultant for [Company Name]. Author C holds stock in [Company Name]. These relationships had no influence on the study design, data interpretation, or manuscript preparation.

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- **Scope:** Should present novel techniques, significant new data, or new insights in interventional radiology.
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How I do It

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Article in press.

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