Embollisation of localized pulmonary arteriovenous malformations in adults

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Résumé
Embollisation des malformations artério-veineuses pulmonaires localisées de l’adulte.

J Radiol 2007;88:367-75


Matériel et méthodes. Tous les patients présentant une forme localisée de fistules artério-veineuses pulmonaires traités par embollisation ont été inclus. La présentation clinique (signes respiratoires, antécédents d’embolie paradoxale systémique) et les caractéristiques des fistules artério-veineuses (unique ou multiples, localisation, diamètre de l’artère afférente et angioarchitecture simple ou complexe) avant embollisation ont été analysées. Les détails concernant la procédure d’embollisation en particulier le nombre de fistules traitées, le nombre de coils utilisés et les complications au cours du geste ont été recueillis. Le suivi clinique et tomodensitométrique des patients traités était détaillé.

Résultats. Quarante deux patients (26 femmes et 16 hommes, âgés de 45 ans en moyenne) dont trente six présentaient une maladie de Rendu-Osler ont été traités par embolisation. Vingt deux patients (53 %) étaient dyspnéiques et 12 (29 %) avaient des antécédents d’embolie paradoxale avant l’embolisation. Quarante sept séances d’embolisation ont été réalisées pour traiter un total de 99 fistules artério-veineuses pulmonaires (soit 2,3 par maladie) à l’aide de 530 coils (12,6 par malade). Les fistules siègaient dans les lobes inférieurs dans 60 % des cas et étaient de forme simple dans 81 % des cas. L’artère afférente mesurait en moyenne 6 mm de diamètre. Aucune complication n’a été observée lors de l’embolisation. À distance du traitement, 2 patients (5 %) ont présenté une embolie paradoxale et 5 patients sur 22 (23 %) restaient dyspnéiques. Le taux d’occlusion complète des fistules traitées était de 92 % sur le suivi tomodensitométrique.

Conclusion. L’embollisation des fistules artério-veineuses pulmonaires localisées est une technique efficace pour corriger l’hypoxémie et réduire les risques d’embolie paradoxale systémique. Un fort taux de succès technique peut être obtenu par des opérateurs entraînés.


Abstract

Objectives. To report our experience using embolization in managing localized pulmonary arteriovenous malformations in adults.

Material and methods. All patients presenting with localized pulmonary arteriovenous malformations treated with embolization were included in the study. Clinical presentation (respiratory symptoms and previous history of paradoxical embolism) and the characteristics of pulmonary arteriovenous malformations (single or multiple, location, diameter of the afferent artery and simple or complex angioarchitecture) before embolization were analyzed. The details of the procedure, including the number of pulmonary arteriovenous malformations embolized, the number of coils used, and the type of intraoperative complications were recorded. Postembolisation clinical and imaging follow-up were described.

Results. Forty-two patients (26 women, 16 men; mean age, 45 years), including 36 with hereditary hemorrhagic telangiectasia were treated with embolization. Twenty-two patients (53 %) were dyspneic and 12 (29 %) had a previous history of paradoxical embolism prior to embolization. Forty-seven procedures were carried out on a total of 99 pulmonary arteriovenous malformations (mean, 2.3 per patient), using 530 coils (12.6 per patient). The pulmonary arteriovenous malformations were located in the lower lobes in 60% of cases and a simple architecture was reported in 81% of cases. The average diameter of the afferent artery was 6mm. No preoperative complications were reported. After embolization, two patients (5 %) presented with a paradoxical embolism and five patients out of 22 (23%) remained dyspneic. The rate of complete occlusion of treated arteriovenous malformations was 92% using computer tomography.

Conclusion. Embolization is a highly effective and safe technique for treating pulmonary arteriovenous malformations. Improvement in dyspnea and prevention of paradoxical embolism can be expected. A high technical success rate can be obtained by experienced interventional radiologists.

Key words: Pulmonary arteriovenous fistula. Rendu-Osler-Weber syndrome. embolization.

Pulmonary arteriovenous fistulae (PAVF) provide an abnormal direct communication between a pulmonary artery and a pulmonary vein through an aneurysmal sac (1, 2). The absence of a pulmonary capillary filter can be manifested by the onset of paradoxical systemic embolism (gaseous, crueor, or septic) responsible for mainly neurological manifestations (transitory ischemic accident [TIA], a completed stroke, or a brain abscess) (1-3). When there are many or voluminous pulmonary arteriovenous fistula, this right-to-left shunt can also lead to hypoxemia (1, 2). Finally, the risk of rupture in the airways (hemoptysis) or in the pleural cavity (hemoptoxus) have been also reported, particularly during pregnancy (1, 2, 4, 5). In 60%-90% of cases, PAVFs occur in patients who have Rendu-Osler-Weber syndrome (hereditary hemorrhagic telangiectasia), which is an autosomal dominant hereditary multivisceral angiodyplasia (1, 2, 6). These are pulmonary arteriovenous malformations (PAVMs). In
Embolization of localized pulmonary arteriovenous malformations in adults

Following a thoracic injury or surgery (7, 8). PAVFs may more rarely occur as a complication of certain chronic liver diseases (cirrhosis) or pulmonary artery hypertension (1, 2, 9). Because of high morbidity and a not insignificant mortality rate, preventive treatment of PAVF complications should be proposed, including in asymptomatic patients (1, 2, 6).

Reported for the first time in 1977, embolization has become the reference treatment for PAVFs and PAVMs as an alternative to vascular ligature or surgical resection (10). It is commonly admitted that preventive embolization for PAVMs with an afferent artery measuring more than 3 mm in diameter prevents the majority of embolic complications (11, 12). Normally, two different PAVM clinical presentations are contrasted: localized PAVMs and diffuse PAVMs (1, 2, 13-15). In the diffuse form, almost all the segmental arteries of at least one lobe have small PAVMs fed by the subsegmental branches (14). The diffuse forms are more often associated with signs of hypoxemia, whereas in the localized forms, the prognosis is for the most part conditioned by the risk of paradoxical embolism (1, 2). However, PAVMs can be several in number and either unilateral or bilateral (1, 2, 13). We report herein our experience with the embolization management of the localized forms of PAVMs.

Material and methods

Population and pretherapy workup

From 29 November 1991 to 30 November 2005, 43 consecutive patients with a localized form of PAVM were sent to our center for embolization. Children (<18 years of age) and patients with a diffuse form of the disease were not included in this study. The indication for embolization was decided within a primary prevention strategy (systematic discovery) or a secondary prevention strategy (previous history of embolism) of neurological complications (paradoxical embolism) or to improve signs related to hypoxemia. The clinical workup included a search for a previous history of neurological accident (transitory vascular accident or completed stroke, seizure disorder, or abscess) relating to the presence of the PAVM, a search for dysnea (the severity evaluated on the three Sadoul stages), and the measurement of oxygen pressure in ambient air (PaO₂).

The diagnosis of hypoxemia was established in dyspneic patients presenting a PaO₂ less than 80 mmHg. In addition, a general clinical examination was provided, notably to search for signs suggesting Rendu-Osler-Weber syndrome (16). The Curaçao criteria defining this diagnosis were systematically: family history, epis-taxis, cutaneousomous telangiectasias, and visceral involvement (digestive, hepatic, neurologic, and pulmonary) (17). Since June 2003, all patients with Rendu-Osler-Weber syndrome were seen in our multidisciplinary consultation (with the participation within the day hospital of the following specializations: cardiology, dermatology, functional explorations, genetics, hepatogastroenterology, internal medicine, ENT, pneumology, radiology, and neuroradiology). In patients with Rendu-Osler-Weber syndrome, we looked for an endoglin mutation (type 1 Rendu-Osler-Weber syndrome) or an ALK1 mutation (type 2 Rendu-Osler-Weber syndrome) (16, 18). Before the procedure, the diagnosis of PAVM was confirmed using echocardiography with injection of isonic fluid shaken to form microbubbles (shunt diagnosis) and a thoracic CT with no injection (first patients evaluated) or with injection of iodinated contrast material (since June 2003) to visualize the PAVMs (19). CT provided the diagnosis, confirming the vascular nature of the lesion and guiding therapy by evaluating the number of PAVMs (single or multiple), their location (superior lobe, middle lobe/lingula, or inferior lobe) as well as the size of the afferent artery (mm). Since the advent of multidetector spiral CT technology, the precise angiography of the PAVMs (simple or multipedicular) was studied with multiplanar reconstruction (20). The simple or multipedicular type (complex) of the dominant PAVM architecture was studied and confirmed at angiography (13, 15). In the initial classification proposed by White et al. in 1983, simple PAVMs presented a single afferent artery and a single drainage vein (13). On the CT and angiographic data, this classification was then modified: a simple PAVM can have one or several afferent arteries provided that they all stem from the same segmental artery (fig. 1) (15). In complex PAVMs, the afferent arteries stemmed from at least two segmental arteries (fig. 1) (15).

Embolization technique

The procedures were performed with local anesthesia via a femoral artery approach, most often on the right, with placement of a long, 6-French Cook introducer. Pulmonary arterial pressure (expressed in mmHg) was measured before and after embolization. The mean pulmonary arterial pressure (PAPm) was used for the final analysis. The abnormal vascular pedicles identified on CT were selectively explored with a 5-F angiographic catheter, most often a right coronary catheter (JR4, Mérit Médical). Whether the PAVM was simple or complex was specified. After the PAVM was identified, the catheter was positioned in the afferent artery (or arteries) as close as possible to the sac. In this series, no direct embolization of the aneurysmal sac was performed. The artery was embolized with self-extending, spiral, “cottony” coils whose diameter and length were chosen depending on the diameter of the afferent artery (between 3 and 8 mm in diameter in most cases) (MReye coils, Cook). The first coil was voluntarily oversized so as to prevent paradoxical migration during deployment. The following coils were then positioned at the center for the first coil deployed using the packing technique so as to obtain complete occlusion of the vascular lumen (fig. 2) (21). Since summer 2005, 14-cm-long coils of a diameter adapted to the size of the PAVM’s afferent vessel (Nester coils, Cook) were used to obtain better packing (21). When the fistula was wide (>8 mm in diameter for the afferent artery) or presented substantial flow, the anchoring technique was used (21). This technique consists in placing the first centimeters of a long coil in a normal artery branch located immediately upstream of the sac so as to block the coil and prevent its migration (21). All the fistulae presenting afferent arteries greater than 3 mm were systematically treated. The procedure was performed with an antibiotic cover (amoxicillin and clavulanic acid, Augmentin before and during embolization) and general heparin therapy adapted to the patient’s weight was given during embolization (20-30 mg IV at the beginning of embolization, with this dose repeated every 60-90 min during long procedures). Particular attention was paid to preventing the risk of gas embolism during catheter and guidewire manipulation. The technical success rate was defined as the possibility of embolizing all the PAVMs whose afferent artery

Embollisation de malformations arterio-veineuses pulmonaires localisées chez l'adulte

JP Pelage et al.

Fig. 1: Angioarchitecture of pulmonary arteriovenous malformations.

a Simple pulmonary arteriovenous malformation (PAVM). Simple PAVMs are fed by one or several arteries branching from the same segmental artery (A, B, and C subtypes). Diagrams courtesy of Dr. RI White Jr.

b Multipedicular PAVM (complex form). Multipedicular PAVMs are fed by at least two segmental arteries. Diagrams courtesy of Dr. RI White Jr.

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Patient follow-up

Patient follow-up included a clinical evaluation by the pneumologist in our department. Oxygen pressure (PaO₂) was also measured. A thoracic CT, with or without iodinated contrast material, was done systematically 6-12 months after embolization and then every 5 years. Patients were also seen again after embolization by interventional radiologists. When the clinical symptoms were imperfectly improved or there were CT arguments in favor of reperfusing the embolized arteriovenous fistulae, a new embolization session was scheduled. During the early clinical follow-up, particular attention was paid to procedure-related complications (pulmonary infarction or pleural effusion). During the long-term follow-up, the complications related to insufficient treatment (recurrence of cerebral accident or persistence of dyspnea) were specifically sought.

Statistical analysis

The last clinical follow-up and CT follow-up available for each patient were used for the final analysis. In addition, the analysis involved mainly the patients who had Rendu-Osler-Weber syndrome. The descriptive statistics, with the mean, minimum, and maximum values were used. Nonparametric tests were used, as was the Mann-Whitney U test to show whether the afferent pedicle diameter of the PAVM was related to the clinical symptoms (i.e., dyspnea and previous history of embolism). The Wilcoxon test was used to demonstrate a significant variation in the PaO₂ figures before and after treatment as well as changes in PAP between before and after the procedure. The Spearman rank test was used to determine whether there was a correlation between the presence of hypoxemia and the number of PAVMs or the diameter of the dominating PAVM.

Results

Population

Forty-two patients (26 women and 16 men; mean age 45.5 ± 18.2 years, range 18-80 years) were treated with an embolization procedure. From November 1991 to June 2003, 16 patients were treated. From June 2003 to November 2005, 26 additional patients were treated. One patient with pulmonary arterial hypertension (PAH) (mutation ALK1) had a hemodynamic exploration that found a systolic PAP at 99 mmHg. It was decided not to embolize before starting medical treatment for the PAH. Thirty-six patients out of 42 (86%) had Rendu-Osler-Weber syndrome according to the Curacao criteria. Of these 36 patients, 16 presented an endoglin-type mutation, two an ALK1 mutation, and one patient who had familial colonic polyposis presented an SMAD4 mutation. In the other cases, no mutation was found (five patients) or the results are pending (12 patients).

Clinical presentation

Twenty-two patients (53%) presented with dyspnea, which was stage 1, 2, or 3 in 15 cases (36%), six cases (14%), and one case (2%), respectively. The diameter of the dominant PAVM’s afferent artery was greater in dyspnea patients (7.1 ± 4.1 mm versus 4.7 ± 1.6 mm, p = 0.02, Mann-Whitney U test). PaO₂ before treatment was measured at 76.4 ± 15.4 mmHg (range, 45-102 mm). Twenty-two patients (53%) presented with hypoxemia. PaO₂ was significantly correlated with the diameter or the dominant PAVM’s afferent artery (Spearman rank test).

Twelve patients (29%) had a previous history of crur or septic embolism: completed vascular accident (four patients) or transitory vascular accident (three patients), and brain abscess (five patients). Another patient with Rendu-Osler-Weber syndrome presented with epilepsy related to a cerebral arteriovenous malformation. The diameter of the dominant PAVM’s afferent artery or the number of PAVMs was different in patients with or without a previous history of paradoxical embolism (Mann-Whitney U test).

Two patients had already presented a hemoptysis episode. Five patients had already had a lobectomy to treat their PAVM before embolization. Three patients were sent to us after embolization had failed (two cases) or when embolization was deemed incomplete (one case).

Four patients (including the nonembolized patient) presented PAH, one with an ALK1 mutation and the other with an SMAD4 mutation. A total of three embolized patients out of the 36 with Rendu-Osler-Weber syndrome (8%) presented a PAH associated with PAVM. PAH and liver involvement were statistically correlated (present in all cases).
Characteristics of the fistulae

Twenty-two patients out of 42 (52%) presented multiple PAVMs versus 20 out of 42 (48%) presenting a single PAVM. The majority of the dominant PAVMs were located in the inferior lobes (25/42, 60%). The other PAVMs were located in the middle lobe or the lingula in 12 cases (28%) and the superior lobes in five cases (12%). The mean diameter of the dominant PAVM’s afferent artery was 6.0 ± 3.4 mm (range, 3-20 mm). All the fistulae treated presented an afferent artery more than 3 mm in diameter. In 34 patients, the dominant PAVM presented a simple architecture (81%) and in eight patients it showed a complex architecture (several pedicles) (fig. 2, 3).

Embolization procedure

A total of 47 embolization procedures were done on 42 patients. The PAVMs were treated in a single procedure in 38 patients (93%). In three patients, two embolization sessions were carried out. In one patient, three embolization sessions were necessary. One re-embolization was done because of the recanalization of one PAVM and/or the occurrence of an episode of paradoxical embolism during the follow-up (fig. 4).

The total number of embolized PAVMs was 99. Per patient, the mean number of PAVMs embolized was 2.3 ± 2.0 (range, 1-9). The total number of coils used in the 42 patients was 530. The mean number of coils used was 12.6 ± 11.8 per patient (range, 2-55).

We observed no paradoxical migration of coils (of the 530 coils deployed) during the procedure. One patient presented supraventricular arrhythmia that resolved spontaneously. One patient had unexplained hiccups for several days after the embolization.

Three patients, including two with PAH, presented hemoptysis that was not abundant related to vascular injury (of the fistula’s afferent artery in two cases and of the aneurysmal sac in one case of a PAVM with a short afferent pedicle) during embolization. In these three cases, rapid embolization of the PAVM’s arterial pedicle stopped the hemoptysis.

Before embolization, PAPm was 17.2 ± 8.8 mmHg (range, 2-43). It did not change significantly after embolization: 18.5 ± 9.4 mmHg (range, 2-49) (Wilcoxon test). For the three patients who had HAP, no significant increase in the PAPm was observed after embolization.

Patient follow-up

• Follow-up during hospitalization: four patients presented moderate fever during the days following embolization.
• Early follow-up after embolization: four patients (10%) presented pulmonary infarction complications. This infarction occurred during the 1st month after embolization in two cases and during the 2nd month in the other two cases. Another patient presented abundant pleural effusion (1 500 ml) 4 days after embolization of a large proximal PAVM whose afferent artery measured 20 mm in diameter.
• Long-term follow-up of the embolization: 39 patients of 42 (93%) were followed up regularly. Three patients living far from the center were lost to follow-up. The mean follow-up after embolization was 36.7 ± 32.3 months (range, 3-133 months). Four patients died during the follow-up period. None of these deaths was related to the PAVM or the embolization. The causes of death were a traffic accident, a case of bronchopulmonary cancer, a massive gastrointestinal hemorrhage, and complications of PAH. After embolization, only five of 38 patients (PaO2 figures not available in four cases, 13%), had a PaO2 lower than 80 mmHg. PaO2 improved significantly, from a mean of 76.4 ± 15.4 mmHg to 92.3 ± 9.8 mmHg (range, 69-116) (p = 0.0001, Wilcoxon test) in all patients, including the hypoxemic patients.
Of the 39 patients followed up, two (5%) presented an embolic neurologic event. In one case, this was a transitory ischemic accident that occurred 5 months after embolization. CT examination demonstrated a central recanalization of the multipedicular dominant fistula’s afferent artery. A new embolization was carried out. On the new CT follow-up, the fistula sac was not retracted, so a third embolization was done. With 6 months of follow-up after this third embolization, the patient had not presented a new neurological episode and the CT showed a satisfactory occlusion of the PAVM treated.
One patient presented a brain abscess occurring 51 months after embolization because a recanalization of the dominant PAVM (initially not diagnosed on the CT exam), but he refused a new embolization procedure.
A 30-year-old woman who had Rendu-Osler-Weber syndrome and presented a single PAVF carried an uncomplicated pregnancy to term 15 months after embolization.
• Imaging follow-up: of the 39 patients followed up after embolization, 24 had at least one CT follow-up exam at 12 months. The 15 others were treated during the past 12 months and have not yet had a follow-up CT.

The 12-month CT examination done after the first session showed complete retraction of the aneurysmal sac of all the fistulae treated in 20 patients (83%) out of 24 (fig. 2), making for 48 satisfactory PAVM occlusions out of 52 (92%). In two of the patients followed up (8%), small PAVMs that did not warrant a new embolization procedure were identified. In four other patients (16%), incomplete retraction of the sac with a fistula that remained open was demonstrated in four PAVMs out of 52 (8%) (fig. 4). The four cases were a multipedicular PAVM (fig. 4). In all cases, recanalization in the center of the coils because of deficient packing, including in the patient who had presented with a TIA, were found. In one patient, the sac was also fed once again by an accessory segmental branch and by a dilated bronchial artery (a bronchial arteriography was done at the same time). A second embolization procedure was done in the four patients, for definitive treatment in three of them. The observation of the patient who had three embolizations sessions is described above.

Discussion

PAVMs can be discovered in several different circumstances. They can be demonstrated on a chest x-ray or CT, either by chance or when the patient is symptomatic (1, 2). Since PAVMs are for the most part encountered in patients with Rendu-Osler-Weber syndrome, a screening strategy is usually proposed to detect PAVMs for preventive treatment (6). Several strategies are distinguished: it is possible to indirectly detect PAVMs with contrast echocardiography (22-24). This examination consists in injecting isotonic solution into a peripheral vein so that microbubbles are formed (1, 22). Simulta-
Fig. 2: A 66-year-old patient with Rendu-Osler-Weber syndrome with an endoglin type mutation. A systematic workup of the disease is done.

a Front chest x-ray found a right basal rounded opacity (asterisk) connecting to the hilum.

b, c CT parenchymal window images obtained at the inferior lobes.

b Demonstration of segmental artery dilatation of the right laterobasal segment (A9). The PAVM's draining vein is also demonstrated (asterisk).

c On a view taken under level B, demonstration of a voluminous PAVM of the anterior basal segment (asterisk). There was also a small PAVM of the external segment of the middle lobe (not presented). Both PAVMs were embolized.

d Selective injection in right A9 segmental artery demonstrating simple architecture MAVP (F) with a single afferent artery (A9).

e At venous time, large draining vein can be seen (V).

f Embolization with seven 5- to 10-mm-diameter coils. Good occlusion was obtained. The presence of a microscopic PAVM (asterisk) can be seen on the follow-up angiogram. Its pedicle is less than 1 mm in diameter.

g Lung x-ray 6 months after embolization shows retraction of the basal-thoracic opacity. The coils can be clearly identified.

h, i Thoracic CT with no injection of contrast material 1 year after embolization at the same level as B and C show occlusion of the afferent artery by the coils (h) and satisfactory retraction of the aneurysmal sac (i).
Embolization of localized pulmonary arteriovenous malformations in adults

JP Pelage et al.

neously with the injection, an echocardiography is done according to the four-cavity view (22, 23). The operator searches for the passage of hyperechogenic contrast bubbles in the left cavities. When the pulmonary capillary filter is normal, the bubbles are never visible in the left cavities. If there is an intracardiac shunt, the passage of bubbles is nearly immediate. When there is PAVF or PAVM, the bubbles pass in the left cavities beyond the third cardiac cycle (23).

The operator looks for PAVFs directly on the standard x-ray, CT, or MRI (17, 21, 24, 25). Plain x-ray only detects PAVMs whose sac is voluminous and appears to provide better performance in the multiple forms (21, 24). The role of MRI has yet to be determined, in particular in PAVM screening (21). Thoracic CT with no injection seems to be the most sensitive imaging technique to detect PAVMs, particularly when they are small (1, 2, 19, 21). Diagnostic angiography does not seem to have a place in the search for PAVMs (1, 2, 26).

This screening is proposed to patients with Rendu-Osler-Weber syndrome but also to those suspected of having the syndrome (21, 24). This diagnosis is mainly clinical, based on demonstrating at least three signs (Curaçao criteria) among the following: family history, (dominant autosomal transmission), cutaneous telangiectasias, recurrent epistaxis, and visceral involvement (hepatic, gastrointestinal, neurological, or pulmonary) (17). If there are missing criteria, screening for visceral involvement (liver and lung) is critical. In other cases, PAVMs should be suspected after the occurrence of an embolic or septic neurological accident.

The morbidity and mortality of the patients presenting a localized form of pulmonary arteriovenous fistulae are for the most part conditioned by the risk of paradoxical embolism (1-3). Preventive therapy should therefore be envisaged, not only when this right-to-left shunt is symptomatic (1, 2). Embolization has become the reference treatment to prevent paradoxical blood clot embolism and improve dyspnea in patients presenting respiratory symptoms. It is normally considered that 25% of patients with PAVMs have a previous history of a stroke and nearly 10% of them have a previous history of brain abscess (1, 2, 21). These manifestations sometimes reveal the disease (3). In the experience of White and collaborators, a previous history of TIA was observed in 37% of patients, a previous history of completed vascular accident in 18%, and a previous history of brain abscess in 9% before treatment (27). In our experience, 12 patients (29%) presented a previous history of neurological accident. This difference may be related to the fact that only the localized forms are considered in our study. It is commonly recognized that all fistulae whose afferent artery measures more than 3 mm in diameter should be embolized to prevent embolism (27, 28). This threshold may seem empirical since an embolic vascular accident was reported in one patient presenting a PAVM that was less than
In localized PAVMs, the risk of recurring embolism after embolization is low, evaluated at 5% in our experience, which is comparable to the experience of Mager and colleagues, who reported five paradoxical embolisms out of 112 (4%) patients treated (30). Recurrence is most often related to the embolization technique used, which should be perfectly rigorous.

Of the different embolization agents used to treat the PAVMs, coils are currently the first-intention agent (21). Controlled coil deployment (mechanical or using electrolysis) are expensive, present a thrombogenic power less than the cottony coils that we use, and seem rarely necessary for experienced operators (21). In our experience, no migration has been observed in more than 500 coils deployed. Embolization balloons are not currently on the market (11). They had the disadvantage of deflating progressively with time, with a risk of secondary migration (11). Finally, the experience with the plug-type occlusion devices recently introduced onto the market is currently too limited in the field of PAVMs to make recommendations (21).

During embolization, the coils should be deposited in the afferent artery that is as near as possible to the aneurysmal sac so as to limit the risk of reperfusion by collateral branches, as occurred in one of our patients. When the pedicle is short, rupture of the aneurysmal sac whose wall is fragile should be avoided because there is a risk of hemoptysis, as in one of our patients. The technique should also allow complete occlusion of the arterial lumen according to the principles of packing. If this technique is not rigorously applied, recanalization at the center of the coils can occur. This recanalization (8% of the PAVMs treated in our experiment, as in Mager’s) can cause recurrence of embolic complications, as we observed in two of our pa-

**Fig. 4:** A 59-year-old patient with Rendu-Osler-Weber syndrome. PAVM was diagnosed after occurrence of brain abscess. There was a multipedicular PAVM of the middle lobe embolized by eight coils with good angiographic results. Thoracic CT with injection of contrast material 1 year after embolization found there was no retraction of the aneurysmal sac, suggesting a diagnosis of recanalization at the center of the coils.

a On an axial view at the middle lobe (mediastinal window) a non-retracted sac taking up contrast material can be seen downstream from the coils (S).

b Axial view just above A: the afferent artery embolized by coils and the more internal draining vein can be seen.

c Parasagittal reconstruction (parenchymal window) provides objective evidence of central recanalization between the coils by showing the permeability of the afferent artery and the opacification of the sac. A coil can also be seen in the apical segment of the right inferior lobe. A new embolization session was scheduled.

d Recanalization in the center of the coils of one of the two pedicles already embolized is confirmed.

e Supplementary embolization is done for complete occlusion of the two afferent pedicles.
Embolization of localized pulmonary arteriovenous malformations in adults

Rémy-Jardin et al. reported successful embolization of localized PAVMs, contrary to embolization of diffuse PAVMs, which is associated with less long-lasting results, in particular because of the increase in size of microscopic PAVMs (14). Contrary to diffuse forms of PAVM, the hypoxemic manifestations are considered rarer in the localized forms except if the PAVMs are large or multiple (2, 14, 21). However, in our series, more than 50% of patients presented dyspnea and hypoxemia, whereas it is present in more than 90% of patients with the diffuse form of PAVM (14). We have observed that the presence of respiratory signs was related to a large-diameter dominant PAVM. Therefore, the embolization has improved or even corrected the dyspnea, and only 13% of patients remained hypoxemic after the treatment. Follow-up thoracic CT 6-12 months after embolization is essential to demonstrate a recanalization of the embolized PAVMs. CT without contrast material is usually recommended (19). Remy et al. defined the main criteria of embolization success as the complete retraction of the aneurysmal sac at the contact of coils (19). In another recent series on 38 patients with 64 embolized PAVMs, Remy-Jardin et al. reported successful embolization in 75% of PAVMs (31). PAH or hepatic involvement were factors of incomplete PAVM occlusion (31). Our higher rate of complete occlusion may be attributable to the improvement in embolization techniques (catheters and coils). We believe that injection of isolated contrast material during follow-up CT after embolization may sensitize the possibilities of early detection of reperfusion of treated PAVMs (32). Although retraction of the sac is a good criterion in simple forms, the diagnosis of reperfusion seems more difficult to advance in PAVMs with complex architecture, particularly if there are artifacts related to the many coils necessary to occlusion. Furthermore, reperfusion is not always related to recanalization in the center of the coils, but sometimes to the recruitment of adjacent pulmonary arteries (32, 33). We believe that contrast material injection could also make it possible to demonstrate the systemic supply by other bronchial or nonbronchial arteries even if the relevance of this clinical recurrence is difficult to evaluate (34, 35). However, the involvement of the bronchial arteries in the onset of a recurrence of paradoxical embolism has already been demonstrated (35). It goes without saying that if a CT is done with contrast material injection, strict asepsis rules must be respected and injection of air bubbles prevented. Echo-cardiography has only a limited role after therapy because most often it remains positive, particularly in patients presenting diffused forms of PAVM (a population that was not reported on here) or a multiple form (21, 22). This positive result can be explained by the detection of microscopic PAVMs that cannot be detected on CT, whose size does not require treatment, and whose afferent artery would be too small for a selective embolization (22).

We identified a particular population of patients: those who presented PAH. Four patients had Rendu-Osler-Weber syndrome; an ALK1 mutation was identified in two cases and an SMAD4 mutation in a third case. PAVMs are most often encountered in patients presenting type 1 Rendu Osler-Weber syndrome (mutation on the endoglin) even if, as in our series, patients with the ALK1 mutation can present PAVMs (18). The association between PAH and Rendu-Osler-Weber syndrome is undoubtedly not accidental. The BMPR2 mutation often found in patients with PAH and the ALK1 mutation are both involved in the regulation of protein synthesis of the vascular endothelium (18). These anomalies may be manifested by vascular dilatations during Rendu-Osler-Weber syndrome and by vascular occlusions during PAH (18). The mechanisms of PAH during Rendu-Osler-Weber syndrome are poorly known. The interaction between the lung and the liver is probably underestimated (36). The prognosis for patients with Rendu-Osler-Weber syndrome and PAH is not good. The patient in whom we did not do an embolization because of major PAH died of hemothorax from a ruptured PAVM. A second patient whose only PAVM was successfully embolized died of complications of PAH. Finally, endovascular navigation in patients presenting PAH is more difficult through the dilated right cavities and the pulmonary arteries are tortuous and fragile. Two out of three episodes of hemothorax during the procedure occurred in patients with PAH. Moreover, there is a theoretical risk of aggravating the pulmonary artery pressure while embolizing multiple PAVMs, even if in our experience there was no significant rise in mPAP after embolization.

Conclusion

Today embolization is a first-intention treatment for PAVMs but should be reserved for specialized centers. In our experience, the indication for surgical resection is no longer relevant, even in cases of proximal and/or large-caliber PAVM. In the localized forms, the risk of paradoxical embolism recurrence is low if complete occlusion of the treated PAVM is obtained. Similarly, respiratory signs improved significantly in dyspneic and hypoxemic patients. Rigorous CT monitoring with injection of iodated contrast material seems indispensable to look for reperfusion of the PAVMs treated.

Références

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Pulmonary arteriovenous malformations in adults

J Pelage et al.

Embolization of localized pulmonary arteriovenous malformations


