Aneurysms of the Pulmonary Arteries*

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Historic Perspective and Overview

Descriptions of pulmonary artery aneurysm(s) (PAA) date back to the 1700s, but the history is fragmented and difficult to follow. Deterling and Clagett1 noted that in a 1785 review of 530 intrathoracic aneurysms, two involved the pulmonary arteries. The early historians of PAA indicate that individual reports of PAA began to accrue during the early 1800s.1-5 The first reviews of PAA as a separate topic appeared in the late 1800s and early 1900s and were fueled by two ancient diseases of man, tuberculosis and syphilis. Both diseases, when unchecked, have a significant capacity to cause PAA, and in the preantibiotic era the two together appear to have caused the majority of cases. While both are infectious diseases, they cause PAA by different mechanisms, and syphilitic aneurysms almost always occur in the large pulmonary arteries, while tuberculous aneurysms almost always involve small intraparenchymal arteries. These differences spawned two literatures, one dealing with proximal PAA1,2,5 and the other with peripheral PAA.7 A third subset of PAA was created when Charlton and DuPlessis8 and subsequent authors wrote only on aneurysms of the "large intrapulmonary arteries."9,10 Finally, arteriovenous aneurysms, including those associated with hereditary hemorrhagic telangiectasia (HHT), have followed yet another pathway in the literature.11 As (1) awareness of PAA has increased, (2) the use of antimicrobials has diminished the incidence of PAA caused by syphilis and tuberculosis, and (3) the differential diagnosis of PAA has expanded, the historical subdivisions of PAA have become less clinically useful.

Different authors have applied different definitions of the word "aneurysm" to their studies of the pulmonary vascular tree. For example, Boyd and McGavack3 defined pulmonary arterial aneurysms pathologically as localized vascular dilatations with deterioration of one or more layers of the arterial wall. The disadvantage of their definition is that it requires tissue before one can make the diagnosis; only postoperative or autopsied patients could be considered. The authors recognized some of the pitfalls of their own definition, and they added to their series 30 cases that did not fit their own definition but in which there were "reasonably positive clinical findings."3 The use of the term "mycotic aneurysm" with respect to the pulmonary vascular tree is another example of idiosyncratic definitions. Two major reviews of "mycotic pulmonary aneurysms" eliminated aneurysms of tuberculous origin from their discussions and differentiated between "mycotic" and "syphilitic" aneurysms.9,12

It is clear that PAA are rare. In 1947, Deterling and Clagett1 published an extensive review of proximal PAA. They reviewed 92,026 autopsy studies and added 17,545 of their own, and they concluded that only eight cases of PAA had been documented in a total of 109,571 autopsies. Despite the restrictions of their study, it helps to point out the rarity of PAA. An accurate current incidence is hard to establish, as (1) definitions of PAA have been inconsistent; (2) no authors have addressed the topic of all PAA regardless of etiology; (3) retrospective reviews of autopsies looking for mention of PAA will probably yield fewer cases than a prospective study in which the pathologist is actively looking for PAA; and (4) antimicrobials have had an impact on the incidence and etiology of PAA. Thus an incidence culled from an historical review of the entity would not apply to PAA today.

In this review, we present a unified overview of classification based on etiology and pathogenesis which we hope will be clinically useful. Diagnosis, therapy, and prognostic implications will also be discussed. While we will attempt to unify the literature conceptually, we will not attempt to cover every case of PAA reported to date.
DEFINITION OF TERMS

According to Dorland's Illustrated Medical Dictionary, an aneurysm is "a sac formed by the dilatation of the walls of an artery, or of a vein and filled with blood." The word "sac" excludes diffuse dilatations of the vasculature, whether of the larger arteries, as can occur with some cases of pulmonary artery hypertension of any cause,1 or of the arteriovenous channels, as can occur with cirrhosis13-15 or COPD.16 Because of advances in invasive radiology and their clinical relevance, we would join other authors17 and add one more facet to this definition; we will define an aneurysm clinically as a radiologically demonstrable sac formed by the dilatation of the walls of an artery or of a vein and filled with blood. There are two shapes of true aneurysms; saccular, defined as an essentially symmetric aneurysm formed by distention of the entire circumference of the vessel wall, and fusiform, an asymmetric shape caused by weakening and dilatation of only part of the circumference of the vessel.18 Differentiation between these two in the literature on PAA does not appear to have diagnostic or prognostic value and will not be pursued here.

The term "dissecting aneurysm" implies extension of blood within the wall of an artery.18 This usually occurs via a tear in the intima of a vessel, which allows blood to enter and course between layers of the vessel wall. While there is some dispute about the role of medial degeneration in dissecting aortic aneurysms,19 there appears to be a strong association between dissecting PAA and medionecrosis, and dissecting PAA will be discussed under that heading. We will use the word "medionecrosis" in its more generic sense—degenerative disease of the media without specific implications regarding the specific medial component which is most affected.18

A mycotic aneurysm is one caused by infectious involvement of a vessel wall. The term does not exclude aneurysms due to mycobacterial, syphilitic, and fungal infections.

False aneurysms are the result of a breach of all layers of a vessel wall.18 Extravasating blood is contained by compressed extravascular tissues or by clot, which make up the "wall" of the aneurysm. The vessel wall itself need not be stretched; extravasated blood gives the appearance of vessel enlargement on angiography. False aneurysms are usually caused by penetrating trauma or by the shear forces of a deceleration injury. Since almost all false aneurysms are due to trauma, they will be covered under the Trauma section of this article.

Finally, we will use the term PAA to describe an arteriovenous communication large enough to be demonstrated radiologically. As such, it is a subset of the larger category of arteriovenous malformations as delineated in the recent excellent review of Burke et al.17

CLASSIFICATION BY ETIOLOGY AND PATHOGENESIS

We have opted to subdivide PAA into those with and those without arteriovenous communication, because we find that this separation makes sense both in terms of etiology and in terms of some of the complications of PAA (Table 1). In addition, a high percentage of arteriovenous PAA are caused by HHT, a diagnosis which has genetic implications.11,17

PAA without Arteriovenous Communication

Several underlying conditions are recurrent themes in the literature and appear to be "risk factors" for PAA occurring proximal to the pulmonary capillary bed: infection, structural cardiac abnormalities, structural vascular abnormalities, and pulmonary hypertension. In many of the documented cases, PAA appear to have resulted from an interplay between more than one of these cofactors. For example, PAA in a patient with congenital heart defects and endocarditis is a recurrent association, as is PAA in a patient with pulmonary hypertension and cystic medionecrosis. Which factor played a predominant role is often unclear.

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<th>Table 1—Classification of PAA</th>
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<td><strong>Causes of PAA without arteriovenous communication</strong></td>
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<td>Tuberculosis (Rasmussen's aneurysms)</td>
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<td>Syphilitic</td>
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<td>Other (bacterial and fungal)</td>
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<td>Structural cardiac abnormalities</td>
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<td>Congenital heart disease</td>
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<td>Acquired cardiac abnormalities</td>
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<td>Structural vascular abnormalities</td>
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<td>Congenital</td>
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<tr>
<td>Cystic medionecrosis/atherosclerosis</td>
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<td>Acquired</td>
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<td>Marfan's syndrome</td>
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<td>Vasculitis</td>
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<td>Behçet's syndrome</td>
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<td>Other</td>
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<td>Pulmonary hypertension</td>
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<td>Idiopathic</td>
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<td>Syndromes</td>
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<td>Hughes-Stovin syndrome</td>
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<td>&quot;Isolated&quot;</td>
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<td>Associated with hereditary hemorrhagic telangiectasia</td>
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Infection

Infection is clearly the most important cause of acquired PAA. Syphilis and tuberculosis were major causes of diagnosed PAA in the past, and mycotic aneurysms caused by other organisms play a major role in the more recent history of the entity.

Tuberculosis was perhaps the first identified agent capable of causing PAA, and tuberculous PAA was reported in the early 1800s, when the disease was still called "pthisis" in the English literature. Rasmussen published a detailed pathologic study of 11 cases in 1868 and 1869, his name became attached to the entity. The pathogenesis of Rasmussen's aneurysms has been thoroughly studied and is unlike that of most other PAA. (PAA due to infectious pneumonia may at times share the same pathogenesis.) Rasmussen's aneurysms develop in vessels which run through or are tangential to tuberculous cavities. Thus, they occur in patients with chronic progressive disease. The outer vessel wall is affected first, and a process of tissue destruction and replacement by granulomatous tissue progresses towards the lumen, leaving a thickened and weakened wall. The affected wall has a propensity to break down, leading either to an aneurysm, with the flow of blood contained by the intima of the vessel, or to rupture. The fact that infection invades the vessel from a surrounding parenchymal focus accounts for the peripheral distribution of Rasmussen's aneurysms.

In the preantibiotic era, Rasmussen's aneurysms may have been the most common type of PAA. Rasmussen thought that, once attuned to their presence, he could find a mycotic aneurysm in every case of tuberculosis with hemoptysis. Autopsy studies of patients with tuberculosis have cited prevalences of Rasmussen's aneurysms in the 4 to 11 percent range. That chronic progressive tuberculous disease is less common today probably explains why Rasmussen's aneurysms do not figure heavily in recent reports of PAA in the literature.

Both the history and pathogenesis of syphilitic PAA are of particular interest. The first descriptions of syphilitic involvement of the pulmonary artery and of syphilitic PAA appeared in the late 1800s. The predominantly proximal location of syphilitic PAA is due to the fact that the vasa vasorum supply these vessels and are the avenue of injury; syphilitic infection of the vasa vasorum leads to weakening of the vessel and appears to induce atherosclerotic changes. While earlier authors presumed syphilis to be the cause of most aneurysms of the proximal pulmonary arteries, the authors of later major reviews of the topic thought syphilis to be the cause in only about 33 percent of cases. As with tuberculous PAA, syphilitic PAA have figured less importantly in recent literature; the use of antibiotics and the initiation of major public health screening programs appear to have had a major impact upon this entity.

Several bacteria and fungi have been causally implicated in mycotic PAA. These include Staphylococcus aureus, Corynebacterium diphtheriae, Corynebacterium acnes, Actinomyces spp, Aspergillus flavus, and Candida albicans. S aureus and streptococci have caused the vast majority of the cases.

When organisms other than M tuberculosis and T pallidum cause PAA, they appear to do so in most if not all cases via septicemia and endovascular seeding of the pulmonary artery in question. Several lines of evidence support this pathogenesis. PAA have occurred in association with right or left-sided endocarditis, osteomyelitis, skin abscesses, and pneumonias. With all but pneumonias, the endovascular route was the only available route of access. In the case of pneumonia, some authors have documented an angiocentric pattern of pneumonia and/or PAA in an area not involved by infiltrate, either of which strongly suggests that the primary event was endovascular seeding. ("Angiocentric pneumonia" is a pattern of parenchymal infiltrate circumferentially surrounding a pulmonary artery in the absence of inflammation of airways and peribronchial parenchyma. Also in keeping with an endovascular route of injury is that mycotic PAA not due to M tuberculosis or T pallidum can occur in either proximal or peripheral pulmonary arteries or in both locations in the same patient.) Thus, neither vasa vasorum of large vessels nor surrounding parenchymal infection appears to be necessary to the process of PAA formation due to these organisms. In some cases of PAA associated with pneumonia, the aneurysm occurred within a pneumonic area and the pneumonia was not documented to be angiocentric; in these cases, we cannot exclude a pathogenesis as described for Rasmussen's aneurysms.

Congenital heart disease, which will be discussed in more detail below, appears to be a "cofactor" in a substantial number of patients with mycotic PAA not due to syphilis or tuberculosis. Another factor that may be of some importance is the presence of pulmonary hypertension. The association is weaker than that with congenital heart disease, although it is clear that hypertension will increase wall stress and thus increase the force dilating a weakened wall. The role of pulmonary hypertension in nonmycotic PAA is also discussed below. A third cofactor that deserves special mention is a history of IV drug abuse. While one study of 70 autopsies of IV drug users found no cases of PAA, another found three clinically silent
cases of PAA in a consecutive series of 25 drug users, and the investigators speculated that PAA may be more common than expected in this population. Both the strong association between IV drug use and right-sided endocarditis and the fact that the pulmonary arterial vasculature is the first site that strains intravenously injected foreign material probably contribute to this association.

Structural Cardiac Abnormalities

Most structural cardiac abnormalities are congenital, and congenital abnormalities are a recurrent theme in the literature on PAA. If we average the two major autopsy reviews of "proximal" PAA, congenital abnormalities were present in 56 percent of cases. Their importance is not, however, limited to proximal PAA; there are many case reports of congenital heart disease associated with peripheral PAA. As noted above, many of the cases of PAA with congenital heart disease also involved infection. Vascular seeding of the organism probably played a major role in the pathogenesis of those cases. There is also a large number of cases of PAA associated with congenital abnormalities without concomitant infection. For the latter group, possible mechanisms acting alone or in combination include: (1) marantic embolization causing local vascular inflammation and breakdown; (2) weakness of the pulmonary arterial wall caused by congenital structural abnormality; (3) infection that was not detected; and (4) increased pulmonary blood flow and pulmonary arterial hypertension associated with structural cardiac abnormalities. None of these mechanisms has been clearly substantiated, although the first possibility has special appeal because it could be a pathogenic mechanism for PAA in the Hughes-Stovin syndrome. (See Idiopathic section below.) While the overall incidence of PAA may be too low for these possibilities to be sorted out, it is clear that the presence of congenital abnormalities puts a patient at markedly increased risk for PAA.

Certain types of congenital abnormality are more strongly associated with PAA than are others. PDA appears in the literature more frequently than any other abnormality. The pathogenesis of PAA with PDA may be as follows: when PDA is present with a left-to-right shunt, a "jet stream" hits the wall of the pulmonary artery opposite the PDA. The jet stream can cause local injury and weakness of the arterial wall at its point of impact and can thus lay the groundwork for marantic and/or infectious involvement. The second most common congenital defect associated with PAA is atrial septal defect. Other defects reported in conjunction with PAA include ventricular septal defect, tetralogy of Fallot, Klinefelter's syndrome, pulmonary valvular stenosis, pulmonic regurgitation, bicuspid pulmonary valve, and transposition of the great vessels.

Although they are extremely rare, there are cases of PAA with structural cardiac abnormalities that were probably acquired rather than congenital. These include mitral stenosis, pulmonic stenosis, tricuspid insufficiency, and pulmonic insufficiency.

In addition to infection, pathologic findings that frequently present in the cases of PAA with structural cardiac abnormalities include the vascular changes associated with pulmonary artery hypertension and those of medionecrosis.

Structural Vascular Abnormalities

Unlike structural cardiac abnormalities, which are usually congenital, most structural vascular abnormalities are acquired degenerative diseases. Some of the congenital malformations mentioned above involve vascular abnormalities, and there are rare case reports of isolated congenital vascular abnormalities associated with PAA. These include pulmonary artery atresia, aortic hypoplastia, and diffuse vascular hypoplastia.

Medionecrosis and atherosclerosis are degenerative vascular diseases often mentioned in the literature on PAA. Excellent studies of the pathogenesis of these lesions in the literature dealing with the aorta give reason to believe that both lesions are the result of a continual process of damage to and repair of the vascular structures. Males predominate in studies of medionecrosis of the aorta. Medionecrosis of the pulmonary artery is different in that there is no sex bias but in other ways is similar to aortic medionecrosis. In the literature on PAA with medionecrosis or atherosclerosis, a confluence of other risk factors such as congenital heart disease and pulmonary hypertension is again seen. One proposed pathogenesis is as follows: patients with congenital heart defects may sometimes inherit a faulty template for connective tissue. Pulmonary hypertension often accompanies congenital heart disease, and could cause continual damage of this already unsound connective tissue. This damage accelerated by the synergy between connective tissue defects and hypertension would require constant repair and accelerate the development of medionecrosis or atherosclerosis. They in turn put the patient at markedly increased risk of arterial rupture or aneurysm. Medionecrosis or atherosclerosis were present in the arterial walls in most cases of dissecting PAA reported to date.

Patients with Marfan's syndrome form a special subset of patients with structural vascular abnormalities. In these patients, a disorder of connective tissue is passed on as a dominant trait from generation to generation, and its multisystem involvement is usually overtly manifest. Although aortic disease usually dominates the vascular picture in Marfan's syndrome, patients with overt Marfan's disease, and with an
unacknowledged *forme fruste* of Marfan’s have been subject to dissecting PAA.

*Vasculitis* seems to be an obvious substrate for vascular degeneration and PAA formation, but reports of PAA with vasculitis (other than focal inflammatory reactions as with mycotic aneurysms) are strikingly rare. *Behçet’s disease* is a rare idiopathic disease that appears to be mediated by a vasculitis, and PAA are associated with it, as discussed below. We found only two documented case reports of PAA associated with other vasculitides. In one, PAA were associated with *giant cell arteritis* affecting both the pulmonary and systemic vasculatures. In the second, an unclassified *large vessel arteritis* appeared to be the precipitant for PAA formation. In two more case reports vasculitis may have played a role in PAA formation. In one the patient had sarcoid, scleroderma, and interstitial pulmonary fibrosis. In the second case vascular inflammation occurred in a patient with a history of recurrent infection, raising the possibility of an infectious etiology.

**Pulmonary Hypertension**

The vast majority of cases of PAA with pulmonary hypertension occurred in the presence of the other cofactors mentioned above, which may have abetted the process of PAA formation. There are, however, a few cases in which pulmonary hypertension is the only recognizable “risk factor.” Examples are a case of *primary pulmonary hypertension* with PAA and a case of *drug-induced pulmonary hypertension* and subsequent PAA formation.

**Idiopathic**

Two idiopathic syndromes are associated with PAA. In 1959, Hughes and Stovin published a study of four young males with a syndrome of recurrent superficial and deep venous thrombosis, increased intracerebral pressure (due to venous thrombosis), and PAA. All four died of hemoptysis. All had had recurrent fevers, but premortem and postmortem studies were all unable to document an infectious cause. While the *Hughes-Stovin syndrome* is extremely rare, cases continue to be reported. The aneurysms can resemble mycotic aneurysms histologically, but an infectious agent has not been identified in any case to date. Nevertheless, some authors assert that these aneurysms must be mycotic and due to an unidentified organism.

In 1981 a French group published case studies of several young males with *Behçet’s syndrome* and PAA. (Expanded major criteria for Behçet’s now include oral ulcerations, genital ulcerations, uveitis, joint involvement, and cutaneous vasculitis.) They noted that three previous cases of Behçet’s with PAA had been reported and that the roentgenographic abnormalities in other cases were consistent with PAA that had not been diagnosed. They also presented a case of a 35-year-old man who fulfilled criteria for both Behçet’s disease and for the Hughes-Stovin syndrome, and they posited a relationship between the two. They pointed out that the clinical presentations can overlap significantly, that the pulmonary manifestations of the two can be identical, and that the histology of the aneurysms in both entities can be similar. The concept of pathogenic kinship between the two diseases is appealing but not very tenable at the current time. Although the precipitating events remain unclear, the manifestations of Behçet’s syndrome are the result of a systemic vasculitis that may be caused by immune complex deposition. There is also some evidence for genetic predisposition to the syndrome.

A diffuse vasculitis was described in one patient who met criteria for the Hughes-Stovin syndrome, but other reports have emphasized the lack of systemic vascular involvement. We also note that PAA have been described in women with Behçet’s whereas the Hughes-Stovin syndrome has heretofore only been documented in men. The underlying causes of both the Hughes-Stovin syndrome and of Behçet’s syndrome are still unclear, but we cannot presume that the points of clinical overlap between the two signify a common pathogenesis.

There are cases of idiopathic PAA in patients with none of the cofactors listed above and whose disease did not occur within the context of a syndrome known to be associated with PAA. While it is always possible that in some of the cases a cofactor was present and was overlooked, it seems likely that rare cases of isolated PAA do exist.

**Trauma**

Trauma is another rarely documented cause of PAA. Two types of pulmonary vascular trauma are possible, extravascular and endovascular. Both blunt and penetrating trauma to the chest have been known to cause PAA, penetrating stab wounds being the most frequent cause of extravascular trauma. The advent and increasing use of the balloon-tipped pulmonary artery catheter has brought with it case reports both of pulmonary artery rupture and of PAA due to endovascular trauma. PAA due to balloon-tipped catheters can be unstable and produce delayed fatalit. We believe that they occur more frequently than is suspected.

**Miscellaneous**

A few cases of PAA (without arteriovenous communication) defy our classification scheme. One patient with squamous cell cancer of the lung developed a left-sided PAA several months after left upper lobectomy and radiation to the left side. In one patient a ventriculoatrial shunt embolized and became the focus
for a mycotic PAA. The authors presumed that myxomatous emboli had invaded and weakened the arterial wall. Another patient developed an aneurysm postoperatively at the site of a Pott's anastomosis. Finally, one patient who had had his left pulmonary artery banded six years earlier during operative repair of congenital abnormalities developed a false aneurysm where the banding fabric eroded the arterial wall.

PAA with Arteriovenous Communication

Although congenital factors figure prominently in the etiologies of both PAA without arteriovenous communication and PAA with arteriovenous communication (PAVA), there are fundamental differences in how they contribute. In the former group, congenital structural abnormalities put the pulmonary vascular structures at increased risk of injury, infection, and aneurysm formation. With most PAA, the congenital defects are the aneurysms themselves. They are present before birth and enlarge over time. Other factors such as infection and pulmonary hypertension are not necessary to their formation and are not normally present. PAA without arteriovenous communication and PAA can also differ in their clinical presentations. (See Clinical Manifestations section below.)

Churton wrote on "Multiple aneurysms of the pulmonary artery" in a 12-year-old boy in 1897 and is credited with the first description of PAA. Hereditary epistaxis had been described by Babington in 1865 and picked up the names "Osler-Weber-Rendu" as other physicians expanded the description of the entity. While knowledge of both PAA and Osler-Weber-Rendu disease (later named hereditary hemorrhagic telangiectasis, or HHT) grew over the years, the strong association between HHT and pulmonary aneurysms did not become apparent until the 1930s. Most PAA, with or without HHT, are congenital, but there are rare reports of acquired PAA.

Congenital Pulmonary Arteriovenous Aneurysms

In the normal embryologic development of the respiratory system, arterial and venous vascular buds divide separately and then meet and anastomose in subpleural regions of the embryonic lung, creating arteriovenous fistulas. Only after they have anastomosed do vascular septa subdivide the anastomotic channels, creating capillaries. With this in mind, it is easy to imagine that PAA could be congenital either as a result of "mistakes" in the embryologic translation of a normal genetic template or as a result of a faulty genetic template that "misspells" in the area of arteriovenous connections. It follows that most PAA are the result of congenital errors in the development of the capillary bed, with two major subsets: (1) cases in which the PAA appear to occur in isolation (i.e., mistranslation of genetic material in the absence of an inheritable genetic defect); and (2) cases of HHT, in which many organs can be involved, and the defect is passed from generation to generation as an autosomal dominant trait. Congenital PAA occur in isolation approximately 60 percent of the time; the other 40 percent occur in association with HHT. (PAVA are not present in every case of HHT; the incidence is about 15 percent.) Symptoms and physical findings do not differentiate these two subsets, and the physician is obliged to look for systemic involvement whenever PAA are diagnosed. In keeping with their embryogenesis, the lesions are usually subpleural. For unclear reasons, patients with PAA in the context of HHT are probably at more risk of complications from their PAA than those without the genetic defect. They have a greatly increased morbidity and mortality when other organ involvement is factored in.

There are extremely rare PAA that reflect errors of embryologic development and inappropriate confluence of venous and arterial channels proximal to the anastomosis which is destined to become the capillary bed. These PAA tend to be perihilar rather than peripheral. Some of them have anomalous venous drainage, and some are fed by the systemic arterial circulation. They are outlined and classified by Anabtawi et al. Because of their extreme rarity, they are most useful as lessons in embryology.

Acquired PAA

Mycotic PAA have been reported, apparently forming as the result of erosion of a mycotic arterial aneurysm into an adjacent vein to cause a communication that bypasses the capillary system. Traumatic PAA have also been reported.

Clinical Manifestations and Diagnosis

Most of the presenting features of PAA are nonspecific, and the diagnosis must be considered as multiple clues add up (Table 2). Only when there is a typical presentation of HHT with its autosomal dominant transmission, history of bleeding from mucosal sites, or visible telangiectasias will the clinician be able to

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<th>Table 2—Clues to the Presence of PAA*</th>
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<td>Typical manifestations of HHT</td>
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<td>Hemoptyis</td>
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<td>Abnormal chest roentgenogram</td>
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<tr>
<td>Large right-to-left shunt</td>
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<td>Cyanosis</td>
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<td>Clubbing</td>
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<td>CNS phenomena</td>
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<td>Chest pain</td>
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<td>Cough</td>
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*In approximate order of diagnostic utility/importance.
approach a patient with PAA (PAVA) specifically in mind. There are four presentations that appear to be adequate to raise suspicion when found in isolation: hemoptysis; abnormalities on chest roentgenogram which are consistent with PAA; evidence of a right-to-left shunt; and CNS phenomena attributable to infected or noninfected emboli without an obvious source. The former two apply to all PAA, while the latter are common with PAVA.

PAVA of any etiology often present with hemoptysis. When one considers patients who present with massive hemoptysis, PAA appear to be the cause in 3 to 6 percent of cases.\(^3\) One of the most strikingly recurrent themes that we have encountered in the cases reviewed is that hemoptysis in a patient with PAA is a marker of instability of the lesion and a strong indicator of a need for intervention. This appears to be true regardless of the etiology.\(^1,10,11,71,72,74,75,98,99,102,112\)

With the exception of Rasmussen's aneurysms, PAA are usually visible (though not always diagnosable) on the chest roentgenogram. This is most strikingly true with PAVA. Because of the predominantly subpleural location of PAA, they appear as peripheral, noncalcified nodular lesions in over 95 percent of cases, and the vessels subtending them may be seen connecting them to the hilum.\(^11,17,107\) While one can often see the aneurysm(s) on chest roentgenogram, subtending vessels may not be apparent, and there are cases of PAA and other PAA which have been mistaken as metastases or, when single, as a malignant or infectious lung nodule.\(^17,44,62,107,108,113,114\) Failure to include PAA in the differential diagnosis of pulmonary nodules has even led to percutaneous needle biopsy of PAA.\(^44,82\) More proximal lesions that involve the main branches of the pulmonary artery are also usually apparent on chest roentgenogram.\(^1,14,46,62,65,70,87,115,116\) PAA in these locations can be confused with hilar adenopathy, aortic aneurysm, vascular dilatation without aneurysm, and PDA without PAA.\(^1,3\) Thus, the chest roentgenogram is usually abnormal when PAA are present, but the abnormality can often be mistaken for another more common lesion.

PAVA by definition involve right-to-left shunting through non-gas-exchanging vessels. Although hypoxemia is present with up to 80 percent of PAA,\(^107\) and a "classic clinical triad" of dyspnea, cyanosis, and clubbing has been described,\(^109\) 13 to 56 percent of patients may be asymptomatic.\(^17\) Arteriovenous conduits also allow paradoxical embolization; patients with PAA have a markedly increased incidence of brain abscess and other less specific neurologic events.\(^11,117,118\) Unexplained brain abscess should raise suspicion of PAVA. If a patient with PAVA also has HHT; bleeding from nonpulmonary sites (nose, GI tract) may herald the disease.\(^11,17,106,119\)

Unless PAA present with one or more of the above features, their presentation may be very nonspecific, and they can be extremely difficult to diagnose. This is easy to understand when one considers that among the possible etiologies are two of the great mimickers, syphilis and subacute bacterial endocarditis. Signs, symptoms, and findings that patients with PAA may manifest in addition to those noted above include dyspnea, chest pain,\(^1,3\) signs of pulmonary hypertension and right ventricular failure,\(^51,130\) cough,\(^3\) and a bruit on physical examination.\(^1,3\) Right ventricular hypertrophy or dilatation may be evident on chest roentgenogram.\(^1,130\) The ECG may reveal right axis deviation.\(^1,51\)

In addition to the morbidity mentioned above, PAA have a tremendous capacity for mortality regardless of etiology (Table 3). Aneurysms are inherently unstable because any dilatation in turn increases the dilating force, the wall tension, according to the law of Laplace: \(T = P R/2\). This is a classic vicious cycle; while some (though not all) PAA dilate continuously until they rupture, all have the potential to rupture.

Angiography is the gold standard of diagnosis of PAA and is integral to some interventions (see Treatment section). Angiography allows one to clarify the vascular etiology of a lesion, to separate diffuse dilatation from aneurysm(s), and to identify any unusual vascular channels leading to or from the lesion. Other modalities have been used in past cases and may be of help in diagnosis (Table 4). MRI has clear promise, as flowing blood is not "organized" by the magnetic field and thus appears as empty space on the scan, allowing clear separation of vascular from nonvascular lesions.\(^181\) Since MRI allows one to avoid both radiation and the injection of contrast material, it may become the best available modality for following a patient with multiple

### Table 3
*Mortality due to PAA (by Etiology)*

<table>
<thead>
<tr>
<th>Etiology</th>
<th>% Mortality</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myotic</td>
<td>82</td>
<td>2,7,20</td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Hughes-Stovin*</td>
<td>100</td>
<td>76</td>
</tr>
<tr>
<td>HHT(^*)</td>
<td>16</td>
<td>17</td>
</tr>
</tbody>
</table>

\(^*100\%\) if untreated; some documented cures by resection of single PAA.

\(^*HHT = hereditary hemorrhagic telangiectasia. The figures underestimate mortality, as they reflect only a 6-year follow-up period.

### Table 4
*Diagnostic Testing Modalities for PAA*

<table>
<thead>
<tr>
<th>Procedure</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluoroscopy</td>
<td>1</td>
</tr>
<tr>
<td>Angiography</td>
<td>1,17,46,76</td>
</tr>
<tr>
<td>Ultrasonography</td>
<td>43,50,70</td>
</tr>
<tr>
<td>Radionuclide angiography</td>
<td>70</td>
</tr>
<tr>
<td>Computed tomography (with contrast)</td>
<td>23,70,81,94,102,134</td>
</tr>
<tr>
<td>Magnetic resonance imaging</td>
<td>121</td>
</tr>
</tbody>
</table>
Aneurysms over time. Patients in whom there is suspicion of PAA should have shunted measured to determine the functional significance of a lesion(s) and to allow documentation of change over time. 17

**TREATMENT**

We have stressed that PAA of any etiology, particularly when associated with hemoptysis, cannot be assumed to be stable. In the absence of a controlled study, we think that the collected case histories need to be considered, and that they strongly favor intervention. The strongest case for intervention can be made for PAA, with their capacity for paradoxical embolization and CNS morbidity. 17,107,117,118

The first rule in treatment should be to correct any underlying etiologic factors that can be addressed (eg, infection should be treated, PDA and other congenital abnormalities amenable to surgery should be corrected). One must next address the PAA itself (themselves). Treatment options vary with the location of the specific PAA in question. With involvement of the main pulmonary trunk, surgical intervention with aneurysmectomy is the only possible intervention. With more peripheral lesions, options expand to include both vascular ligation with resection of distal tissue and nonsurgical embolotherapy.

The first successful repair of an aneurysm of the main pulmonary trunk was reported in 1971. 112 The operation was made possible by the availability of cardiopulmonary bypass and with experience with repair of the aorta and congenital pulmonary artery abnormalities. The surgeons resected the main pulmonary trunk and the proximal left and right main pulmonary arteries and replaced resected tissue with a woven Dacron graft. Since 1971, there have been several reports of repair of proximal lesions. The majority of groups have opted for aneurysmorrhaphy, with juxtaposition and closure of the remaining arterial wall. 18,38,40,45,115,116,123 Banding of the pulmonary artery has also been reported to be successful. 124 One surgical group used a patch consisting of excised pericardium. 125

When an aneurysm is distal to the main pulmonary trunk, resection becomes a therapeutic option. In the past, resection was often the only therapeutic option for these lesions. 11,106,114 Some surgeons have opted for pneumonectomy as the intervention for aneurysms of a main pulmonary artery or multiple more peripheral aneurysms. 23,34,90,109,114 Peripheral aneurysms have also been treated with lobectomy. 126,127,128,130 or with resections of lesser amounts of pulmonary parenchyma. 78,88,107,108,114,121 While such resections can be performed with low morbidity/mortality, surgery has limitations as a therapeutic approach. Patients with limited pulmonary function or in tenuous medical conditions may not be able to tolerate the surgery or the loss of tissue. Patients with PAA may have too many lesions and are at risk for enlargement of small PAA over time, and multiple resections may not be possible.

Over the last few years, embolotherapy has become the treatment of choice for PAA not involving the pulmonary trunk or main pulmonary arteries. The dual circulation of the lungs allows interruption of pulmonary arteries with minimal necrosis. This fact coupled with advances in interventional radiology has dramatically altered the approach to PAA located distal to the main pulmonary arteries over the past few years. Percutaneous localization and occlusion of vascular lesions is a technique developed in the 1970s and used initially to treat cerebral arteriovenous lesions. 106,127 The first embolotherapy of the pulmonary vasculature was performed in 1978; Taylor et al 128 described wire coil occlusion of a PAA in a 35-year-old man in whom they wished to avoid a second lobectomy. Since that time, embolotherapy has been used with increasing frequency for PAA, with minimal loss of lung tissue, minimal morbidity, and no mortality reported to date. 17,129-132 The two occlusive materials most commonly used are wire coils and detachable balloons— we are unaware of documented superiority of one over the other. Though initially used to treat PAA, embolotherapy has since been used for traumatic, 97,118 postsurgical, 100, and mycotic PAA. 94,133 Some questions, such as the advisability of embolization of a mycotic PAA during active infection, remain unanswered, but embolotherapy is currently at the forefront of therapy of peripheral PAA.

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