Diagnosis and treatment of paradoxical embolus

Jeffrey A. Travis, MD, Stanley B. Fuller, MD, John Ligush, Jr, MD, George W. Plonk, Jr, MD, Randolph L. Geary, MD, and **Kimberley J. Hansen, MD,** *Winston-Salem, NC*

Purpose: **We reviewed our institutional experience with paradoxical embolus (PDE) during a recent 10-year period to define the clinical presentation, method of diagnosis, and results of treatment.**
Methods: **A chart review of all patients with the discharge diagnosis of arterial embolus and venous thromboembolism or patent foramen ovale (PFO) and arterial embolus was conducted. Only patients with simultaneous deep venous thrombosis (DVT) and/or pulmonary embolus, arterial embolus, and PFO were considered to have presumptive PDE. Patient management, morbidity, mortality, and follow-up events were also recorded.**
Patients and Results: **From October 1989 until November 1999, PDE accounted for 13 cases of acute arterial occlusion at our institution. There were seven men and six women (mean age, 57 ± 11 years). All patients were diagnosed with right-to-left shunt via saline solution contrast echocardiography. Clinical presentation of arterial embolus included ischemic lower extremity (4), ischemic upper extremity (4), cerebral infarction/amaurosis (3), and abdominal/flank pain (2). Five patients also presented with concomitant respiratory distress. Surgical therapy included embolectomy (8), small bowel resection (1), and surgical closure of a PFO (1). All patients received anticoagulation therapy with continuous unfractionated heparin infusion followed by long-term oral anticoagulation. Five inferior vena caval filters were placed.**
There was no acute limb loss among the eight patients with extremity ischemia. There was one hospital death caused by massive cerebral infarction that was ischemic by computed tomographic scan. Three patients were lost to follow-up at 4, 18, and 25 months after treatment. Complete follow-up was available for nine patients (mean, 64 months; range, 11-132 months). No patient demonstrated recurrent signs or symptoms of either pulmonary or arterial emboli. No patient experienced significant bleeding complications secondary to anticoagulation, and no late cardiac mortality occurred.
Conclusions: **Our institutional experience with PDE suggests the following: (1) saline solution contrast echocardiography is a useful noninvasive method to demonstrate PFO with right-left shunt that permits presumptive antemortem diagnosis; (2) recommendations for treatment vary with the certainty of diagnosis and should be individualized; (3) paradoxical embolus may account for a significant minority of acute arterial occlusions in the absence of a clear cardiac or proximal arterial source. (J Vasc Surg 2001;34:860-5.)**

Paradoxical embolism (PDE) describes the passage of venous or right-sided cardiac thrombus into the arterial or systemic circulation. This occurs most commonly through an intracardiac defect at the atrial level.[1] First reported by Cohnhein in 1877,[2] PDE was once believed to account for few acute arterial occlusions. Recent reports, however, have suggested that PDE could account for as many as 47,000 unexplained ischemic strokes in young patients each year.[3] These divergent views regarding the incidence of PDE may reflect the varied criteria used to establish the diagnosis.

The diagnosis of PDE has been termed definitive when made at autopsy or when thrombus is seen crossing an intracardiac defect during echocardiography in the face of an arterial embolus.[3,4] Other diagnoses of PDE may be considered presumptive if the following criteria are fulfilled: (1) systemic arterial embolus in the absence of left-sided cardiac or proximal arterial source; (2) a right-to-left shunt at some level; (3) venous thrombosis and/or pulmonary embolus. The diagnosis of PDE is termed possible only if arterial embolus and PFO are detected.[4]

This retrospective review describes a single center's experience with 13 patients fulfilling the criteria for presumptive PDE. In addition to the clinical presentation and methods of diagnosis, specific areas of interest included the early and late results of treatment.

PATIENTS AND METHODS

From October 1989 until November 1999, 3429 patients had a discharge diagnosis of venous thromboembolism and 2764 had a discharge diagnosis of arterial occlusion at our center. A retrospective chart review of all patients with the discharge diagnosis of venous thromboembolism and arterial embolus (27 patients) or patent foramen ovale (PFO) and arterial embolus (24 patients) was conducted. Only patients with simultaneous deep venous thrombosis (DVT) or pulmonary embolus (PE), arterial embolus, and PFO were considered to have presumptive PDE. Patient management, morbidity, mortality, and follow-up events were recorded. Follow-up events were determined from office chart review and telephone survey.

From the Division of Surgical Sciences, Section on Vascular Surgery of the Wake Forest University School of Medicine.
Supported in part through the Bradshaw Fellowship.
Competition of interest: nil.
Presented at the Twenty-ninth Annual Symposium of the Society for Clinical Vascular Surgery, Boca Raton, Fla, April 4-8, 2001.
Reprint requests: Kimberley Hansen, MD, Division of Surgical Sciences, Wake Forest University School of Medicine, Medical Center Blvd, Winston-Salem, NC 27127 (e-mail: kjhansen@wfubmc.edu).
Published online Oct 4, 2001.

0741-5214/2001/$35.00 + 0 **24/6/118815**
doi:10.1067/mva.2001.118815

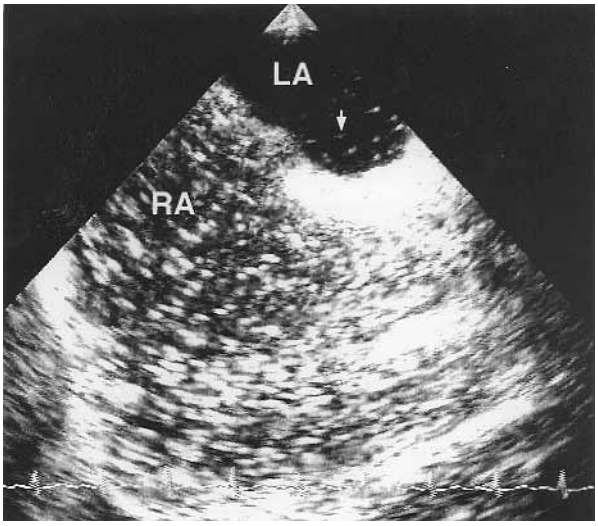

Fig 1. Echocardiogram demonstrating a positive saline solution agitation study with micro bubbles seen in the left atrium (*LA*) after complete opacification of right atrium (*RA*).

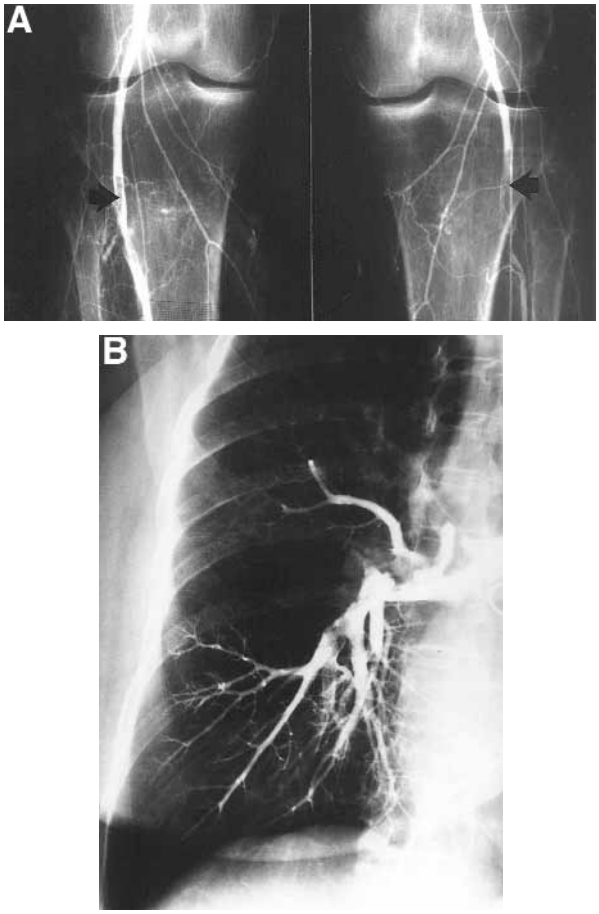

Fig 2. A, Arteriogram demonstrating bilateral filling defects in the popliteal arteries consistent with embolic occlusions. **B,** Pulmonary arteriogram in the same patient demonstrating large pulmonary embolus. Contrast echocardiography demonstrated a PFO with right-to-left shunt.

During the study period, PDE accounted for 13 cases of acute arterial occlusion at our institution. Patient demographics, presenting signs and symptoms, and treatment are summarized in the Table. All patients were diagnosed with PFO by contrast (saline solution agitation), transthoracic, or transesophageal echocardiography with documented right-to-left shunt at rest or with provocative maneuvers. A test was considered positive when two to five micro bubbles crossed the interatrial septum within three cycles of complete opacification of the right atrium (Fig 1). Pulmonary embolism was diagnosed by ventilation-perfusion lung scan, pulmonary arteriogram, or spiral computed tomography (CT). DVT was diagnosed via venous duplex sonography.

There were seven men and six women (mean age, 57 ± 11 years) diagnosed with PDE. Clinical presentation included ischemic upper extremity (4), ischemic lower extremity (4), cerebral infarction/amaurosis (3), abdominal/flank pain (2). All three patients with cerebral symptoms had negative carotid duplex examinations. Five patients also presented with concomitant respiratory distress (Fig 2A).

DVT and/or PE was diagnosed at the time of arterial embolization in all patients. PE was documented in seven patients by pulmonary angiogram (3), high probability ventilation-perfusion scan (3), or spiral CT scan (1) (Fig 2B). DVT was detected via venous duplex in eight patients. A right atrial thrombus was detected on echocardiography in one patient.

Surgical embolectomy was performed for each of the eight patients presenting with limb-threatening ischemia. Two patients had visceral or renal artery emboli both presenting with abdominal pain. One presented with peritonitis and underwent resection of ischemic bowel at a referring institution. Subsequent aortography demonstrated embolic occlusion of the superior mesenteric artery. The second patient with abdominal and flank pain had a right renal infarct demonstrated via abdominal CT scan and renal artery occlusion confirmed with renal duplex sonography. Neither patient underwent further surgical intervention. One patient had surgical closure of his PFO in combination with right atrial thrombectomy.

On presentation, all patients received systemic anticoagulation by continuous infusion of unfractionated heparin followed by chronic Coumadin therapy. In addition, five patients had inferior vena caval filters placed. All filters were placed below the renal veins. No patient had an identifiable coagulation disorder.

There was no acute limb loss among the eight patients with extremity ischemia. There was one hospital death caused by massive cerebral infarction that was ischemic by CT scan. Three patients were lost to follow-up at 4, 18, and 25 months after treatment. Complete follow-up was

Case summaries (n = 13)

Age (y)	*Sex*	*Presentation*	*DVT*	*Site of embolus*		*Embolectomy*	*IVC filter*	*Chronic anticoagulation*
				Pulmonary	*Peripheral*			
68	M	Abdominal pain	Y	N	Renal	N	Y	Y*
51	M	Amaurosis/dyspnea	Y	Y	Cerebral	N	Y	Y†
65	F	Ischemic leg/dyspnea	N	Y	Popliteal	Y	N	Y†
49	F	Ischemic arm	N	Y	Brachial	Y	Y	Y*
43	M	Abdominal pain	Y	Y	SMA	N	Y	Y*
42	F	Ischemic leg/dyspnea	Y	Y	Femoral	Y	N	Y†
63	M	CVA	Y	N	Cerebral	N	Y	N‡
50	M	CVA	N§	N§	Cerebral	N	N	Y†
63	M	Ischemic arm/dyspnea	N	Y	Brachial	Y	N	Y†
48	F	Ischemic leg	Y	N	Femoral	Y	N	Y†
79	F	Ischemic leg	Y	N	Femoral	Y	N	Y†
69	M	Ischemic arm/dyspnea	N	Y	Subclavian	Y	N	Y†
60	F	Ischemic arm	Y	N	Brachial	Y	N	Y†

*Lost to follow-up.
†Remains on Coumadin.
‡Expired.
§Right atrial thrombus.
IVC, inferior vena cava; *M*, male; *F*, female; *SMA*, superior mesenteric artery; *CVA*, cerebrovascular accident.

available for nine patients (mean, 64 months; range, 11-132 months). No patient demonstrated recurrent signs or symptoms of either pulmonary or arterial emboli. No patient had significant bleeding complications secondary to anticoagulation, and no late cardiac mortality occurred.

DISCUSSION

Although widely considered an uncommon cause of acute arterial occlusion, PDE should be considered in all patients with an arterial embolus in the absence of a cardiac or proximal arterial source. In this review, we present 13 patients who met presumptive criteria for PDE. All patients presented with simultaneous DVT and/or PE, arterial embolus, and a PFO with right-to-left shunt. All patients were treated with early intravenous anticoagulation and maintained on long-term oral anticoagulation. Vena caval filters were placed selectively. No patient experienced a recurrent pulmonary or systemic embolic event. Although small in absolute number of patients and likely an underestimation of the true incidence of PDE, this review describes the largest single-center experience for presumptive PDE.

Data regarding the true contribution of PDE to acute arterial occlusions are incomplete; however, the presence of a PFO cannot be viewed as equivalent to that of PDE. Autopsy studies have described a 25% to 30% incidence of PFO.[6,7] Saline solution agitation echocardiography has suggested that 5% to 15% of "normal" patients have PFO associated with a right-to-left shunt.[3,8] However, only when clot is seen traversing a PFO on echocardiography can the antemortem diagnosis of PDE be considered the definitive cause of an acute arterial occlusion.[3,4] Other cases may be considered presumptive and can be treated with confidence when the three criteria of DVT and/or PE, arterial embolus, and PFO with right-to-left shunt are present in a single patient.[3-5] When concomitant DVT and/or PE is not present, the diagnosis of PDE based on an arterial embolus associated with PFO can, at best, be termed possible.[5] Consequently, reported results from recommended treatment must be considered in the context of the certainty of diagnosis—definitive, presumptive, or possible.

Recommended treatment to prevent recurrent arterial emboli after PDE have included observation, antiplatelet agents, systemic anticoagulation, and closure of the PFO.[9-11] However, the clinical course of patients with definitive or presumptive PDE is unknown. Bogousslovsky et al[9] reported 140 patients with PFO and either stroke or transient ischemic attack (TIA) treated with aspirin (66%), Coumadin (26%), or closure of PFO (8%) with a mean follow-up 3 years (10-91 months). Only 11 of 140 patients had a history of DVT or PE. Therefore, in 92% of patients, the diagnosis was only possible. Recurrence of stroke or TIA was 3.8% per year. Method of treatment was not a predictor of recurrence. Mas et al[10] described 132 patients with cerebrovascular symptoms and PFO. No patient was diagnosed with concomitant DVT or PE. All patients were treated with Coumadin or aspirin. Mean follow-up was 22.6 months, and risk of recurrent cerebrovascular symptoms was 3.4% per year. Although both of these series describe large numbers of patients, the diagnosis of PDE was possible and therefore uncertain in the vast majority. Consequently, it is difficult to draw conclusions regarding the effectiveness of the proposed treatment.

In addition to antiplatelet agents and systemic anticoagulation, PFO closure has been recommended in selected patients with PDE. Closure can be accomplished via percutaneous or open surgical methods. Hung et al[12] presented 63 patients averaging 46 years of age with PFO and neurologic symptoms thought to be secondary to PDE.

Although each patient underwent percutaneous closure of his or her cardiac defect, no documentation of concomitant DVT or PE was made, and the diagnosis of PDE was only possible. After percutaneous treatment, there were three deaths unrelated to the device placement, but one patient died of a massive pulmonary embolus. The PFO was closed or had "minimal" residual shunting in 86% of patients by echocardiography. The average risk of recurrent neurologic symptoms was 3.2% per year after percutaneous intervention.[12] In another recent report, Windecker et al[13] described 80 patients who had percutaneous closure of their PFO for "suspected" PDE. No patient had a diagnosis of concomitant DVT or PE. There was no periprocedural mortality, but a 10% procedural morbidity was observed that included embolization of device (3), cerebrovascular accident (1), cardiac tamponade (1), air embolus (2), and a hematoma requiring surgical intervention (1). The average risk of recurrence of neurologic symptoms was 3.4% per year with a mean follow-up of 1.6 ± 1.4 years.[13]

Open surgical methods have been used to close PFO and prevent recurrent systemic emboli. In the largest series to date, Dearani et al[14] reported 91 patients with stroke or TIA who underwent open surgical closure of PFO. Only nine patients had documented DVT or PE. There was no 30-day mortality; however, 20% of patients had significant periprocedural morbidity. The PFO was successfully closed on repeat postoperative echocardiography in all patients, and 54% of patients were maintained on chronic Coumadin anticoagulation. Despite this, there were eight recurrent neurologic events on mean follow-up of 2 years, providing an average risk of four embolic events per year.[14]

Recurrence of cerebrovascular events after medical treatment of PDE may reflect failure of treatment or failure of diagnosis. However, recurrent cerebral events after successful closure of PFO for possible PDE almost certainly reflects failure of diagnosis. These considerations are pertinent considering the perceived role of PFO in young patients with cryptogenic strokes.[10-17] Although PDE may be an attractive explanation for cerebral events in this group, the true cause and effect of a PFO and stroke is uncertain.[9-18] In our retrospective series of 13 patients with presumptive PDE, the most common site of arterial embolus was the extremities, not the cerebral circulation. This is consistent with other peripheral arterial emboli from cardiac sources.[4] Moreover, in a review of 30 definitive cases of PDE when clot was visualized traversing a PFO on an echocardiogram, only 28% of arterial emboli involved the cerebral circulation, whereas 28% involved the peripheral circulation and 38% reached the mesenteric vessels.[3]

In patients with suspected PDE, evaluation should include contrast echocardiography. The transesophageal approach is preferable because it more accurately demonstrates cardiac pathophysiology. It readily demonstrates right-to-left shunts at the atrial level and has a sensitivity and specificity of almost 95%.[19] The development of this technique has allowed more frequent antemortem diagnosis without the use of invasive procedures.[3,19] After establishing an intracardiac defect with a right-to-left shunt, a venous evaluation for the presence of DVT is performed. Both upper-extremity and lower-extremity venous duplex sonography should be performed in all patients evaluated for PDE. Ventilation-perfusion lung scans, spiral CT scans, or pulmonary angiography may be used in patients with symptoms of concomitant pulmonary embolism. An evaluation for a procoagulant disorder may guide the duration of anticoagulation.

Based on our experience and the available literature, we have adopted the following strategy for the diagnosis and management of PDE. Using clinical and pathologic criteria, a presumptive diagnosis can be made with demonstration of a right-to-left shunt, concomitant DVT and/or pulmonary embolism, and systemic arterial embolization. If a clot is not visualized traversing a PFO, the diagnosis involves varying degrees of likelihood and omission of any of the three presumptive criteria, specifically DVT and/or PE, increases the uncertainty of the diagnosis. Systemic anticoagulation is used as the mainstay of therapy for presumptive PDE, providing treatment and prophylaxis for DVT, PE, and arterial embolism in the majority of patients. Continuous intravenous unfractionated heparin followed by chronic oral anticoagulation is routine. The duration of anticoagulation therapy is individualized. Patients with an identifiable but finite risk for DVT (eg, extremity fracture with cast immobilization) receive 6 to 12 months of oral anticoagulation. Patients who remain at risk for venous thrombosis (eg, a procoagulant disorder) and patients who have experienced repeated venous thrombosis and/or pulmonary embolism may require lifelong therapy.

Inferior vena caval interruption is not considered primary therapy for PDE because small (<3 mm) emboli that may be asymptomatic as pulmonary emboli may contribute to catastrophic arterial occlusion in the systemic circulation. Commonly accepted guidelines are applied to determine whether inferior vena cava filter placement is necessary in conjunction with PDE.[20] In particular, vena cava filters appear indicated as primary therapy in patients who have a contraindication for anticoagulation.[20] Inferior vena cava ligation is an effective immediate treatment for PDE of lower-extremity origin; however, operative and postoperative morbidity are significant.[21] In addition, the inevitable development of collateral venous circulation with subsequent embolization argues against the use of vena cava ligation for PDE.[21]

The decision to close an intracardiac defect should also be individualized. The risk of the procedure must be compared with the certainty of diagnosis and the probability that closure will prevent the recurrence of PDE. Only when all three conditions for presumptive PDE are present are invasive procedures recommended. However, closure of a PFO does not treat venous thromboembolic disease. Closure of a PFO by open or percutaneous methods with inferior vena cava interruption is recommended in patients with presumptive PDE who have contraindications to systemic anticoagulation.

These treatment recommendations can be considered general guidelines at best. No data exist which accurately define the incidence or natural history of PDE. The management strategy employed for this patient group must emphasize the certainty of diagnosis. With increasing awareness and evaluation for PDE, future studies may accurately estimate the incidence of PDE in acute arterial occlusions. Studies that describe the natural history and risk of repeated embolization will provide the rationale for future treatment recommendations.

REFERENCES

1. Leonard CF, Neville E, Hall RJC. Paradoxical embolism: a review of cases diagnosed during life. Eur Heart J 1982;3:362-70.
2. Cohnheim J. Thrombose und embolie. Vorlesungen uber allgemeine pathologie. Vol 1. Berlin: Hirschwald; 1877.
3. Meacham RR, Headley AS, Bronze MS, Lewis JB, Rister MM. Impending paradoxical embolism. Arch Intern Med 1998;158:438-48.
4. Loscalzo J. Paradoxical embolis: clinical presentation, diagnostic strategies, and therapeutic options. Am Heart J 1986;112:141-5.
5. Johnson BJ. Paradoxical embolism. J Clin Pathol 1957;4:316-432.
6. Thompson T, Evans W. Paradoxical embolism. Q J Med 1930;23: 135-50.
7. Hagen PT, Scholz DG, Edwards WD. Incidence and size of patent foramen ovale during the first 10 decades of life: an autopsy study of 965 normal hearts. Mayo Clin Proc 1984;59:12-20.
8. DeBelder MA, Tourikis L, Leech G, Camm AJ. Risk of patent foramen ovale for thromboembolic events in all age groups. Am J Cardiol 1992;69:1316-20.
9. Bogousslavsky J, Garazi S, Jeanrenaud X, Aebischer N, Van Melle G. Stroke recurrence in patients with patent foramen ovale: the Lausanne Study. Neurology 1996;46:1301-5.
10. Mas JL, Zuber M. Recurrent cerebrovascular events in patients with patent foramen ovale, atrial septal aneurysm, or both and cryptogenic stroke or transient ischemic attack. Am Heart J 1995;130:1083-8.
11. Nendaz M, Sarasin FP, Bogousslavsky J. How to prevent stroke recurrence in patients with patent foramen ovale: anticoagulants, antiaggregants, foramen closure, or nothing? Eur Neurol 1997;37: 199-204.
12. Hung J, Landzberg MJ, Jenkins KJ, King ME, Lock JE, Palacios IF, et al. Closure of patent foramen ovale for paradoxical emboli: intermediate-term risk of recurrent neurological events following transcatheter device placement. J Am Coll Cardiol 2000;35:1311-6.
13. Windecker S, Wahl A, Chatterjee T, Garachemani A, Eberli FR, Seiler C, et al. Percutaneous closure of patent foramen ovale in patients with paradoxical embolism. Circulation 2000;101:893-8.
14. Dearani JA, Ugurlu BS, Danielson GK, Daly RC, McGregor CG, Mullany CJ, et al. Surgical patent foramen ovale closure for prevention of paradoxical embolism-related cerebrovascular ischemic events. Circulation 1999;100(19 suppl):II171-5.
15. Kristensen B, Malm J, Carlberg B, Stegmayr B, Backman C, Fagerlund M, et al. Epidemiology and etiology of ischemic stroke in young adults aged 18 to 44 years in northern Sweden. Stroke 1997;28:1702-9.
16. Ranouz D, Cohen A, Cabanes L, Amarenco P, Bousser MG, Mas JL. Patent foramen ovale: is stroke due to paradoxical embolism. Stroke 1993;24:31-4.
17. Lechat PH, Mas JL, Sascault G. Prevalence of patent foramen ovale in patients with stroke. N Engl J Med 1988;318:1148-52.
18. Di Tullio M, Sacco RL, Gopal A, Mohr JP, Homma S. Patent foramen ovale as a risk factor for cryptogenic stroke. Ann Intern Med 1992;117:461-5.
19. Chen W, Kuan P, Lein W, Lin FY. Detection of patent foramen ovale by contrast transesophageal echocardiography. Chest 1992;101:1515-20.
20. Greenfield LJ, Proctor MC. Twenty-year clinical experience with the Greenfield filter. Cardiovasc Surg 1995;3:199-205.
21. Donaldson MC, Wirthlin LS, Donaldson GA. Thirty-year experience with surgical interruption of the inferior vena cava for prevention of pulmonary embolism. Ann Surg 1980;191:367-72.

Submitted Apr 11, 2001; accepted Jul 17, 2001.

DISCUSSION

Dr Peter Gloviczki (Rochester, Minn). I was asked to discuss the paper and I enjoyed very much this presentation. I also had a chance to review the manuscript which is a very well written manuscript and I am sure it will be accepted for publication.

Paradoxical embolus is a rare cause of acute ischemia but really not as rare as I think we all think. In a busy vascular practice, as you have heard, you will see at least one patient every year and maybe it is only the tip of the iceberg because there may be more patients with this type of etiology of embolism. The diagnosis is based on high index of suspicion, although in some of the typical patients, the presentation can be quite dramatic because the patient may be symptomatic in both the arterial and the venous bed, or because in some of the patients multiple arterial beds are affected at the same time.

I remember very well the very first patient that I saw with an acute ischemia due to paradoxical embolism, and I was an intern. It was a patient I was asked to see because of acute chest pain, shortness of breath. The patient developed within minutes an ischemic right arm and a couple of minutes later died of a massive stroke. The autopsy revealed iliofemoral DVT with a large PFO.

That leads to my first question of the paper: is the high incidence of strokes in these patients, probably we see much more frequently than what we see in our patients who present with normal cardiac embolism? Do you have maybe an explanation why patients who have a PFO have much higher incidence of stroke than only those patients who have a thrombus in the atrium or the ventricle and have peripheral embolization, because otherwise the most frequent site of peripheral embolism is the femoral bifurcation?

My second question again comes back to the indication of closure of the PFO and the need for a Greenfield filter. If that patient has a high PFO with a documented shunt, can we still just stick to the classic indications of IVC filter placement or should we be a little bit more liberal and place a filter in that patient because of the serious consequences of arterial embolism?

Finally, you mentioned the technique of cardiac echo. Should we get in these patients routinely transesophageal echo especially those who have chest pain and you are looking for other etiologies of embolism like aortic dissection? Should we routinely get cardiac echo in these patients before we deal with the ischemic limb or the ischemic symptoms of the patients?

I enjoyed very much your presentation and congratulate you on the paper.

Dr Jeffrey A. Travis. Your first question is why patients with PFO seem to have an increased incidence of stroke. I am not sure a true cause and effect actually exist. Certainly many people have strokes and many are termed cryptogenic when no specific cause is identified. In young patients, a higher incidence of PFO than in the general population has been identified, but I do not think we can draw a true cause and effect relationship just based on that. There is an epidemiological study from Sweden that identified new strokes in patients aged 18 to 44 years. Over a 3-year period, there were 88 new strokes. This was from a population base of approximately 500,000. In half of these, no cause could be iden-

tified; however, in only 10% of those did the patient have a PFO. So there are certainly causes of cerebral symptoms in young patients that are not due to paradoxical embolus even in patients who have a PFO.

Your second question about who should have an inferior vena cava filter placed. We do not believe that inferior vena cava filters completely protect someone from a paradoxical embolus. They can admit emboli as small as 3 mm, which are clinically silent in the pulmonary circulation but can be devastating when placed in the arterial circulation.

Who should we perform TEE on? The test does not need to be performed prior to the operating room to do an embolectomy because often the extremity ischemia is a more pressing issue and in many centers echo is not immediately available. In any patient with a cryptogenic embolic event, a transesophageal echo is indicated.

Dr John Ricotta (Stony Brook, NY). A comment and a question. The comment is that sometimes thrombolytic therapy can be effective in these patients. We actually had a patient that we have given thrombolysis because of a pulmonary embolus and, because of the systemic lytic effects, seen the arterial embolus go away. Obviously you cannot use that if the arterial embolus is producing acute ischemia, but if you have a situation where the limb is viable, that actually is an option.

The second point, I would like to expand on what Dr Gloviczki said. It seems to me that one of the keys here is whether the patient has pulmonary hypertension. Usually they get a pulmonary embolus, they get pulmonary hypertension, then the foramen ovale opens and they get an embolus. I again would feel very uncomfortable not putting a filter in somebody that you were pretty sure had a paradoxical embolus, particularly if they had pulmonary hypertension. I wondered whether you would comment on that as possibly a way to broaden your indications for filter placement.

Dr Travis. In a patient who has had a previous pulmonary embolus, they present with a paradoxical embolus, should that patient receive an IVC filter?

Dr Ricotta. Right.

Dr Travis. We believe that anticoagulation still maintains its role as the mainstay of therapy. If you prevent venous thromboembolism, then you prevent paradoxical embolus.

Dr Gloviczki. Have you had any of your patients develop paradoxical embolus on anticoagulation?

Dr Travis. No, sir, not in our experience.

Dr Gloviczki. Dr Greenfield, should we use the filter more liberally in these patients?

Dr Lazar Greenfield (Ann Arbor, Mich). I think a significant part of the problem has not been addressed, and that is the pulmonary hypertension. That is a major driver of the right-to-left shunt, and you did not mention information in your series about the level of pulmonary artery pressure in your patients. What you are also obligated to treat is the level of pulmonary vascular reserve, and I guess the question is, are you satisfied in a patient with serious elevation of pulmonary artery pressures to manage that patient's venous thrombotic disease with anticoagulation alone, recognizing that even a small recurrent pulmonary embolic event could be just as disastrous as a paradoxical embolus?

Dr Travis. We do not have the information on all patients and their pulmonary artery pressures and whether or not they had pulmonary hypertension. I can tell you that none of these patients had a history of previous pulmonary embolus. Many of the patients require provocative maneuvers to demonstrate a right-to-left shunt. In other words, you have to have them Valsalva or cough. This is a well-known presentation of paradoxical embolus in a patient who is straining to defecate or coughing, and then has an acute arterial embolus, but I do not have the discrete information on all their pulmonary artery pressures.

Dr Alan Dardik (Baltimore, Md). Two quick questions. First, how did you determine your study population? Was it by ICD-9 coding and review of the database? Because you quoted to us a 10% incidence of PFO and if you queried over 2700 patients, you should have gotten over 200 patients with PFOs. Are you undercoding your database and thereby underestimating the incidence of this problem? This leads me to the second question, if we are going to design a prospective study, who should we be screening for PFO?

Dr Travis. In regards to the first question, yes, I think this is obviously an underestimation of this problem, but by applying strict criteria to the diagnosis I think we can better evaluate our treatment efficacy.

As far as the second question, who should we screen? I think any patient with cryptogenic arterial emboli with an unknown cause. DVT is undetected in 50% of people with proven pulmonary embolism; therefore, it is difficult to detect. Therefore, anybody with an unexplained arterial event should probably be screened for PFO and possible paradoxical embolus.