In this issue of Mayo Clinic Proceedings, Sareyyupoglu et al of Mayo Clinic describe a series of 18 patients who had aggressive surgical treatment for acute pulmonary embolism (PE). The authors were careful to define the presence of cardiogenic shock and severe right ventricular dysfunction as indications for urgent surgical embolectomy in these critically ill patients. The surgical technique used for acute pulmonary embolectomy is a variation of the modified Trendelenburg procedure used by many surgeons.2-4 Specifically, the operation was conducted through a median sternotomy with aortic and bicaval cannulation and normothermic cardiopulmonary bypass. Incisions into the main pulmonary artery to remove the clot were extended into the distal pulmonary arteries when necessary. The lungs were massaged through bilateral pleurotomies to facilitate clot removal. Inferior vena cava (IVC) filters were placed either preoperatively or within the first 24 hours after surgery to prevent reembolization. Perioperative management included the widely accepted measures of heparin anticoagulation and vena cava filters to prevent progression of deep venous thrombosis and recurrent PE.5-7 Sareyyupoglu et al reported a respectable 78% early and 67% long-term survival rate in these severely compromised patients. This aggressive approach to an otherwise lethal problem suggests that acceptable survival is possible in a selected group of patients. Their approach may herald a resurgence of interest in surgical pulmonary embolectomy to treat severe hemodynamic compromise.

The management of venous thrombosis and PE has evolved from the contributions of many famous historical figures in medicine. Anatomical observations on the direction of circulation (Harvey) and pathological observations on thrombi of the lungs (Morgagni, Laënnec, Cruveilhier) were followed by the description of blood stasis, venous injury, and hypercoagulability (Virchow triad).8-11 Virchow’s recognition in the mid-1850s of the embolic potential of lower extremity venous thrombi is the foundation of our understanding of thromboembolism and was the stimulus for the development of specific therapies to prevent or alter the course of venous thrombosis and PE.

The surgeon’s legacy in the management of PE began in 1872 when Trendelenburg, a noted surgeon and founder of the German Surgical Society, studied the cause of sudden death in 9 hospitalized patients with PE. Through animal experimentation, he developed a surgical approach to pulmonary embolectomy. Trendelenburg later performed pulmonary embolectomy in 2 patients, but neither survived more than 37 hours.12,13 Kirschner,14 a student of Trendelenburg, performed the first successful pulmonary embolectomy in 1924 and reported the case at the German Surgical Conference in Berlin. Ochsner, a visiting surgical resident from the United States at the time, attended the conference and noted “great interest” in the audience. Many German clinics quickly adopted the emergent bedside Trendelenburg operation for physiologically compromised patients in whom PE was strongly suspected. The constant bedside vigil to detect sudden circulatory collapse and respiratory compromise resulting from PE was delegated to surgical residents and was largely a waste of time and manpower.15 Approximately 300 of these operations performed during the ensuing decade yielded fewer than 10 survivors. The results of this early surgical approach were discouraging and led many surgeons to develop alternative approaches to interrupt embolization to the lungs. As early as 1932, Ochsner and DeBakey advocated IVC ligation to prevent PE, and 2 years later Homans first performed prophylactic venous ligation.16,17
Two surgical approaches ultimately evolved for the management of PE: operations that focused on removal of an embolus to the lung and operations that were designed to prevent embolization. Sudden interruption of the vena cava blood flow was accompanied by an occasional decrease in cardiac output, and troublesome chronic lower extremity edema almost always resulted. To avoid these complications, partial caval plication by suture or specially designed clips was popularized by Adams, DeWeese, and Miles. Vena cava interruption by either surgical ligation or clip plication yielded to intraluminal occlusive devices that produced low recurrent embolism rates of approximately 3% and long-term patency approaching 98%. These early devices were often cumbersome to deploy and were accompanied by frequent complications of caval perforation, device migration, and vessel thrombosis. Highly effective, lightweight, percutaneous caval filters developed during the past 2 decades have supplanted the earlier devices.

Paralleling the development of surgical approaches to the management of PE were important advances in the area of anticoagulation. The discovery of heparin by McLean and validation of its utility by Murray et al were pivotal in the management of thromboembolic disease. After the introduction of oral dicumarol in the 1940s, anticoagulation rapidly became the first-line therapy for the treatment and prevention of venous thrombosis and PE. Currently, anticoagulation, used either alone or in combination with thrombolytic agents or rheolytic thrombectomy (hydrostatic fragmentation and evacuation of intravascular thrombi using a specially designed catheter), is used to treat most patients with routine thromboembolism.

In 1932, while a surgical resident, Gibbon witnessed a desperate but unsuccessful open attempt to save the life of a young woman who had sustained a fatal pulmonary embolus. This experience was the catalyst for his work on the development of extracorporeal circulation, which was a seminal event in the development of open heart surgery and surgical treatment of PE. In 1961, Cooley attempted a pulmonary embolectomy on extracorporeal circulation, and the first successful pulmonary embolectomy using extracorporeal support of circulation was accomplished by Sharp 1 year later.

The indications for open surgical embolectomy have remained relatively unchanged during the past 4 decades: persistent and refractory hypotension despite maximal pharmacological support in the presence of a documented PE. Every effort to manage the patient by systemic heparin anticoagulation, inotropic agents, vasopressors, ventilatory support, inhaled nitric oxide, and oxygen supplementation should be undertaken. Systemic anticoagulation is recommended as initial therapy in all patients presenting with acute PE. The benefit of thrombolytic therapy is less clear. Sareyyupoglu et al cite a number of underpowered controlled studies, meta-analyses, and systematic reviews that did not support or only weakly supported the use of thrombolytic agents. The American College of Chest Physicians recommends against the use of thrombolytic agents in most PE patients. A recent review of 108 patients with massive PE (4.5% of 2392 patients presenting with PE) in the International Cooperative Pulmonary Embolism Registry (ICOPER) revealed that recurrent PE and 90-day mortality rates were not influenced by thrombolytic therapy and results were no better than those achieved with heparin alone. In another study, patients undergoing immediate pulmonary embolectomy had a lower mortality rate (7%) than patients receiving a second course of thrombolytic therapy alone (38%). The use of thrombolytic agents should be considered carefully in the presence of acute massive PE. If operative intervention is anticipated, prior thrombolytic use may introduce serious problems with perioperative hemostasis. In the current series, Sareyyupoglu et al placed IVC filters in all patients and cited the experience of Meneveau et al, who reported a 23% incidence of recurrent PE or deep venous thrombosis in their series of 11 patients undergoing surgical embolectomy without IVC filters. In the ICOPER series of patients undergoing pulmonary embolectomy for massive PE, none of the 11 patients with IVC filters had recurrent PE. Inferior vena cava filters have proven to be an important adjunctive measure to avoid recurrent emboli in patients undergoing pulmonary embolectomy.

The lessons of history and the many contributions from various disciplines in medicine are not lost on the contemporary, 3-pronged approach to massive acute PE proposed by Sareyyupoglu et al. Systemic heparinization and IVC filter placement, when combined with aggressive pulmonary embolectomy in patients with severe right ventricular dysfunction, if used before the advent of cardiovascular collapse, resulted in acceptable early and overall survival rates. The success of an aggressive approach in massive PE is supported by other recent series that report a survival rate of 75% and 86%. These contemporary results are far superior to the operative survival rates reported in the mid and late 20th century. Sareyyupoglu et al and others have emphasized a near prohibitive mortality rate (57%-85%) in patients undergoing pulmonary embolectomy during or after cardiopulmonary arrest for salvage.

We think there should be renewed enthusiasm for acute pulmonary embolectomy on the basis of the improved survival rates observed in patients with severe right ventricular dysfunction. Both identification and selection of appropriate candidates for acute pulmonary embolectomy have become easier because transesophageal echocardiography and computed chest tomography can detect early right ven-
tricular dysfunction.35-39 Treatment of most patients with PE will remain systemic anticoagulation and IVC filters, used either alone or in combination with thrombolytic or rheolytic therapy. Treatment of severely compromised patients with the current multidisciplinary approach, including early emergent pulmonary embolectomy as proposed by the Mayo Clinic investigators, shows great promise in improving patient survival.

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