Case Presentation
A 67-year-old man with no previous medical history presented to the emergency department with 5 days of insidious, progressive dyspnea and chest congestion. On physical examination, he was found to be tachycardic to 126 beats/min, borderline hypotensive with blood pressure of 95/50 mm Hg, and hypoxemic to 87% on 4 L of oxygen by nasal cannula. He underwent contrast-enhanced chest computed tomogram that demonstrated a bilateral pulmonary embolism (PE) (Figure 1). Urgent bedside echocardiography demonstrated a severely dilated and hypokinetic right ventricle, interventricular septal flattening, and a serpiginous mobile mass (clot-in-transit) in the right atrium, prolapsing across the tricuspid valve with each cardiac cycle (Figure 2 and online-only Data Supplement Movie). The emergency department team discussed administering systemic fibrinolytic therapy, but also considered consulting Cardiology, Interventional Cardiology, Cardiothoracic Surgery, Pulmonology, and Radiology to evaluate the patient’s case and review the imaging studies.

PE: A Clinical and Logistic Quandary
PE is a prevalent and potentially life-threatening cardiovascular condition that may be difficult to diagnose. It has protean and often nonspecific manifestations. It is the third most common cardiovascular cause of death in the United States, and yet, in comparison with ischemic heart disease, does not enjoy a similar robust clinical trial evidence base to dictate appropriate therapeutic strategies. Treatment of PE is generally guided by severity, yet risk stratification classifications are not universally accepted and differ between major evidence-based clinical practice guidelines, including those promulgated by the American Heart Association,1 American College of Chest Physicians,2 and European Society of Cardiology.3 Inadequate clinical trial data limit these guidelines to offering class IIa and IIb recommendations for all but the lowest-risk PE patients. Such recommendations are supported primarily by expert opinion and case series.4 The fact that some PEs mandate urgent intervention compounds these problems. An additional challenge is that multiple specialties may diagnose PE, including Emergency Medicine, Internal Medicine, Obstetrics and Gynecology, and Surgical Services. Furthermore, in the traditional model of care, a practitioner faced with a patient with acute PE may choose to consult a Cardiologist, Vascular Medicine specialist, Vascular Surgeon, Interventional Radiologist, or Cardiothoracic Surgeon for assistance treating the PE.

To address these limitations, improve access to advanced therapies, streamline individual patient care, and collect data regarding the care of PE patients, a number of medical centers across the United States, including Massachusetts General Hospital (MGH) and Brigham and Women’s Hospital, have founded multidisciplinary PE response teams. These teams merge the expertise of a variety of specialists, as such as Vascular Medicine, Interventional Cardiology, Multidisciplinary Pulmonary Embolism Response Teams

Multidisciplinary Pulmonary Embolism Response Teams
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Cardiothoracic Surgery, Pulmonology, Hematology, Echocardiography, and Radiology, in real time to assist the primary providers with patient evaluation and enhanced clinical decision making. The success of the MGH PE Response Team (PERT), founded in October 2013, has served as a model for other medical centers. The PERT concept was borne of 2 modern operational concepts in systems-based health care: the Heart Team and Rapid Response Systems.

**Methodologic Rationale for PERT: Heart Team**

The Heart Team concept has achieved importance in modern cardiovascular medicine, where multidisciplinary collaboration facilitates patient management with a consensus opinion of different specialists, who together can weigh the risks and benefits of different therapeutic approaches. Analogous endeavors have previously existed for heart transplantation and congenital heart disease, and tumor boards in Oncology, as well. Heart Teams are now endorsed in guidelines as applied to decision making for complex interventions in ischemic heart disease and in regard to transcatheter aortic valve replacement. Similarly, multidisciplinary stroke teams are endorsed by guidelines to conduct a protocolized emergency evaluation.

The Heart Team concept transcends the traditional silo mentality pervasive in medicine, and is inherently dependent on cross-specialty collaboration. Each member of the Heart Team contributes information and a distinct perspective as part of a “cognitive interchange,” and members may even contribute specific technical or procedural expertise. Collaborative evaluation and decision making help avoid biases from individual specialties or individual practitioners in planning therapeutic strategy. For coronary intervention and transcatheter aortic valve replacement, patient selection is believed to be a major advantage of the Heart Team approach, because most patients cannot be categorized into the extremes in which either surgery or percutaneous therapy is clearly optimal. Rather, these patients represent a point of clinical equipoise for which no single clinical trial or group of clinical trials is likely to provide the answer. Instead, a careful, individualized risk–benefit assessment is required, with experts weighing available data in terms of study methodology and data quality, measured end points, and generalizability to the current patient.

A critical role for PE evaluation is rapid and accurate risk stratification. Although the majority of patients will recover with anticoagulation alone, a proportion of PE patients will present with overt hemodynamic instability or will subsequently deteriorate, often unexpectedly, after appearing to be well compensated. The Heart Team approach helps to balance the benefits of intervention against potential risks of cardiopulmonary failure, hemodynamic instability, or death. The proliferation of novel interventional devices and technology underscores the need to have an integrative multidisciplinary approach, flexible enough to evaluate and use multiple options, even in the absence of controlled clinical trial data or guideline recommendations.

For PE and clot-in-transit, there are a growing number of options not available even a few years ago, including large-bore suction embolectomy, ultrasound-facilitated catheter-based fibrinolysis, and mechanical circulatory support as a bridge to definitive therapy. In addition, traditional approaches, such as surgical pulmonary embolectomy, have enjoyed a renaissance at many medical centers in recent years. Many of these therapies require a team approach with multiple skill sets of interventionalists, cardiac and vascular surgeons, echocardiographers, anesthesiologists, and perfusionists. The team approach in such high-stakes scenarios, without the compass of robust randomized controlled trial data or definitive clinical practice guidelines, requires tailored, integrated recommendations and careful patient selection.

A team-based decision-making process obviates serial consultation and multiple divergent or ambivalent opinions, in favor of a single, reasoned, and collaborative opinion presented to the patient, family, and the primary providers at the key clinical juncture.

**Methodologic Rationale for PERT: Rapid Response Systems**

Rapid response systems provide a protocolized response to in-hospital deterioration as a means to prevent cardiopulmonary arrest and death. The key components are an (1) afferent limb including mechanisms to identify patients at risk, criteria to trigger the rapid response system, and means to quickly notify and activate the response team; (2) an efferent limb

![Figure 1. Axial image from a contrast-enhanced chest computed tomogram showing significant right and left main pulmonary artery filling defects (arrows).](image-url)
that contemplates swift, decisive action by a predetermined response team (eg, critical care trained nurses and physicians); (3) administrative infrastructure; and (4) continuous quality improvement.13,14 This specific concept of a rapid response system reduces nonintensive care unit cardiopulmonary arrest and may decrease total hospital mortality in adults.13

“Failure to rescue,” namely the inability of clinicians to “react promptly or commensurately escalate care,” has been cited as a causal driver of adverse events and another rationale for rapid response systems.14 As applied to PE, there is great difficulty identifying the patients at risk. For example, ≈5% of submassive PE patients, who initially appear clinically stable, experience decompensation.15 Thus, using a multidisciplinary council of expert clinicians may provide superior clinical gestalt to both assess a PE patient’s risk of decline and candidacy for more invasive therapeutics in comparison with an individual clinician’s judgment.14

PERT: Composition and Operation at MGH
The specific clinical goals of the MGH PERT are to convene “multiple specialists to rapidly evaluate intermediate- and high-risk patients with PE, formulate a treatment plan, and mobilize the necessary resources to provide the highest level of care.” Analogous to Heart Teams, PERT is staffed by select experts from Cardiovascular Medicine, Interventional Cardiology, Vascular Medicine, Cardiothoracic Surgery, Echocardiography, Emergency Medicine, Hematology, Pulmonary and Critical Care Medicine, and Radiology, all of whom have a particular interest and competency in treating PE. Like rapid response systems, PERT components include a well-defined afferent limb, a process for team evaluation and action, and an efferent limb (Figure 3). This acute response to an individual patient is supported by a longitudinal infrastructure of core leadership and administrative faculty, data collection, and process improvement.8 An intramural educational campaign consisting of Grand Rounds seminars, presentations at House Staff didactic conferences, cross-training with existing hospital rapid response systems and nursing supervisors, and distributing color posters on inpatient floors preceded the program launch. The process of accessing the PERT specialists was “democratized”13 so that any clinician caring for a patient with a submassive or massive PE could activate the system with a single contact to a central call service. On activation, the patient is promptly evaluated by a physician representative from Vascular Medicine. The evaluation is tailored to patient acuity and severity, with a review of relevant history and assessment of the severity of the event (eg, syncope), examination indicative of right heart dysfunction and stigmata of deep vein thrombosis, contraindications to systemic fibrinolysis and other treatment modalities (eg, active bleeding, history of stroke), comorbidities, and data, which may include cardiac biomarkers, electrocardiography, and bedside ultrasonography.9 Next, PERT faculty and the referring clinician are alerted to log onto a real-time multispecialty discussion held as a virtual meeting using commercially available software (www.gotomeeting.com); in this password-protected environment, the case is presented, and imaging data are simultaneously reviewed by the PERT faculty. Echocardiography and radiology specialists join the conference to provide expert, real-time imaging interpretation and insights. Individual patient discussions may involve 8 to 15 PERT physicians and last up to 20 minutes. During this conference call, the treatment strategy is planned, and the efferent limb effectuated, which may require mobilization of an operating room or angiography suite, perfusion team and cardiac anesthesiologists, and transesophageal echocardiography. In line with institutional policy on urgent single-specialty consultation, PERT strives to complete the online group meeting within 90 minutes of activation, although for patients in extremis, meetings are held within a few minutes. The on-call PERT physician representative subsequently reevaluates the patient, thereby bringing the consolidated treatment recommendation to the patient and his or her current treatment team.

In the first 2.5 years of operation, nearly 400 PERT consults were provided at MGH. Unlike traditional rapid response systems, which do not typically serve patients in emergency departments or intensive care units, 60% and 20% of PERT consults arose from patients in these areas,

Figure 2. The transthoracic echocardiogram, apical 4-chamber view, at end diastole shows dilatation of the right ventricle and a serpiginous intracardiac mass (arrow) in the right atrium, prolapsing across the tricuspid valve into the right ventricle. Please also see the online-only Data Supplement Movie.
respectively. Median time from consultation to meeting was 107 minutes.

Follow-up for patients treated by PERT at MGH is centralized through a growing monthly multidisciplinary PERT clinic. Enhanced clinic availability allows for acute follow-up of post-PE patients usually within a few weeks of presentation. This multidisciplinary clinic extrapolates the Heart Team concept to the longitudinal care of PE patients, with PERT faculty in Vascular Medicine, Pulmonology, and Hematology jointly overseeing follow-up, discussing the cases of all scheduled clinic patients, and thus continuing to provide a unified, consensus treatment plan. Patients are also evaluated by Interventional Cardiology or Cardiothoracic Surgery if an intervention was performed. Additionally, patients for whom there are concerns about thrombophilias or who are contemplating treatment with non-vitamin K oral anticoagulants may have Hematology follow-up, whereas Pulmonology may specifically coordinate management of persistent dyspnea or suspected chronic thromboembolic pulmonary hypertension.

PERT at MGH was built with institutional and departmental support for administrative, research, and quality aims. The MGH PERT group meets monthly for a morning business meeting and then bimonthly in the evening for a discussion of challenging cases or journal club. Since its establishment, PERT members have created a secure Web-based registry of all PERT consultations, prospectively tracking ≈500 pieces of patient-level data for each case to serve as a platform for ongoing quality improvement analyses and research questions. Ongoing efforts include extramural outreach to local institutions with consideration of regional spoke-and-hub models of advanced PE care and a national educational symposium, entitled “Pulmonary Embolism: What is Known and What We Need to Know” which was held in 2015 (Boston, MA).

**PERT: Implementation Issues and Challenges**

Multiple obstacles stand in the way of modern healthcare redesign and innovation. Logistically for any Heart Team, the physician participants must be gathered to engage in productive discussion. Unlike transcatheter aortic valve replacement and coronary interventions Heart Teams, which may discuss nonurgent cases at prescheduled meetings, PERT necessarily must have a flexible ad hoc design. For this reason, and because of the high number of involved physicians, virtual electronic meeting software was built in as a core of the PERT concept, so that convenience for physician members might be optimized, and so that members could participate remotely, including from home and during off hours.

**Figure 3.** An algorithm for activation and operation of a Pulmonary Embolism Response Team (PERT). This flow chart depicts the steps in operation of the Massachusetts General Hospital PERT from the initial consultation on a patient with massive or submassive PE through urgent PERT evaluation and treatment. The Web-based video conference involves discussion of the patient’s specific presentation, thromboembolic risk factors, comorbidities, and goals and preferences, and concludes with a consensus decision on treatment strategy. PE indicates pulmonary embolism.
One potential downside of the PERT approach is that only a single senior physician directly evaluates the patient, and perhaps there may be value in having each individual consultant see and examine the patient separately; however, the benefit of the PERT approach is that the patient receives a single consensus instead of fragmented and possibly conflicting opinions from various services.

In the traditional model of consultation, 1 specialty physician is reimbursed for evaluating a patient and rendering an opinion. Reimbursement and compensation models are in evolution for Heart Team concepts and models such as PERT, but at present only a single supervising physician, assigned on a rotating basis from the Vascular Medicine, Interventional Cardiology, and Pulmonary and Critical Care Medicine services, will bill the initial consultation. Indirect costs of the current PERT model include uncompensated time of other participating physicians. Potential overuse of novel invasive technologies was feared. However, for the first 350 MGH PERT patients, 9.6% underwent advanced percutaneous therapies and 4.1% underwent surgical pulmonary embolectomy, whereas 62% received anticoagulation alone, 21% received an inferior vena cava filter, and 3% received systemic fibrinolysis. Liability is another concern, to the extent that all physicians who participate in the virtual multidisciplinary consult may bear some responsibility for the ultimate decision.

The PERT model has engendered institutional culture shifts in the treatment of PE. One benefit has been a more centralized pathway and the development of focused expertise by the PERT faculty. This may cause conflict with the patient’s primary team, because the primary team necessarily cedes some control in asking for assistance and then possibly is outvoted by a team of experts in PE.13,14 Potential detriments to centralizing the care of a disease that spans every medical discipline are the deskilling of other physician practitioners13 and even a desensitization to the full range of outcomes and derangements secondary to PE.14

Conclusion

PERT exists to bring immediate multidisciplinary cognitive and technical expertise to the care of patients with submassive and massive PE, for which existing clinical data and consensus guidelines are insufficient. The team approach promotes consensus and provides a unified, reasoned plan for the individual patient, improving efficiency over the traditional practice of independently consulting numerous subspecialty physicians. Operational challenges exist, and rigorous empirical data supporting improved outcomes or cost efficiency from this approach are needed.6,13 Nevertheless, the PERT concept has shown great promise, has streamlined the care of complex PE patients at MGH, forged collaborative relationships, and generated centralized data for addressing critical PE research questions.

Case Presentation

The patient presented with submassive PE and right ventricle dysfunction on echocardiography, with an increased risk of adverse clinical events. Additional clinical markers of high risk included relative hypotension, marked hypoxemia, and clot-in-transit. The emergency medicine team had difficulty finding a guideline recommendation to assist with the decision making. For example, the American Heart Association Scientific Statement offers suggestions for the scenario of acute submassive PE with right ventricle dysfunction but does not address the issue of clot-in-transit.1 Given the inherently high-risk nature of clot-in-transit and potential risk of deterioration with further embolization, imminent clot evacuation by either surgical pulmonary embolectomy or large-bore suction embolectomy was considered. PERT physicians conferred, reviewed the relevant imaging, and arrived at a consensus decision. The PERT representative presented options to patient, family, and emergency department team, who together ultimately selected percutaneous embolectomy. Three hours after initial presentation, a 17-cm venous thrombus was successfully removed en bloc (Figure 4). Vasopressor-dependent hypotension developed; therefore, ultrasound-facilitated catheter-based fibrinolysis was performed to dissolve the residual bilateral PE. On postprocedure day 7, the patient was discharged with a plan for 6 months of anticoagulation with warfarin. At the 3-month follow-up in the PERT Clinic with Vascular Medicine, Interventional Cardiology, and Pulmonology, he was asymptomatic and had echocardiographically normal right ventricle size and function. Mobilization of PERT provided the patient with a multidisciplinary evaluation of his case and facilitated a rapid, multispecialty, and potentially life-saving intervention.

Disclosures

None.

References


Figure 4. Suction embolectomy specimen demonstrating en bloc extraction of a 17-cm embolized deep vein thrombosis. Image courtesy of Dr Kenneth Rosenfield, PERT Director and Head of Vascular Medicine, Massachusetts General Hospital.


Key Words: hospital rapid response team • pulmonary embolism • venous thromboembolism • venous thrombosis
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