CASE RECORDS of the MASSACHUSETTS GENERAL HOSPITAL

Case 40-2012: A 43-Year-Old Woman with Cardiorespiratory Arrest after a Cesarean Section

Jeffrey L. Ecker, M.D., Ken Solt, M.D., Michael G. Fitzsimons, M.D., and Thomas E. MacGillivray, M.D.

From the Department of Obstetrics and Gynecology (J.L.E.), the Divisions of Obstetrical Anesthesia (K.S.) and Cardiac Anesthesia (M.G.F.), Department of Anesthesia, Critical Care, and Pain Medicine, and the Department of Surgery (T.E.M.), Massachusetts General Hospital; and the Departments of Obstetrics, Gynecology, and Reproductive Biology (J.L.E.), Anesthesia (K.S., M.G.F.), and Surgery (T.E.M.), Harvard Medical School — both in Boston.

N Engl J Med 2012;367:2528-36.
DOI: 10.1056/NEJMcpc1201413

PRESENTATION OF CASE

Dr. Britta Panda (Obstetrics and Gynecology): A 43-year-old woman (a multigravida) was admitted to the labor and delivery service of this hospital at 36.4 weeks of gestation because of vaginal bleeding.

The patient had had regular prenatal care at this hospital; routine prenatal screening tests were negative. She had had four previous uncomplicated pregnancies, with spontaneous vaginal deliveries, the most recent 14 years earlier. She had a history of obesity (prenatal body-mass index [the weight in kilograms divided by the square of the height in meters], 32.1) and migraine headaches; she had no known allergies. She did not smoke, drink alcohol, or use illicit drugs. Marginal placenta previa was seen on obstetrical ultrasonography, and two episodes of bleeding occurred, at 27.7 weeks and 32.7 weeks of gestation, which resolved after the patient was admitted for bed rest, hydration, and the administration of betamethasone. She was advised to maintain bed rest at home and continue prenatal visits; the medications on discharge were iron sulfate and prenatal vitamins. At a routine prenatal visit 8 days before this presentation (at 35.3 weeks of gestation), obstetrical ultrasonography revealed an anterior placenta with the edge covering the internal os, a finding consistent with placenta previa. Heavy vaginal bleeding developed on the day of admission; the patient came to this hospital and was admitted to labor and delivery.

On examination in the labor and delivery unit, the vital signs and oxygen saturation were normal; there was active vaginal bleeding. Plans were made for emergency cesarean delivery. The hematocrit was 30.9% (reference range in women who are not pregnant, 36.0 to 46.0), the hemoglobin level was 10.7 g per deciliter (reference range, 12.0 to 16.0), and the ABO blood type was O, Rh-positive, with negative antibody screening; the white-cell and platelet counts were normal. A spinal anesthetic was administered, and a cesarean section was performed, with delivery of a healthy boy; the 1-minute and 5-minute Apgar scores were 8 and 9, respectively. The placenta previa was removed. Twenty minutes after delivery, as the

abdominal fascia was being closed, the patient's systolic blood pressure fell to 70 to 80 mm Hg, the pulse to 30 to 39 beats per minute, and oxygen saturation to 70 to 80%. The patient reported chest pain, and her lips became white; apnea developed rapidly thereafter, and she became unresponsive. Electrical activity was present on electrocardiography (ECG), but radial and carotid pulses were not palpable. The trachea was intubated, and cardiopulmonary resuscitation was begun, with closed chest compressions and the administration of pressors.

Diagnostic procedures were performed, and additional management decisions were made.

DIFFERENTIAL DIAGNOSIS

Dr. Jeffrey L. Ecker: All discussants are aware of the diagnosis in this case. This healthy woman had a sudden and profound cardiorespiratory collapse in the middle of what appeared to be an uncomplicated cesarean delivery at term. Such situations require clinicians to focus promptly on a most-likely diagnosis in order to direct problem-specific therapies.

CAUSES OF SUDDEN INTRAOPERATIVE CIRCULATORY COLLAPSE

Primary cardiac events need to be considered as a cause of intraoperative cardiorespiratory collapse. Myocardial ischemia and infarction can cause profound alteration in vital signs, yet this patient was relatively young and had no history of heart disease, and the intraoperative cardiac monitoring did not suggest ischemic changes. Arrhythmias may also produce dramatic alterations in physiology, but the only dysrhythmia seen in this case was a bradycardia, a finding associated with what we soon determined was the likely diagnosis.

Complications associated with anesthesia also need to be considered. Regional anesthesia affecting a higher spinal level than expected can cause apnea but would be unlikely to lead immediately and concomitantly to loss of respiration and cardiac output. Inadvertent intravascular injection of anesthetic agents has been associated with cardiovascular collapse; in this case, however, so much time had passed since the successful initiation of anesthesia that it seems unlikely that the subsequent events were directly linked to an anesthetic complication.

Embolic events can produce sudden collapse of the sort seen in this case. There are three varieties of emboli. A thrombotic pulmonary embolus belongs in the differential diagnosis. However, formation (and migration) of a clot of the necessary size after less than 30 minutes of immobilization seems unlikely, especially since the patient was wearing intermittent pneumatic-compression stockings, as we use in all patients undergoing cesarean deliveries. Air emboli have been reported at the time of cesarean deliveries.[1] Although this patient had received no intravenous injections close to the time of collapse, the uterus had been exteriorized for repair of the hysterotomy; since it had been raised slightly above the level of the heart, the possibility of an air embolus cannot be entirely ruled out. Embolization of amniotic fluid and fetal material is the third type of embolic event we considered.

AMNIOTIC-FLUID EMBOLISM

Amniotic-fluid embolism is thought to result from maternal reaction to fetal material entering the pulmonary circulation and can cause apnea, hypotension, and bradycardia. Amniotic-fluid embolism, although rare, is well known and feared by obstetricians, and because it seemed the most likely explanation for this patient's condition, this diagnosis will be the focus of the discussion here, as it was that day.

Two analyses of administrative data report amniotic-fluid embolism as a complication in 1 in 10,000 and 1 in 100,000 deliveries.[2,3] Amniotic-fluid embolisms are described in association with both vaginal and cesarean deliveries and can occur at any time during labor and delivery, as well as during the postpartum period. Risk factors for amniotic-fluid embolism include advanced maternal age, precipitous labor, cesarean delivery, and conditions associated with bleeding in pregnancy. This patient was of older maternal age, with placenta previa, and she had just undergone cesarean delivery. However, regardless of how many risk factors one patient has, each individual risk factor is relatively common, although amniotic-fluid embolism itself is quite rare; therefore, the conclusion of many observers is that amniotic-fluid embolism is unpredictable and unpreventable.

The clinical presentation of amniotic-fluid embolism includes cardiovascular collapse (bradycardia or hypotension or both), apnea, bleeding, or evidence of fetal compromise (if delivery has

not yet occurred). Often, as in this patient, there is a period of anxiety or agitation preceding the alteration in vital signs and physiology.[3]

Pathophysiologically, amniotic-fluid embolism is thought to be a maternal anaphylactic reaction that unfolds in two phases. A first phase, often lasting less than 30 minutes, is marked by sudden pulmonary vasoconstriction with resulting pulmonary hypertension and right-sided heart failure. This is followed by a second phase, involving left-sided heart failure, endothelial activation and subsequent leakage, and bleeding, all probably caused in part by either the hypoxemia of the first phase or the release of injury-associated agents in the serum. It is not known why some women mount a vigorous reaction and others apparently little reaction at all. However, individual variation, including variation in the time until any response is apparent, most likely accounts for the observation that many cases of amniotic-fluid embolism occur after delivery.[4-7]

Amniotic-fluid embolism poses a serious risk to a mother's life and is a leading cause of maternal death in the developed world; in a report from the Centers for Disease Control and Prevention, the condition accounts for 5% of maternal deaths.[8] It was not so long ago that survival of an amniotic-fluid embolism merited a case report; series from the 1970s and 1980s report mortality rates associated with amniotic-fluid embolism of 50% or higher.[4] More recent series from both the United States and United Kingdom report mortality rates of approximately 20%.[2,3,9]

Treatment of an amniotic-fluid embolism is supportive. As was done in this patient, the airway should be secured and supplemental oxygen delivered. Either crystalloid or blood products are used with pressors as needed to maintain blood pressure. Although volume may be needed acutely, all involved need be mindful of the second phase of amniotic-fluid embolism, in which peripheral and pulmonary edema are prevalent; central monitoring may be vital. Extraordinary measures, including cardiopulmonary bypass,[10] have been used to provide circulatory support and oxygen exchange when such resources are available. A final component of support in cases of amniotic-fluid embolism is treatment of bleeding due to either coagulopathy or atony. Replacement of blood products is central to treating either condition. Uterine atony should be treated first with uterotonic agents, such as ergot derivatives and prostaglandins, tamponade from an intrauterine balloon, or some combination of these. If these measures are ineffective, hysterectomy may be considered, but performing an operation on women who have this condition and have ongoing coagulopathy is itself fraught with peril.

Unfortunately, there is no quick, standard confirmatory test for the diagnosis of amniotic-fluid embolism. The condition was diagnosed in the past when large amounts of fetal material were seen in a mother's lungs at the time of autopsy; it was thought that the presence of fetal material in the pulmonary circulation was always pathological.[11] However, pulmonary arterial-blood samples analyzed as part of studies of right heart catheterization in pregnant patients contained fetal cells more often than previously thought, and the presence of these cells did not always indicate clinical amniotic-fluid embolism.[12] Therefore, amniotic-fluid embolism is a clinical diagnosis that is made after ruling out other common causes for a patient's condition. It has been suggested that transesophageal echocardiography (TEE) may support the diagnosis.[13]

Our working diagnosis was amniotic-fluid embolism. The real story is in the resuscitation and the support that an institution like this one can provide to optimize the outcome in an individual patient. We quickly asked for help, and help quickly came. At the outset, I want to recognize that many people participated in this patient's care. Not all will speak today, but that in no way diminishes their vital contributions.

Dr. Ken Solt: Approximately 20 minutes after delivery of the neonate, as the abdominal fascia was being closed, the patient had an acute onset of bradycardia. Over the course of 1 minute, her heart rate decreased from 81 beats per minute to 42 beats per minute (Fig. 1). During cesarean section, a sudden increase in vagal tone may occur in response to manipulation of the uterus, fallopian tubes, or ovaries, resulting in acute bradycardia. However, this patient had bradycardia during closure of the abdominal fascia. Occasionally, a patient may have a vasovagal response to the stress of undergoing a major operation while awake, but this patient initially appeared well despite the bradycardia. We administered glycopyrrolate (0.2 mg intravenously),

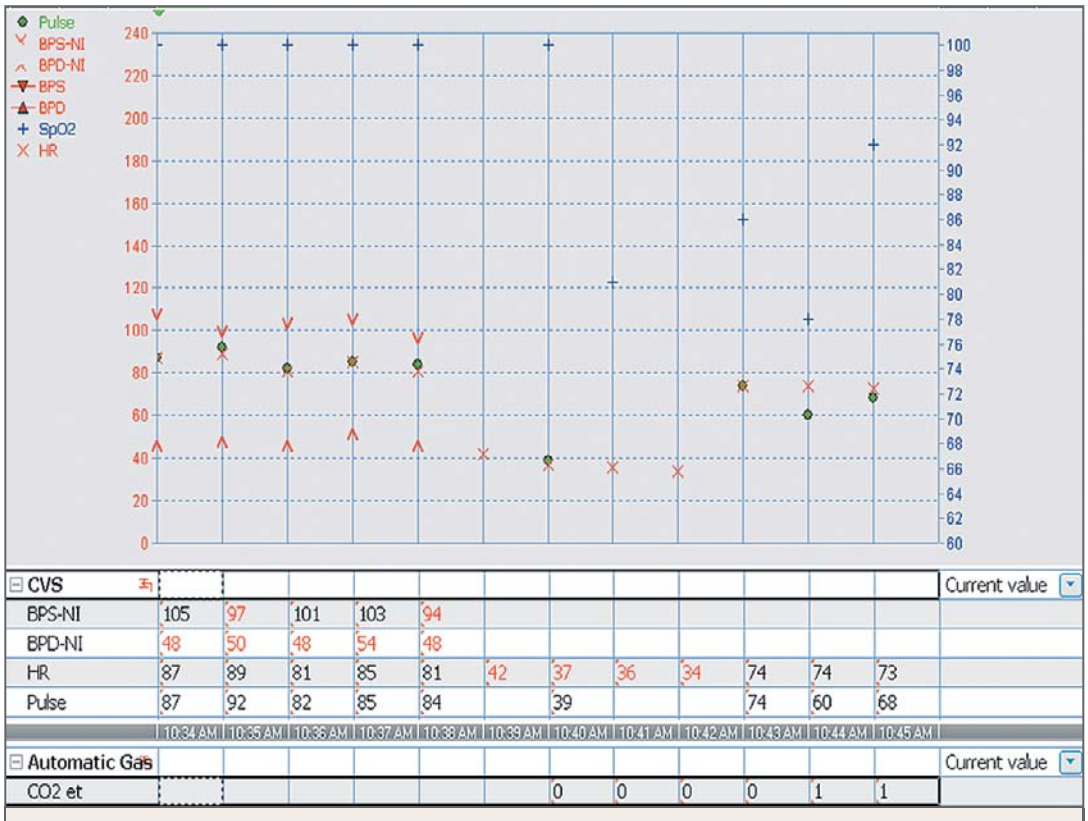

Figure 1. The Patient's Electronic Anesthesia Record from the Time of the Event, as a Graph and as a Table.

Each vertical line represents 1 minute. In the graphical display, a green symbol represents the heart rate (HR) computed from the pulse oximeter, a red "×" the heart rate (HR) computed from the electrocardiogram (ECG), a blue "+" the oxygen saturation (SpO2), the downward-pointing arrowheads the noninvasive systolic blood pressure (BPS-NI), and the upward-pointing arrowheads the noninvasive diastolic blood pressure (BPD-NI). The tabular display shows clinical vital signs (CVS) — BPS-NI, BPD-NI, ECG-derived HR, pulse oximeter–derived heart rate (Pulse), and end-tidal carbon dioxide (CO2 et) — for each minute. Leading up to the event, the patient was hemodynamically stable, with good correlation between the ECG-derived heart rate and the pulse oximeter–derived heart rate. Suddenly, over the course of 1 minute, the patient's heart rate on the ECG decreased from 81 to 42 beats per minute. About 1 to 2 minutes later, she reported pain and clutched her chest, and she rapidly became unresponsive and apneic. Succinylcholine was administered, and the patient was intubated. Chest auscultation revealed clear bilateral breath sounds, but as shown at the bottom of the anesthesia record, no end-tidal carbon dioxide was detected by the capnograph. Despite electrical activity on the ECG, the patient had no palpable radial or carotid pulses. Chest compressions were initiated, and epinephrine was administered.

but the heart rate continued to decrease, into the 30s. The patient then reported pain and clutched her chest. Her eyes rolled back, her lips turned white, and she rapidly became unresponsive and apneic. We administered succinylcholine and performed a rapid-sequence intubation. No end-tidal carbon dioxide was detected by a capnograph, despite clear bilateral breath sounds. Despite electrical activity on the ECG, the patient had no palpable radial or carotid pulses. Chest compressions were initiated and epinephrine (1 mg intravenously) was administered. Although the blood pressure was initially restored, she rapidly became hypotensive and pulseless again and required a second dose of epinephrine (1 mg intravenously). Because of the wide swings in blood pressure associated with the administration of bolus doses, we started the patient on an epinephrine infusion for further hemodynamic support.

A subclavian central venous catheter and a radial arterial catheter were placed. The first arterial blood gas measurement was recorded approxi-

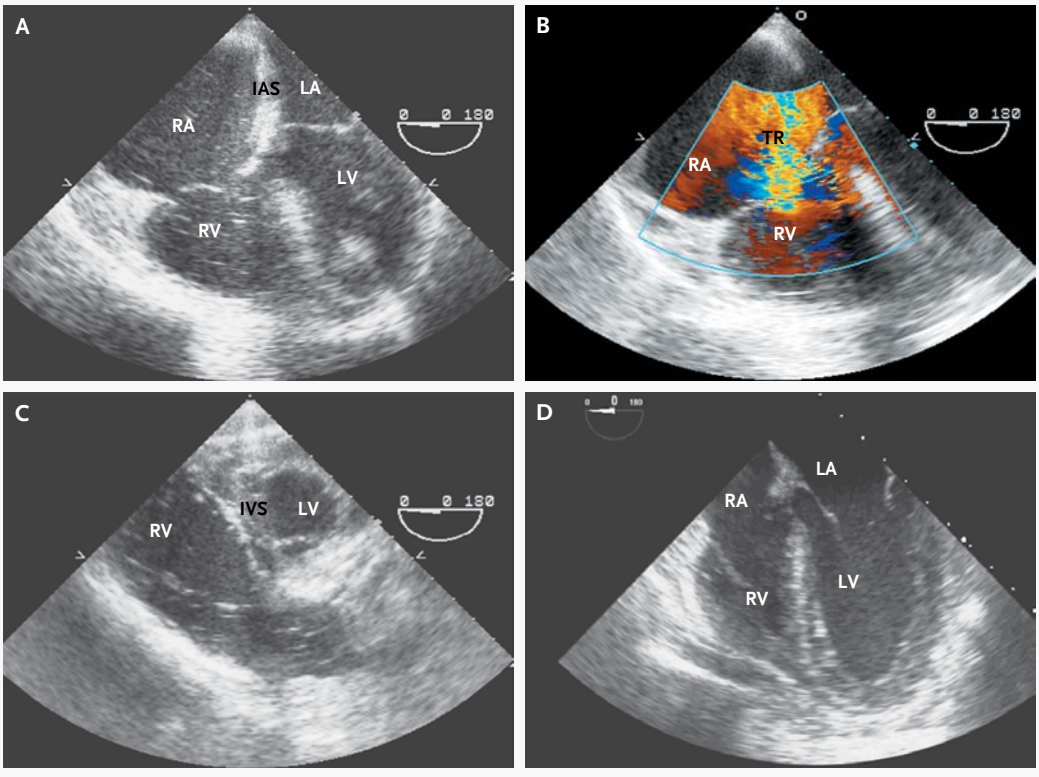

Figure 2. Intraoperative Transesophageal Echocardiograms.

A midesophageal four-chamber image (Panel A) shows dilatation of the right ventricle (RV) and right atrium (RA), with a shift of the interatrial septum (IAS) toward the left atrium (LA). A midesophageal view of the right ventricle and right atrium (Panel B) shows a large jet of tricuspid regurgitation (TR) into the right atrium, indicating severe tricuspid-valve insufficiency. A transgastric view of the right ventricle and left ventricle (LV) (Panel C) shows dilatation of the right ventricle, with a shift of the interventricular septum (IVS) toward the left ventricle. A midesophageal four-chamber view after 24 hours of support (Panel D) shows recovery of right ventricular function and resolution of tricuspid regurgitation.

mately 20 minutes after the initial arrest. This revealed a large gap between the partial pressure of arterial carbon dioxide ($Paco_2$) (48 mm Hg) and the end-tidal carbon dioxide (18 mm Hg). When both the $Paco_2$ and the end-tidal carbon dioxide are known, one may calculate an estimate of the fraction of dead space using the Bohr equation.[14] Under normal conditions, approximately 10% of the tidal volume is dead space, representing the anatomical dead space (i.e., the volume of the tracheobronchial tree, which does not participate in gas exchange). In this patient, the calculated dead space was 62.5% of the tidal volume, implying a large component of alveolar dead space (i.e., 50% of the alveoli were ventilated but not perfused). The end-tidal carbon dioxide of 0 at the time of intubation indicated that the patient's entire pulmonary system was dead space during the initial arrest.

In this patient with the sudden onset of bradycardia, chest pain, loss of consciousness, and apnea during cesarean delivery, performed because of bleeding placenta previa, the finding of 100% pulmonary dead space in the context of cardiac arrest presenting as pulseless electrical activity rapidly led us to the preliminary diagnosis of an amniotic-fluid embolism. We performed TEE to confirm the diagnosis.

DR. JEFFREY L. ECKER AND DR. KEN SOLT'S DIAGNOSIS

Amniotic-fluid embolism.

Table 1. Transesophageal Echocardiographic Findings in Acute Amniotic-Fluid Embolism.

Year	Study	Findings	Outcome
2010	Lee et al.[15]	Severe right ventricular dysfunction Free-floating clot in the right and left atria	Cardiopulmonary bypass and survival
2009	Vellayappan et al.[19]	Enlarged right ventricle Moderate right ventricular hypokinesis Large mass in the right atrium through patent foramen ovale Dilated tricuspid valve annulus Trace-to-mild tricuspid regurgitation Normal left ventricle	Cardiopulmonary resuscitation and survival (pathology report showed squamous-cell epithelium in the mass)
2004	James et al.[13]	Normal left ventricular contractility D-shaped left ventricle Enlarged pulmonary artery and right ventricle Sluggish flow in the pulmonary arteries	Cardiopulmonary resuscitation and death
2003	Stanten et al.[10]	Massive right ventricular dilatation and akinesis Vigorous, small left ventricle	Cardiopulmonary bypass and survival
1999	Shechtman et al.[18]	Right ventricular failure Bulging of interatrial septum and interventricular septum toward the left Severe tricuspid regurgitation Small and decompressed left ventricle	Cardiopulmonary resuscitation and death

DIAGNOSTIC DISCUSSION

Dr. Michael G. Fitzsimons: Emergency TEE was performed by the cardiac anesthesia service (Fig. 2A, 2B, and 2C; and Videos 1, 2, and 3, available with the full text of this article at NEJM.org), and it revealed a dilated right atrium with a shift of the interatrial septum toward the left, severe tricuspid valve insufficiency, mild-to-moderate pulmonary insufficiency, and shifting of the interventricular septum toward the left during systole, resulting in the classic D-shaped left ventricle. The cavity of the left ventricle appeared small. Over time, the right ventricle became more hypokinetic, with bulging of the free wall. There was no evidence of aortic dissection, clot in the proximal pulmonary artery, patent foramen ovale, or pericardial effusion.

TEE is a quick, portable, and reliable means of identifying the potential causes of hemodynamic collapse during labor and delivery. Amniotic-fluid embolism causes intense pulmonary vasoconstriction and an acute pressure overload on the right ventricle, leading to dilatation and hypokinesis. Tricuspid regurgitation leads to dilatation of the right atrium and a shift of the interatrial septum toward the left. Hypotension results from impaired filling of the left ventricle associated with pulmonary vasoconstriction and a shift of the interventricular septum toward the left, resulting in the classic D shape seen in transgastric images. The left ventricle initially appears small and underfilled but hyperkinetic. Worsening left ventricular function may be due to hypoxemia and ischemia. Dilatation of the pulmonary artery and pulmonary regurgitation further support the diagnosis of amniotic-fluid embolism. Several case reports[10,13,15-19] have documented such TEE findings at the time of presumed amniotic-fluid embolism (Table 1).

The utility of TEE in acute cardiopulmonary collapse associated with labor and delivery is not limited to diagnosis but may also include management, the evaluation of the placement of venous and arterial cannulae for extracorporeal membranous oxygenation, the placement and effect of intraaortic balloon counterpulsation, or the effects of inotropic agents.

Videos showing transesophageal echocardiography are available at NEJM.org

DISCUSSION OF MANAGEMENT

Dr. Thomas E. MacGillivray: When I arrived in the obstetrics suite, a well-coordinated resuscitation was under way. The patient was receiving infusions of high-dose vasoactive agents and intermittent chest compressions to maintain a palpable pulse and blood pressure. Owing to the echocardiographic findings of right ventricular distention and an underfilled left ventricle, combined with the marginal hemodynamic status,

we decided to proceed with mechanical circulatory support.

MECHANICAL CIRCULATORY SUPPORT

Numerous devices can support the cardiopulmonary circulation. Percutaneous devices that can be expeditiously inserted include the intraaortic balloon pump, the Impella pump (Abiomed), and the TandemHeart (CardiacAssist). These devices support the failing left ventricle, but because they do little to support the right ventricle or pulmonary circulation, we did not think they would be appropriate for this patient.

Traditional ventricular assist devices can be used to support the left ventricle, right ventricle, or both. Implantation is performed in the operating room; the pumps are usually implanted through a sternotomy and with the use of cardiopulmonary bypass. These pumps are not ideal in situations such as this one, in which active resuscitation is under way, unless you can quickly get the patient to a cardiac-surgery operating room and rapidly initiate cardiopulmonary bypass. Although they can completely replace the pumping function of either or both ventricles, these pumps do not provide any respiratory support or gas exchange, which was a major issue for this patient.

EXTRACORPOREAL MEMBRANE OXYGENATION

We chose to initiate extracorporeal membrane oxygenation (ECMO) in this patient.[20] The two types of ECMO are venovenous ECMO and venoarterial ECMO. Venovenous ECMO is essentially lung support. Cannulae are placed through the femoral vein and through the internal jugular vein. One cannula removes the deoxygenated blood, which is pumped through a membrane oxygenator. The oxygenated blood is then pumped back in through a cannula in the vena cava. The right ventricle must pump the oxygenated blood through the lungs, and the left ventricle pumps the blood through the systemic circulation.

We chose venoarterial ECMO, which is essentially a heart–lung machine without a reservoir, to provide both respiratory and circulatory support. We used the Seldinger technique[21] and quickly obtained access to both the left femoral artery and the right femoral vein with guidewires. A heparin bolus increased the activated clotting time to more than 180 seconds. An 18-French arterial catheter was introduced over one guidewire into the femoral artery, and a 25-French venous cannula was directed through the femoral vein into the right atrium over the other guidewire, with the assistance of TEE. With the initiation of ECMO, 4 liters per minute of blood could flow, which provided excellent support of the patient's circulation such that most of the vasoactive medications could be discontinued, and we could provide adequate oxygenation and ventilation.

The duration of ECMO support in an adult is best limited to hours or days, although it has been effectively used for several weeks. Given the likely diagnosis of an amniotic-fluid embolism, we predicted that the patient's cardiopulmonary system would recover quickly. We moved the patient from the obstetrics suite to the cardiac surgical intensive care unit (ICU). Initially, she was hemodynamically stable, but later she showed signs of hemorrhagic shock. She had large amounts of vaginal bleeding due to uterine atony. She also had abdominal distention that we initially presumed was due to bleeding from the cesarean section. Exploration of her abdomen and pelvis revealed that, in addition to bleeding from the uterus, she also had lacerations of the liver, most likely from cardiopulmonary resuscitation. A hysterectomy was performed for the uterine bleeding, and the liver hemorrhage was controlled by packing with gauze. As predicted, the hemodynamics, gas exchange, and right ventricular function improved overnight, and we were able to discontinue ECMO the next day.

Dr. Fitzsimons: Midesophageal TEE views obtained after 24 hours of ECMO support showed that the right ventricle had returned to its normal anatomy. Tricuspid regurgitation was reduced from severe to mild (Fig. 2D and Video 4). TEE images obtained during weaning of the ECMO circuit showed further improvement in right and left ventricular function. Transgastric TEE images showed a normal position of the interventricular septum.

Dr. William D. Hoffman (Surgery): The patient's ICU course was complicated by medical events that were a consequence of her initial cardiac arrest, subsequent surgeries, and bleeding. Acute nonoliguric renal failure developed, which required continuous venovenous hemofiltration. The causes of this complication are multifacto-

rial and include renal hypoperfusion and administration of an aminoglycoside antibiotic, which was exchanged for another antibiotic early in the patient's stay in the ICU. The patient was sufficiently awake that we could extubate and remove mechanical ventilation support 7 days after admission.

The patient awoke with an encephalopathy characterized by lack of speech, intact language comprehension, intact nonverbal expression, normal cranial-nerve function, and normal motor and sensory functions. The symptoms could not be attributed to an infarct in the territory of a major cerebral artery. Brain CT revealed no hemorrhage or infarct. Her speech returned to normal during the next 10 days. She was discharged from the ICU 13 days after admission.

Dr. Ecker: I met this patient only briefly on the morning of delivery. I have subsequently seen her several times and had many conversations with her, which was not something I expected given the initial events. She left the hospital after 32 days and was readmitted very briefly 2 weeks later for a pleural effusion, which resolved. Her baby is healthy.

Dr. Nancy Lee Harris (Pathology): Are there any questions?

A Physician: If initial severe vasoconstriction in the pulmonary vasculature is a trigger for the other events, are there other agents, such as prostaglandins or sildenafil, that might address this pathophysiological feature?

Dr. MacGillivray: The pathophysiological features of pulmonary emboli are fascinating. The profound right ventricular dysfunction seems to be caused by more than just a mechanical obstruction of the pulmonary artery. In thoracic surgery, we can clamp a large branch of the pulmonary artery without circulatory collapse. However, with a pulmonary embolism, there is frequently a severe, diffuse pulmonary vasoconstriction in addition to the mechanical obstruction. Perhaps rapid initiation of a selective pulmonary arterial relaxant, such as nitric oxide, might be beneficial.

Dr. Ecker: One week after this conference, the patient was readmitted to the hospital with multiple pulmonary emboli. A source of the emboli was never identified. The patient was given anticoagulant agents and was discharged after 2 days. She remains well more than 1 year later.

FINAL DIAGNOSIS

Amniotic-fluid embolus.

This case was discussed at Obstetrics and Gynecology Grand Rounds. Dr. Michael F. Greene assisted with organizing the conference.

No potential conflict of interest relevant to this article was reported. Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

REFERENCES

1. Rodgers L, Dangel-Palmer MC, Berner N. Acute circulatory and respiratory collapse in obstetrical patients: a case report and review of the literature. AANA J 2000; 68:444-50.
2. Abenhaim HA, Azoulay L, Kramer MS, Leduc L. Incidence and risk factors of amniotic fluid embolisms: a population-based study on 3 million births in the United States. Am J Obstet Gynecol 2008; 199:49.e1-49.e8.
3. Knight M, Tuffnell D, Brocklehurst P, Spark P, Kurinczuk JJ. Incidence and risk factors for amniotic-fluid embolism. Obstet Gynecol 2010;115:910-7.
4. Clark SL, Hankins GD, Dudley DA, Dildy GA, Porter TF. Amniotic fluid embolism: analysis of the national registry. Am J Obstet Gynecol 1995;172:1158-69.
5. Gist RS, Stafford IP, Leibowitz AB, Beilin Y. Amniotic fluid embolism. Anesth Analg 2009;108:1599-602.
6. Clark SL, Cotton DB, Gonik B, Greenspoon J, Phelan JP. Central hemodynamic alterations in amniotic fluid embolism. Am J Obstet Gynecol 1988;158: 1124-6.
7. Vanmaele L, Noppen M, Vincken W, De Catte L, Huyghens L. Transient left heart failure in amniotic fluid embolism. Intensive Care Med 1990;16:269-71.
8. Berg CJ, Callaghan WM, Syverson C, Henderson Z. Pregnancy-related mortality in the United States, 1998 to 2005. Obstet Gynecol 2010;116:1302-9.
9. Gilbert WM, Danielsen B. Amniotic fluid embolism: decreased mortality in a population-based study. Obstet Gynecol 1999;93:973-7.
10. Stanten RD, Iverson LI, Daugharty TM, Lovett SM, Terry C, Blumenstock E. Amniotic fluid embolism causing catastrophic pulmonary vasoconstriction: diagnosis by transesophageal echocardiogram and treatment by cardiopulmonary bypass. Obstet Gynecol 2003;102:496-8.
11. Roche WD Jr, Norris HJ. Detection and significance of maternal pulmonary amniotic fluid embolism. Obstet Gynecol 1974;43:729-31.
12. Lee W, Ginsburg KA, Cotton DB, Kaufman RH. Squamous and trophoblastic cells in the maternal pulmonary circulation identified by invasive hemodynamic monitoring during the peripartum period. Am J Obstet Gynecol 1986;155: 999-1001.
13. James CF, Feinglass NG, Menke DM, Grinton SF, Papadimos TJ. Massive amniotic fluid embolism: diagnosis aided by emergency transesophageal echocardiography. Int J Obstet Anesth 2004;13:279-83.
14. Respiratory monitoring. In: Miller RD, ed. Miller's anesthesia. 6th ed. Vol. 1. New York: Churchill Livingstone, 2005: 1437-81.
15. Lee PH, Shulman MS, Vellayappan U, Symes JF, Olenchock SA Jr. Surgical treatment of an amniotic fluid embolism with cardiopulmonary collapse. Ann Thorac Surg 2010;90:1694-6.
16. Porat S, Leibowitz D, Milwidsky A, Valsky DV, Yagel S, Anteby EY. Transient intracardiac thrombi in amniotic fluid embolism. BJOG 2004;111:506-10.

17. Saad A, El-Husseini N, Nader GA, Gharzuddine W. Echocardiographically detected mass "in transit" in early amniotic fluid embolism. Eur J Echocardiogr 2006;7:332-5.
18. Shechtman M, Ziser A, Markovits R, Rozenberg B. Amniotic fluid embolism: early findings of transesophageal echocardiography. Anesth Analg 1999;89:1456-8.
19. Vellayappan U, Attias MD, Shulman MS. Paradoxical embolization by amniotic fluid seen on the transesophageal echocardiography. Anesth Analg 2009;108:1110-2.
20. Brodie D, Bacchetta M. Extracorporeal membrane oxygenation for ARDS in adults. N Engl J Med 2011;365:1905-14.
21. Seldinger SI. Catheter replacement of the needle in percutaneous arteriography; a new technique. Acta Radiol 1953;39:368-76.