CASE RECORDS of the MASSACHUSETTS GENERAL HOSPITAL

Case 11-2014: A Man with Traumatic Injuries after a Bomb Explosion at the Boston Marathon

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PRESENTATION OF CASE

Dr. John T. Nagurney (Emergency Medicine): A 34-year-old man was brought to the emergency department at this hospital because of multiple traumatic injuries that he sustained when a bomb exploded while he was watching the 2013 Boston Marathon.

At the scene, the patient reportedly lost consciousness, had a complete amputation of his right leg directly below the knee, and had copious blood loss. A tourniquet had been applied to the right upper leg. He was placed on a backboard, immobilized, and transported to this hospital by ambulance, arriving at 3:20 p.m., 31 minutes after the explosion. He was brought immediately into a trauma bay in the emergency department. No additional history was known.

On examination by Dr. Timothy Fallon (Emergency Medicine Resident) in the emergency department, the patient was covered with ash and smelled of smoke; he was somnolent but arousable to verbal stimuli, and he was oriented to date, self, and place (the hospital). The blood pressure was 98/52 mm Hg, the pulse 128 beats per minute, the respiratory rate 28 unlabored breaths per minute, and the oxygen saturation 100% (oxygen supplementation not recorded). He opened his eyes in response to speech. The Glasgow Coma Scale score was 14 on a scale of 3 (indicating coma) to 15 (indicating normal). There was soot and dirt on the face, and the nasal hairs and eyebrows were singed. The pupils were equal and reactive to light. The mucous membranes were dry. The cervical spine was not tender to palpation. The lungs were clear to auscultation, and there was no tenderness, crepitus, or deformity of the chest wall. The heart sounds were normal. The femoral pulses were 2+. The abdomen was soft, nontender, and nondistended, without guarding. The extremities were pale and cool. There was venous bleeding and a large pool of blood at the site of the amputation of the right leg, as well as an open fracture of the left foot. There were burns involving the face, trunk, and extremities; a puncture wound (3 cm in length) in the posterior aspect of the left thigh with some tissue destruction and no active bleeding; and multiple smaller penetrating wounds. Detailed wound and burn examinations were deferred. The patient moved all extremities and had no gross focal neurologic deficits.

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N Engl J Med 2014;370:1441-51.
DOI: 10.1056/NEJMcpc1314240

DISCUSSION OF INITIAL MANAGEMENT

Dr. George Velmahos: The patient arrived shortly after the hospital-wide notification about the Boston Marathon mass-casualty event. The entire trauma team and many other surgeons were already in the emergency department, working alongside the emergency physicians and nurses to triage and treat the victims as they arrived. The patient had a patent airway and showed signs and symptoms of hemorrhagic shock. His right leg had been amputated immediately below the knee.

A tourniquet had been applied to the right upper leg by prehospital providers but was not controlling the bleeding fully, as evidenced by a large pool of blood at the site of the amputation. The tourniquet was tightened, and a second, military-style tourniquet was added. Tourniquets have been shown to control bleeding effectively and save lives in the prehospital and emergency department setting. Much of the evidence comes from recent wars, in which leg injuries have become frequent and devastating because of the use of improvised explosive devices (IEDs). Application of a tourniquet for up to 1 hour seems to be safe, and even a period of up to 2 hours is associated with low morbidity.[1,2] Complications related to aggressive use of tourniquets are a concern, but the major concern lies with the inadequate control of bleeding due to insufficient tightening, misplacement, or suboptimal design of the tourniquet.[3,4] This patient had bleeding because of an inadequately tightened tourniquet. After application of the second tourniquet, the bleeding stopped. Focused assessment with sonography for trauma (FAST), a rapid bedside ultrasound examination of the abdomen to detect fluid (which is likely to be hemorrhage in cases of trauma), was negative.

Dr. Suhny Abbara: An anteroposterior chest radiograph obtained in the emergency department (Fig. 1A) showed no fractures or pneumothorax. A small, spherical, radiopaque foreign body (4 mm in diameter) projected over the right lower mediastinal border. The object could have been in the soft tissues, bones, lungs or pleural space, mediastinum, or heart. A radiograph of the pelvis showed no fractures, but there were multiple metallic foreign bodies, such as small nails and spheres similar to the one seen in the chest that were consistent with ball bearings (Fig. 1B).

Dr. Velmahos: The decision was made that management of the wounds to the extremities would be the priority. The patient was intubated in the emergency department and then taken on an emergency basis to the operating room, 10 minutes after arrival. Because of the extensive injury to the right knee, a below-the-knee amputation was not possible. The distal femur was intact, so an above-the-knee amputation was performed on the right leg. The muscle and bone were healthy and not near a contaminated field, so primary closure was performed. The burns of the left leg were débrided.

PATHOLOGICAL DISCUSSION

Dr. Vania Nosé: The security team at this hospital was in contact with the Federal Bureau of Investigation (FBI), and the amputated limb and foreign bodies had to be handled by the anatomical pathology service as evidence, with attention to the chain of custody (which required that each specimen be handled by only one person), and all the shrapnel turned over to the FBI. The above-the-knee amputation specimen (Fig. 2A) included the knee joint, a 2.8-cm length of exposed femur, a 7.0-cm area of hemorrhagic and blackened torn skin, and exposed muscle and soft tissue. Radiographs of the specimen showed numerous foreign bodies, including eight metal pellets (Fig. 2B). Foreign material and pellets removed from the specimen (Fig. 2C) were given to the hospital security team and delivered to the FBI. There was necrosis of skeletal muscle at the distal margin, with acute inflammation and bacterial overgrowth (Fig. 2D). Histopathological sections of the skin and subcutaneous tissue revealed foreign material embedded within soft tissue (Fig. 2E and 2F).

DISCUSSION OF MANAGEMENT

ORTHOPEDIC SURGERY

Dr. John Y. Kwon: After the completion of amputation of the right leg, additional imaging studies were obtained to evaluate the patient's other injuries.

Dr. Abbara: Images obtained by contrast-enhanced multidetector computed tomography (MDCT) with volume rendering (Fig. 1C and 1D) and multiplanar reconstruction (MPR) combined with volume rendering (Fig. 1E) show numerous metallic foreign bodies in the soft tissues of the

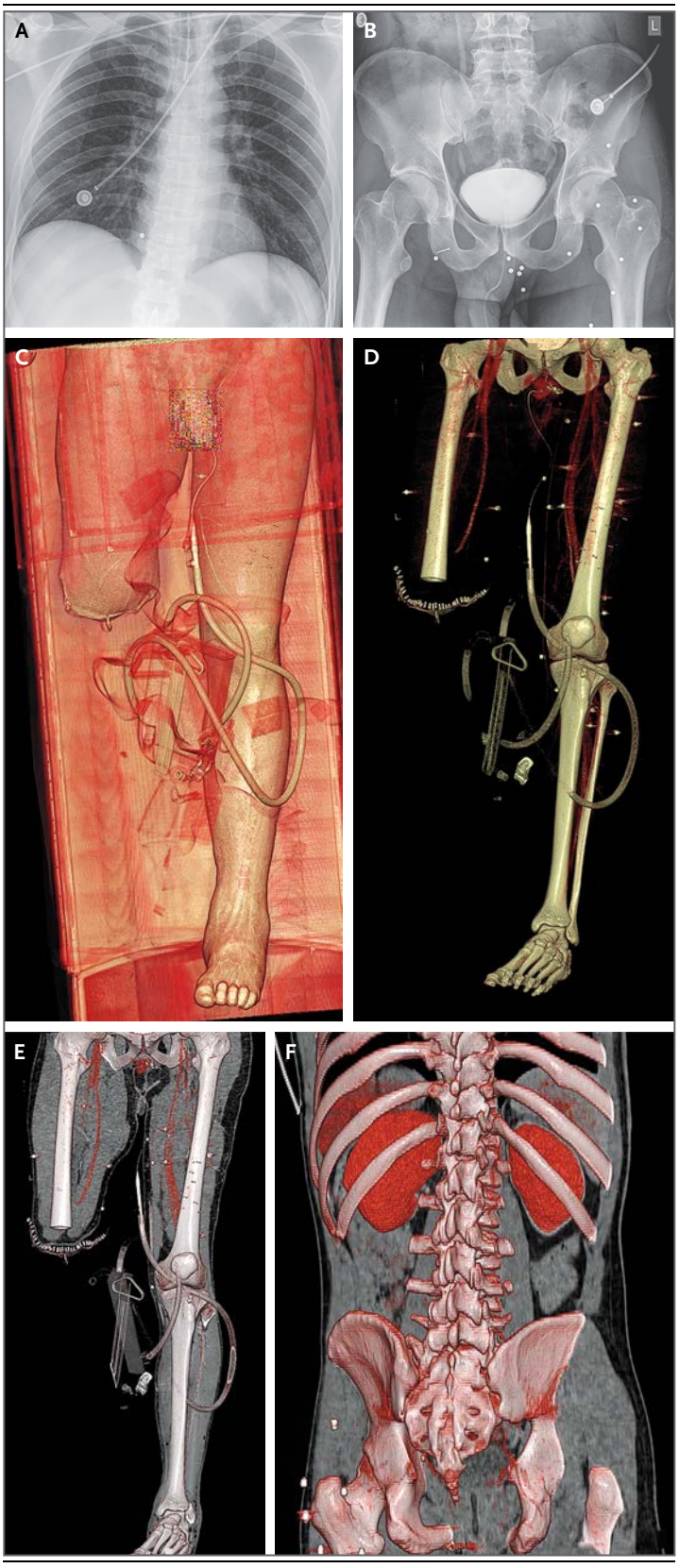

Figure 1. Imaging Studies on Admission.
Plain radiographs of the chest (Panel A) and pelvis (Panel B) show numerous spherical 4-mm foreign bodies, including within the chest overlying the heart. There is also a nail in the pelvis. There are no pelvic or rib fractures or pneumothorax. Images from contrast-enhanced multidetector CT (MDCT) with volume rendering (Panels C and D) and multiplanar reconstruction (MPR) combined with volume rendering (Panel E) show numerous metallic foreign bodies in the soft tissues. An image from abdominal and pelvic MDCT with posterior volume rendering and an MPR view (Panel F) shows metallic foreign bodies in the left gluteal soft tissues.

legs, as well as in gluteal soft tissues (Fig. 1F). Radiographs of the right forearm revealed three metallic spherical foreign bodies in the proximal forearm. A plain radiograph of the left tibia and fibula (Fig. 3A) revealed multiple metallic foreign bodies around the knee and a nondisplaced fracture of the lateral tibial plateau. Plain radiographs of the left foot and ankle revealed a comminuted fracture of the calcaneus (Fig. 3B), minimally displaced cuboid and cuneiform fractures, and subluxation of multiple tarsometatarsal joints, evidence of a ligamentous Lisfranc injury (dislocation of the tarsometatarsal joints due to midfoot trauma; named after the military surgeon in Napoleon's army) (Fig. 3C).

Dr. Kwon: On clinical examination, the patient had multiple shrapnel injuries to the soft tissues, an open calcaneal fracture with a posteromedial stellate wound measuring approximately 3 cm by 5 cm, and a swollen and grossly unstable midfoot.

A comprehensive examination in the operating room revealed complete ligamentous stability of the knee and no fracture displacement with valgus stressing. Orthogonal intraoperative fluoroscopy was performed on the knee, confirming the CT findings showing that the metallic foreign bodies were not intraarticular. Tibial-plateau fractures, in the absence of ligamentous instability, fracture displacement, or both, as in this case, can be treated nonoperatively with protected weight-bearing.

This patient's foot injuries were typical of a blast injury, in which the legs are frequently involved.[5,6] Such foot injuries are seen more often in military personnel than in civilians. A case series of 40 calcaneal fractures sustained from IEDs reported a high rate of infection and sub-

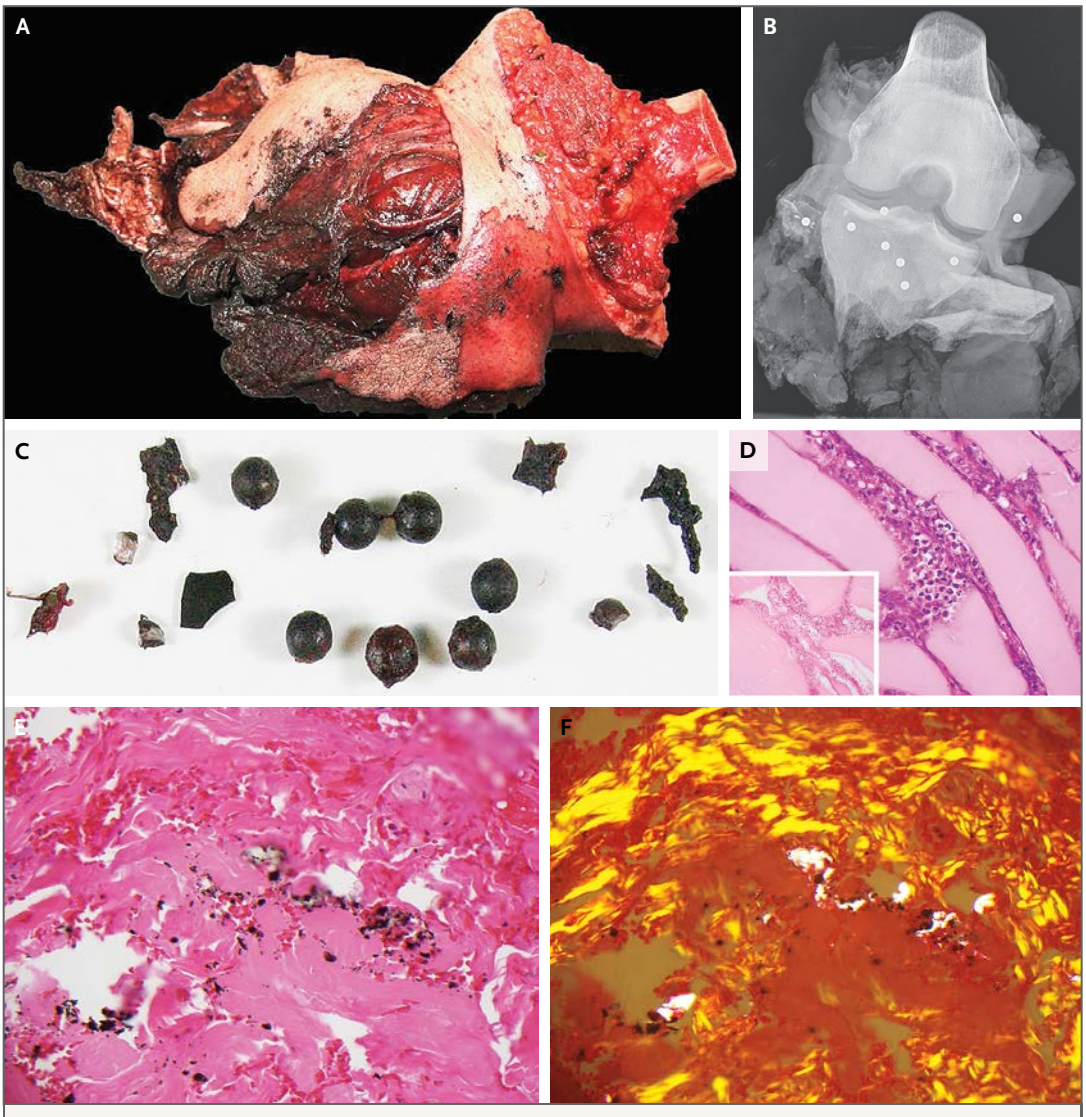

Figure 2. Shrapnel Injuries of the Amputated Right Leg.

A gross photograph (Panel A) of the above-the-knee amputation specimen (completion of the traumatic right below-the-knee amputation) shows the knee joint, with the femur exposed and appearing normal. The distal end has exposed fractured bone and extensive discolored, blackened, and diffusely torn skin and skeletal muscle. The skin is focally necrotic. A radiograph of the amputation specimen (Panel B) shows the knee joint with a fractured bone at the distal end and embedded foreign material in the soft tissue, including eight round pellets. Foreign material removed from the specimen (Panel C) was given to hospital security personnel, who documented the recovery of the material and transferred custody to the FBI. A histopathological section obtained from the distal end of the specimen shows necrotic skeletal-muscle fibers surrounded by edema and a neutrophilic exudate (Panel D, hematoxylin and eosin); the inset (Brown and Hopps) shows numerous bacteria. A histopathological section of the skin and subcutaneous tissue (Panel E, hematoxylin and eosin) shows foreign material, including scattered black material embedded in soft tissue. Under polarized light (Panel F, hematoxylin and eosin), both polarizable material and nonpolarizable black material are evident.

sequent amputation.[6] On surgical exploration, the Achilles' tendon in this patient was intact and the triceps surae was attached to multiple comminuted fragments of the posterior calcaneus that were not amenable to surgical fixation. The open calcaneal wound was débrided and irrigated, and negative-pressure wound therapy (i.e., a vacuum-assisted dressing) was applied.

The presence of a Lisfranc fracture was confirmed with the use of intraoperative fluoros-

Figure 3. Radiographs of the Injuries of the Left Leg.

A radiograph of the left knee (Panel A) shows multiple metallic foreign bodies and a nondisplaced fracture of the lateral tibial plateau (arrow). A radiograph of the left foot (Panel B) shows an open calcaneal fracture and tarsometatarsal subluxation. Anteroposterior (Panel C) and lateral (Panel D) views of the foot show instability of the tarsometatarsal joints, a finding that is consistent with a Lisfranc injury. Intraoperative images (Panels E and F) show reduction of the Lisfranc injury and percutaneous fixation with Kirschner wires (K-wires).

copy, which revealed subluxation of all tarsometatarsal joints and stressing of the midfoot. Lisfranc injuries, whether they involve fracture, ligamentous injury, or a combination of the two, typically occur from an axial load on a plantarflexed foot, a crush injury, or severe twisting of the foot. Lisfranc injuries require surgical reduction and fixation whenever there is subluxation of the tarsometatarsal joints; outcomes have been directly correlated with anatomical reduction.[7] Options include closed reduction and percutaneous pinning, formal open reduction and internal fixation, or open reduction and arthrodesis of the affected joints.[8] Given the massive swelling of the foot, a closed reduction with the percutaneous placement of pins (also known as Kirschner wires, or K-wires) was performed (Fig. 3E and 3F).

INTENSIVE CARE AND PAIN

Dr. Matthias Eikermann: In this hospital, anesthesiologists provide anesthesia and pain therapy, manage perioperative life-threatening cardiopulmonary conditions that do not require surgical interventions, and orchestrate care in the intensive care unit (ICU).

After the above-the-knee amputation and débridement and washout of the open wounds, the patient was admitted to the ICU. Our initial goal was to minimize the risk of additional organ failure. Rhabdomyolysis developed, with creatine kinase levels of more than 10,000 U per liter, indicating a risk of acute renal failure; it was treated with early and aggressive fluid resuscitation to increase renal perfusion and stabilize urinary output, and electrolyte substitution was also performed.[9] In light of the multiple burns and other blast injuries, we initiated antibiotic therapy with ciprofloxacin, metronidazole, and vancomycin. Later that day, the patient returned to the operating room, where burns were débrided and Dr. Kwon treated the fractures of the left leg.

We initiated early rehabilitation, which improves functional mobility and helps prevent ICU-acquired muscle weakness.[10,11] Components of early rehabilitation applied in this case were daily titration of sedation and opioids to allow for spontaneous breathing on the ventilator, as well as early extubation, on the second day after the blast. Subsequently, we implemented goal-directed early-mobilization therapy in collaboration with the physical therapy and rehabilitation services.

Orchestration of multidisciplinary critical care medicine is a key component of an intensivist's responsibilities. We invited colleagues from otolaryngology, psychiatry, rehabilitation medicine, and physical therapy[12] to help us increase the value of care. Evaluation of the patient by the trauma psychiatry service did not reveal acute psychiatric issues, but continued alleviation of pain and optimization of sleep were recommended in order to prevent a post-traumatic stress disorder. Indeed, intractable pain affected the patient's sleep and quality of life, as well as our ability to facilitate his early mobilization. We inserted a tunneled catheter for long-term epidural analgesia with local anesthetic agents, which helped to achieve acceptable control of pain and minimize side effects associated with opioid therapy.

Multimodal pain therapy permitted us to help the patient implement the suggested interventions of the rehabilitation team, which included positioning and exercise training to preserve joint range of motion and muscle length. As the patient improved, his physical therapy progressed to include a focus on aerobic exercise and functional mobility training, which were important early steps in his rehabilitation while he remained hospitalized.

In family-centered critical care medicine, the strengths and needs of all family members are considered. We invited the patient's fiancée (a trained nurse) to participate in our daily rounds and gave her the opportunity to stay in the patient's room overnight in a bed that the nurses made for her.

The threat associated with the foreign body in the patient's chest was a major concern. A radiograph and a CT scan of the chest were inconclusive in determining the position of the foreign body. We scheduled a meeting with cardiac surgery, cardiology, radiology, trauma surgery, and the ICU team to discuss management of the intrathoracic foreign body.

INTRATHORACIC FOREIGN BODY

Dr. Abbara: An MDCT image of the thorax after the administration of contrast material showed a metallic density located near the right heart border that extended a distance of 2.5 cm (Fig. 4A) and was thought to be a metallic streak artifact from a smaller metallic structure that was in motion (most likely cardiac motion) during acquisition of the MDCT image, which was suggestive of an intracardiac position of the foreign object.

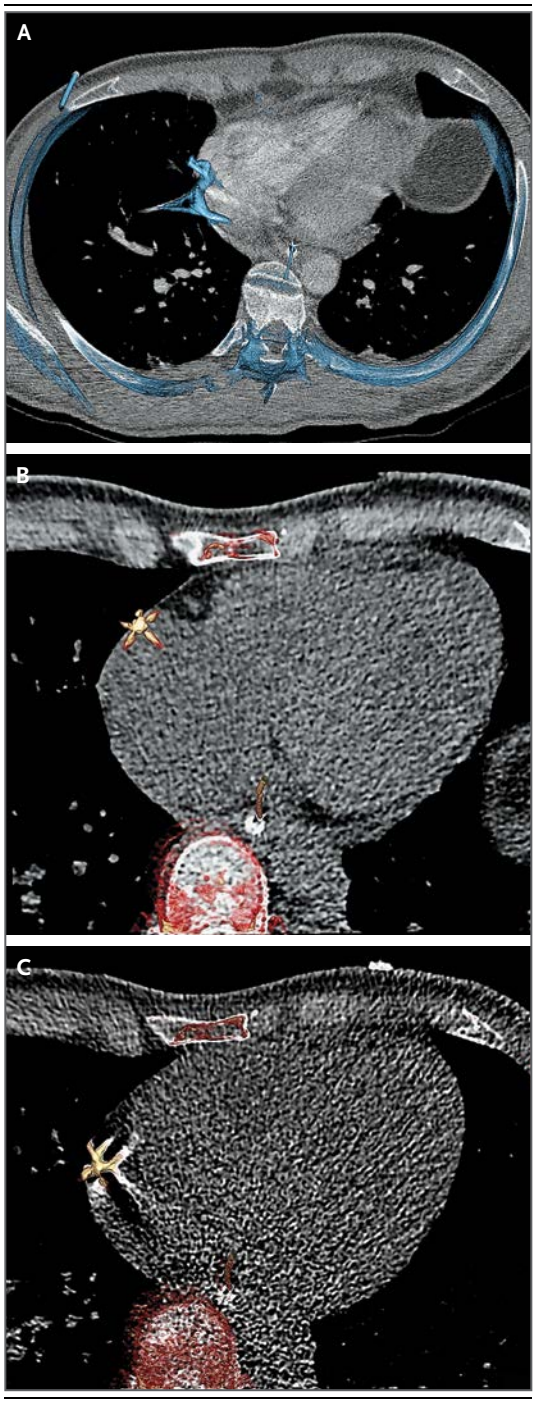

Figure 4. CT Images of the Chest.
Initial contrast-enhanced MDCT (Panel A) shows a metallic artifact that is substantially larger than the foreign body seen on the chest radiograph. The artifact is seen along the lateral wall of the right atrium and could be caused by a single sphere in motion, suggesting an intracardiac location. Systolic (Panel B) and diastolic (Panel C) images from electrocardiogram-gated 128-slice dual-source CT, which minimizes the artifact, show a moving foreign body located in the right atrium approximately 1 cm posterior to the right atrioventricular groove and within or very near the atrial wall.

In order to better determine the position of the foreign body and minimize the artifact, an electrocardiogram-gated 128-slice dual-source CT (DSCT) scan was obtained (Fig. 4B and 4C). This revealed a radiodense foreign body (5 to 6 mm in greatest dimension) that was located near the origin of the right atrial appendage and posterior to the right atrioventricular groove. The object moved with the cardiac cycle, confirming its location within the heart.

Dr. Paul L. Huang: To further evaluate the foreign body in the thorax that was seen on initial imaging studies, transthoracic echocardiography was performed (Video 1, available with the full text of this article at NEJM.org). This study showed normal left ventricular cavity size and systolic function, and no metallic fragments were visualized in or near the right atrium. Transesophageal echocardiography (Fig. 5 and Video 2) revealed an echodensity measuring 5 mm by 4 mm that appeared to be embedded in the myocardium or trabeculae on the atrial side of the tricuspid annulus, near the mouth of the right atrial appendage. Distal acoustic shadowing suggested that the mass was metallic. The mass was located 1.5 cm from the right coronary artery as it courses through the atrioventricular groove.

We considered two possible ways that the foreign body could have entered the heart: direct missile projection through the body into the heart, or hematogenous spread from venous return from the pelvis. Depending on the force of the initial blast and the velocity of the projectiles, direct intracardiac missile projection into the heart can occur.[13] In this case, careful inspection revealed no entry wounds on the chest, back, or axillary regions. Direct projection could also have occurred through the abdomen, since there was substantial traumatic disruption of the tissue of the legs and transection of large vessels. However, no tracks in the tissue were observed, and there was no pericardial fluid or evidence of pericardial disruption. Therefore, we concluded that hematogenous spread was most likely. Hematogenous spread has been reported in cases of shrapnel migrating from the femoral vein to the right atrium[14] and of a bullet embolus migrating from the left brachiocephalic vein to the right ventricle.[15,16]

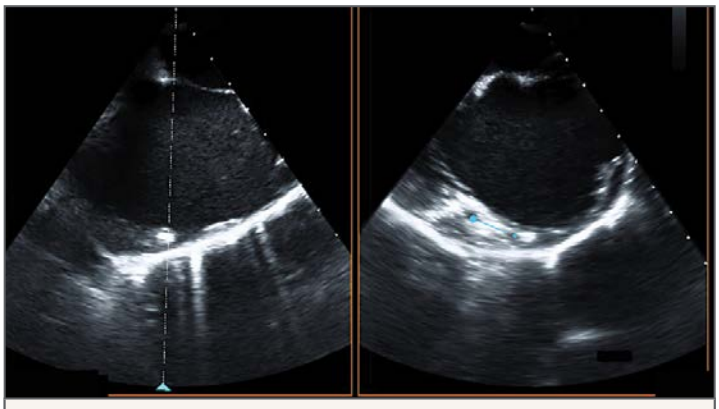

Figure 5. Transesophageal Echocardiography.

Biplane orthogonal images of a gastric view of the right atrium and tricuspid valve show the presence of a foreign body (left image) located 1.5 cm from the atrioventricular groove, where the right coronary artery courses (right image, connected blue dots).

In the case of the intracardiac foreign body in this patient, we had four major concerns: distal embolization into the pulmonary circulation with resulting pulmonary embolus, paradoxical embolization through a right-to-left intracardiac shunt, erosion through the myocardium with possible cardiac tamponade, and erosion into the right coronary artery with possible damage to the coronary artery, myocardial infarction, and tamponade. Additional concerns included the risk of endocarditis, arrhythmogenicity, and thrombus formation.

Videos showing echocardiographic studies are available at NEJM.org

Foreign bodies have been retrieved in the cardiac catheterization laboratory through a percutaneous approach using snares.[17,18] Primary considerations include whether the foreign body can be safely moved so that it does not further embolize or become dislodged, and whether removal of the foreign body would pose a risk of perforation. We concluded that embolization of an object smaller than 5 mm into the lung would be unlikely to be hemodynamically significant because of its small size. Paradoxical embolization across a patent foramen ovale or atrial septal defect to the aorta[19] was considered unlikely, since right-to-left shunting was ruled out by color Doppler echocardiography and injection of an agitated-saline contrast agent at rest and during the Valsalva maneuver.

Penetrating cardiothoracic war wounds may induce pneumopericardium, hemopneumothorax, pericardial effusion, arrhythmia, and myocardial infarction, and the penetrating object may migrate, causing other complications.[20] In this case, we thought that unless there were additional forces on the object, it would probably remain lodged indefinitely in the trabeculae and become endothelialized. The proximity to the right coronary artery was a concern. There have been reports of shrapnel causing a traumatic fistula between the right coronary artery and the right atrium.[21,22] In this case, despite its location near the atrioventricular groove, the object was far enough from the artery that we could monitor its location noninvasively and take action if there was evidence of migration.

Serial imaging over time showed that the foreign body remained stationary. There were no arrhythmias, thrombosis, or evidence of infection to suggest that urgent removal was indicated.

BLAST INJURIES

Dr. Shawn P. Fagan: In this patient, evidence of primary blast injuries (defined as injuries resulting from increased pressure) consisted of bilateral perforated tympanic membranes. Secondary blast injuries (defined as injuries resulting from projectiles from the explosive device) consisted of traumatic right lower leg amputation and injuries to the left leg, and quaternary injuries (defined as injuries resulting from other effects of the blast) consisted of thermal injury to 38% of the total body-surface area. There was no evidence of tertiary blast injuries, which are caused by collision with adjacent objects.

This patient presented with high-grade, central perforations of the tympanic membrane as a complication of the blast[23]; the right ear was worse than the left ear, indicating that the device was to the right of the patient. Tinnitus and hearing loss are the most common initial symptoms; these symptoms continue to be problematic for this patient during his recovery. Initial therapy was conservative and protective in nature, but future operative management of the high-grade perforations is planned. The 3-month follow-up examination revealed a bilateral mixed hearing loss that was worse in the right ear than in the left ear, with word-recognition scores of 88% and 92%, respectively.

The left lower leg was heavily affected by the thermal blast. The zone of injury was complex and was associated with additional secondary blast injuries that included an occluded posterior tibial artery and an open posterior calcaneal frac-

ture. Initial therapy consisted of fasciotomies followed by arteriography that revealed an occluded posterior tibial artery. Serial débridements were supplemented by treatment with topical and systemic antimicrobial agents because of the high risk of infection after IED explosions. The zone of injury revealed deep penetration of foreign material between tissue planes, necessitating aggressive débridements.[24] Reconstruction was accomplished with the use of a staged technique. Split-thickness skin grafts were placed over the areas of third-degree thermal injury, and a synthetic neodermis was placed over a fourth-degree thermal injury just proximal to the ankle joint. After neodermis maturation, split-thickness skin grafts completed the definitive wound closure. Six months after reconstruction, the patient has functional range of motion at both the left knee joint and the left ankle joint.

REHABILITATION

Dr. Ronald E. Hirschberg: The patient's wide range of injuries presents large challenges for the intensive phase of rehabilitation for the following three reasons: the injuries were bilateral (he had an above-the-knee amputation and a non–weight-bearing intact leg), both nociceptive and neuropathic pain limited movement, and there was a risk of flexion contractures of both the right hip and the left knee because of the burn, orthopedic, and soft-tissue injuries.

Enabling optimal healing of the residual right leg was our primary goal. The rehabilitation team's efforts target early treatment and prevention of functional limitations, such as the inability to sit or stand, that will directly affect this patient's level of disability and his ability to reintegrate into the community, including home and work.

When orchestrating early mobilization of patients in the surgical ICU,[25] we need to take into account that traumatic leg amputations increase the body's metabolic demand. A unilateral below-the-knee amputation results in an expenditure of energy that is approximately 25% more than the energy expenditure associated with preamputation ambulation; with unilateral above-the-knee amputation, the energy expenditure is approximately 60% more than that for preamputation ambulation. This patient's intact left limb had multiple orthopedic and soft-tissue injuries to the foot, heel, and leg, creating an additive effect on metabolic demand, further affecting the plans for rehabilitation and outcome.

Our multidisciplinary treatment approach included orthopedic, vascular, neurologic, and dermatologic interventions. Fostering local healing (which requires immobility) while simultaneously mobilizing the patient early was one of the more challenging goals and was facilitated by therapists and nurses. In addition, balancing pain control and alertness in the patient between multiple surgical procedures was necessary in order to achieve the seemingly simple (but deceptively complex) task of sitting up in a chair by 1 month into his hospitalization. Successful early trauma rehabilitation in the ICU uses this team approach, taking into account the nature of the injury, the context of the person's life before the injury, and reasonable rehabilitation goals set after the acute care hospitalization.

This patient was visited in the ICU by military personnel who had had leg amputations, had gone through successful rehabilitation, and had become fully independent vocationally and socially. Having peer visitation from amputees in the acute care setting was uplifting and inspiring to the patient beyond any encouragement provided by therapists or physicians.

The patient was frustrated at times and greatly limited in functioning because of pain, but several times he expressed feelings of relief for being alive. Psychological adjustment to his injuries in the context of the bombing was complicated, with anger and acute stress reactions occurring together with grief for the amputated leg. Preparing this patient for daily physical and psychological rehabilitation at an inpatient rehabilitation facility was important for the next step in his recovery.

During a period of 45 days at this hospital, the patient underwent 15 operations for débridement of wounds, orthopedic fixations, and changes in the vacuum-assisted dressings for the wounds. He was discharged to Spaulding Rehabilitation Hospital, where he spent nearly 2 months and had 5 more operations, mostly for reconstructive surgery related to the burns.

On arrival at Spaulding, he required assistance with bathing and dressing himself and had not yet attempted standing or walking. Intensive physical, occupational, and speech therapy (specifically for high-level cognitive assessment and treatment after a blast injury) occurred daily.

Around-the-clock support was provided by his family and friends. He was discharged home on the 100th day after his injury, able to independently handle all his daily needs and walk with crutches. As the patient continues to recover, additional issues remain, including management of chronic pain and wounds, fitting of his leg prosthesis, and gait training for independent ambulation.

Dr. Eikermann: You have now heard eight of us speak about this patient's care, but there were, of course, countless other professionals who were involved. We would like to thank them all. I'll invite the patient to say a few words.

The Patient: Thank you for inviting me to be here. You all are amazing, and if it weren't for what you did and can do, I wouldn't be here. Three things stand out in my memory. First, just being personable makes a huge difference in a person's recovery. Every time I went for an operation, the anesthesia team and all the nurses who were preparing me were amazing. Second, my family and I always felt included in every discussion with the doctors. I enjoyed being included, and my family was grateful that everybody included them and filled them in. My fiancée could understand what was going on, because she's a nurse. But Dr. Velmahos talked to my father every day, which really helped make my father feel like he knew what was going on.

Finally, the pain. When I first woke up after surgery, the pain was really bad, and I was on a lot of medications that affected my thinking. A lot of people kept trying to solve my pain issues, and they didn't give up. Finally, they gave me an epidural, and it made all the difference in the world to me. I could actually remember what happened, I could talk, I could communicate with my family and my friends; I wasn't so medicated, but the pain went away.

Dr. Paul C. Shellito (Surgery): Dr. Velmahos, this patient had a tourniquet placed at the site of the bombing. In a nonmilitary setting, tourniquets can be ineffective, or worse. What is your opinion or recommendation about tourniquets that are placed by bystanders in a nonmilitary context?

Dr. Velmahos: The major risk is that a tourniquet, if not tight enough, can exacerbate bleeding because it stops venous return without stopping arterial output. Dr. King, do you have anything to add?

Dr. David R. King (Surgery): Although it is possible to improvise an effective arterial tourniquet, a windlass or other device is required for leverage. The problem is that most people don't know how to do that. Simply knotting a shirt around a limb is universally ineffective. We don't want to discourage bystanders from helping the injured, but probably the best thing an untrained bystander can do for a traumatic amputation is pack the wound tightly.

Dr. Keith D. Lillemoe (Surgery): Dr. Fagan, we heard a lot about orthopedic injuries and amputations in the news, but burns weren't emphasized so much. Did all the patients have burns of this magnitude? Were patients with burns selectively sent to burn centers, or were some patients transferred to this burn center later?

Dr. Fagan: Patients were distributed evenly throughout the Boston area, regardless of the nature of the injuries. Many patients had burns, and consistent with the military's experience with IEDs, burns made up approximately 20% of the injuries. Many patients found their way to our outpatient center in the 2 or 3 weeks after the event, for the definitive care of their burns, which was similar to the situation after the 2003 Rhode Island nightclub fire. This patient had the most severe burns of the patients that I treated — 50% of his burns were third-degree or fourth-degree burns that required operative intervention.

Dr. Susan Briggs (Surgery): With regard to the question about prehospital triage — field triage simply divides acute from nonacute cases. It does not take into account the actual nature of the injuries — that is medical triage, which is done at the hospital. Most of the Boston hospitals received an equal number of victims because of field triage, which was very effective.

A measure of the medical response to an event such as this bombing is called the critical mortality rate in blast injuries. This number excludes people who die at the scene and considers those who reach hospitals and then subsequently die. I am happy to report that in Boston, the critical mortality rate after the Boston Marathon bombing was less than 1%, which I think is a testament to the effectiveness of our multidisciplinary teams.

Dr. Eikermann: I have a question for the patient. You have spoken about how happy you were with the care you received, but we are an academic institution, so what could we learn from you that we could improve on?

The Patient: I can't think of anything, except maybe the food.

This case was discussed at Combined Surgery and Anesthesia Grand Rounds.

Dr. Kwon reports receiving consulting fees from Trimed. No other 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.

Dr. Abbara is currently at the University of Texas Southwestern Medical Center, Dallas.

We thank Dr. Michael T. Lu (Radiology), who presented the radiology studies at the conference in Dr. Abbara's absence; Dr. Jeffrey C. Schneider (Physical Medicine and Rehabilitation), who cared for the patient during inpatient rehabilitation and provided acute rehabilitation outcomes; Dr. Brian Yun (Emergency Medicine), who helped with the preparation of the case history; Dr. Walter Dzik (Blood Transfusion Service), who helped with organizing the conference; and to countless other colleagues on acute care therapy teams and in Emergency Medicine, Surgery, Burns, Anesthesia, Critical Care, Pain Medicine, Cardiology, Transfusion Medicine, Pathology, and Psychiatry, among others, and colleagues in Physical Medicine and Rehabilitation and Physical and Speech Therapy at Spaulding Rehabilitation Hospital, who contributed to this patient's care.

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