SPECIAL TOPIC

Plastic Surgeons and the Management of Trauma: From the JFK Assassination to the Boston Marathon Bombing

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Summary: The fiftieth anniversary of the death by assassination of President John Kennedy is an opportunity to pay homage to his memory and also reflect on the important role plastic surgeons have played in the management of trauma. That reflection included a hypothetical scenario, a discussion of the surgical treatment of Kennedy (if he survived) and Governor Connally. The scenario describes the management of cranioplasty in the presence of scalp soft-tissue contracture, reconstruction of the proximal trachea, reconstitution of the abdominal wall, and restoration of a combined radius and soft-tissue defect. The development of diagnostic and therapeutic advances over the past 50 years in the care of maxillofacial trauma is described, including the evolution of imaging, timing of surgery, and operative techniques. Finally, contemporary measures of triage in situations involving mass casualties, as in the Boston Marathon bombings, complete the dedication to President Kennedy. (*Plast. Reconstr. Surg.* 132: 1330, 2013.)

Attending college, without the right to vote, I had little or no interest in national politics (or state or local, for that matter). In the fall of 1960, John Kennedy arrived in Dayton to give a morning campaign speech from the courthouse steps. Cutting classes, I zigzagged through the crowd to watch and hear Kennedy speak to everyone, regardless of age, race, religion, or gender. That speech crystallized his appeal and the potential that went, for the most part, unrealized and terminated by the tragic events on November 22, 1963, just 3 short years after his election. His accomplishments, though, were considerable: the launch of the Peace Corps; a stand-down of the Soviet Union with the Cuban missile crisis; and insistence on the passage of civil rights legislation, to name several. To this day, his favorable public opinion ratings remain high.

The following three pieces are dedicated to his memory: a scenario centered on the injuries, illustrating the progress in the plastic surgeon's management of trauma; a similar discussion focusing on maxillofacial trauma; and a description of the evolution of trauma triage, employing as an example the recent bombing at the Boston Marathon.

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Received for publication June 10, 2013; accepted July 26, 2013.

DOI: 10.1097/PRS.0b013e3182a7094c

ASSASSINATION OF PRESIDENT JOHN F. KENNEDY

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The injuries sustained by President Kennedy and Governor Connally can serve as a conceptual launching point for discussion of the contemporary role of the plastic surgeon in the management of trauma. To do so comprehensively would necessitate an assumption that in addition to Governor Connally, President Kennedy also survived. That discussion framework should not and does not imply disrespect to the memories of JFK, and therefore the two, Kennedy and Connally, will be referenced as victim 1 and victim 2.

Acute Phase

Victim 1

An emergent tracheostomy was placed in the distal cervical trachea, the proximal three to four

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

rings destroyed by the exit of the missile that had penetrated the upper back. Simultaneously, resuscitation was begun with large volumes of crystalloid. Once the victim was resuscitated, neurosurgical débridement of cerebral substance, dura, and skull fragments was accomplished. All bone fragments were salvaged, and an additional craniectomy was performed to accomplish brain decompression. All bone fragments recovered at the scene were salvaged and stored within the tissue bank.

Victim 2

The patient was intubated, resuscitation was initiated, and a tube thoracostomy was placed within the penetrating wound of the right thoracic cavity. An exit wound in the right upper quadrant of the abdomen (actually, Connally's truncal wounds were entirely intrathoracic) mandated an exploratory laparotomy. A through-and-through wound of the lateral aspect of the right lobe of the liver and third portion of the duodenum was addressed with débridement and primary repair of the duodenum. In addition, the abdomen was packed open because of massive transfusion and fluid requirements, development of hypothermia, and hypocoagulability. Forty-eight hours later, the patient was returned to the operating room, where the packing was removed and Vicryl mesh (Ethicon, Somerville, N.J.) was placed. Negative pressure wound therapy was initiated. The right upper extremity sustained a penetrating injury to the dorsum of the wrist, a badly comminuted fracture of the distal radius with obvious bone loss, and soft-tissue loss of the radial-volar aspect of the wrist.

The acute management of the upper-extremity injury could be accomplished coincidently with the operation to repair the truncal injuries, if the patient's general condition permits, and if not, as soon as feasible with no delay. The challenge, therefore, is the initiation of temporizing measures until definitive repair. Those measures would consist of application of an external fixator, pins placed in the second metacarpal distally and the stump of the radius proximally, removal of all devitalized bone and débridement of necrotic soft tissue, placement of an antibiotic-impregnated spacer within the bony dead space, skin coverage with fenestrated Integra (Life Sciences, Plainsboro, N.J.), and placement of the wound in negative pressure wound therapy.

Stabilization Phase

Victim 1

One month post after, the patient was on an oral diet with a tracheostomy in place. The patient was returned to the operating room, and the craniectomy bone flap and salvaged bone fragments were replaced and stabilized by means of low-profile plates and screws. The postoperative course, though, was marked by purulent drainage, necessitating removal of the bone flap and fragments. Wound healing was obtained, and the plastic surgery department was consulted. The problem list for victim 1 (patient 1) consisted of the following:

1. Large parieto-temporal skull defect with contracted scalp/soft tissue.
2. Proximal four-ring tracheal defect.
3. Contracted soft tissue of the anterior neck.

Victim 2

After 2 weeks with a vacuum-assisted closure or negative pressure wound therapy dressing change every 2 or 3 days, the presence of a granulating surface over the exposed intraabdominal contents was closed with split-thickness skin grafts. The patient was extubated, and parenteral nutrition was replaced with oral feedings. The plastic surgery department was consulted. The problem list for victim 2 (patient 2) consisted of the following:

1. Large ventral hernia with intraabdominal contents covered with split-thickness skin grafts.
2. Open wound of the distal forearm-wrist with a 6-cm segmental defect of the radius.

Plastic Surgical Management

Patient 1

Decompressive craniectomy, the excision of a large component of the calvaria to allow expansion of the swollen brain, is frequently employed in massive head trauma.[1] The efficacy may be debatable, and the occurrence of the undesirable sequelae of bone absorption or infection (as in our scenario) is not uncommon—a circumstance that is perhaps not totally unexpected since the resected bone, although autologous, has been frozen and stored. If the replaced craniectomy bone flap must be subsequently removed for infection and an obligatory hiatus before cranioplasty is performed, then the inevitable contraction of the scalp and soft-tissue envelope will need to be addressed as well. As a result, a staged approach to cranioplasty may be mandated. The first step of such a sequence is placement of tissue expanders, followed by serial expansion and then definitive cranioplasty[2] (Fig. 1). Because the magnitude of the bony defect is large in these instances of decompressive craniectomy attended by infection of the replaced bone flap, alloplastic cranioplasty rather

Fig. 1. (*Above* and *center*) Patient with craniectomy defect. (*Below*) Computed tomography scan of the patient.

than autologous bone grafting (rib, ilium) may be performed. Because the size of the defect is also beyond repair with bone substitutes,[3] the choice remains among several other materials (including titanium, titanium-Medpor (Stryker, Kalamazoo, Mich.) combination, polyethylene derivatives alone, and methylmethacrylate), each with a set of benefits and liabilities.[4] Some (porous polyethylene alloplastic reconstruction material, titanium) can be designed and manufactured with the aid of computed tomographic scan data, also known as computer-assisted design and manufacture.[5]

The replacement of the missing tracheal segment is a reconstructive challenge, particularly when combined with deficiency of the overlying skin–soft tissue, as is the case with this patient. The reconstructive demands are for lining, a rigid framework, and coverage.[6] A couple of possibilities exist on the reconstructive landscape. The first of these is the use of a radial forearm, with a portion of the radius for the rigid construct[7]; second, another allograft transplantation with immunosuppression,[8] probably not recommended for this patient; and third, tissue engineering of both epithelial lining and soft tissue, with incorporated cartilaginous framework for stability.[9] Coverage of the skin and soft-tissue defect resultant after release of the contracture could be performed with a pedicled supraclavicular island flap.[10]

Patient 2

Management of the open abdomen by a staged approach of packing, Vicryl mesh, vacuum-assisted closure, and skin closure with split-thickness skin grafts over the resultant granulation tissue culminates in the production of a large ventral hernia.[11] Unless a substantial loss of the abdominal wall attended the original insult, a delayed reconstitution of both the musculofascial component and full-thickness skin–soft tissue is possible. Timing hinges on maturation of the skin graft, as indicated by easy pliability when pinched and retracted, usually in a minimum of 4 to 6 months[12] (Fig. 2). Once it is judged to be mature, the skin graft is excised and repair is accomplished with a separation of components approach,[13] with or without mesh reinforcement placed in a retrorectus position in an inlay technique. If any degree of contamination is noted, such as the presence of a stoma, or if the mesh is in contact with the intraabdominal viscera, then the use of bioprosthetic mesh is indicated. Because of direct tissue ingrowth, placement of synthetic mesh in direct contact with the viscera has an element of transmural[12] bacterial contamination and a higher potential for infected mesh and enterocutaneous fistula.

Although definitive reconstruction of the abdominal wall can be safely and appropriately deferred for months after injury, address of the soft tissue and bony defect of the distal forearm and wrist is of considerable urgency. Failure to address it will result in wrist collapse and progressive radial deviation, not unlike a congenital

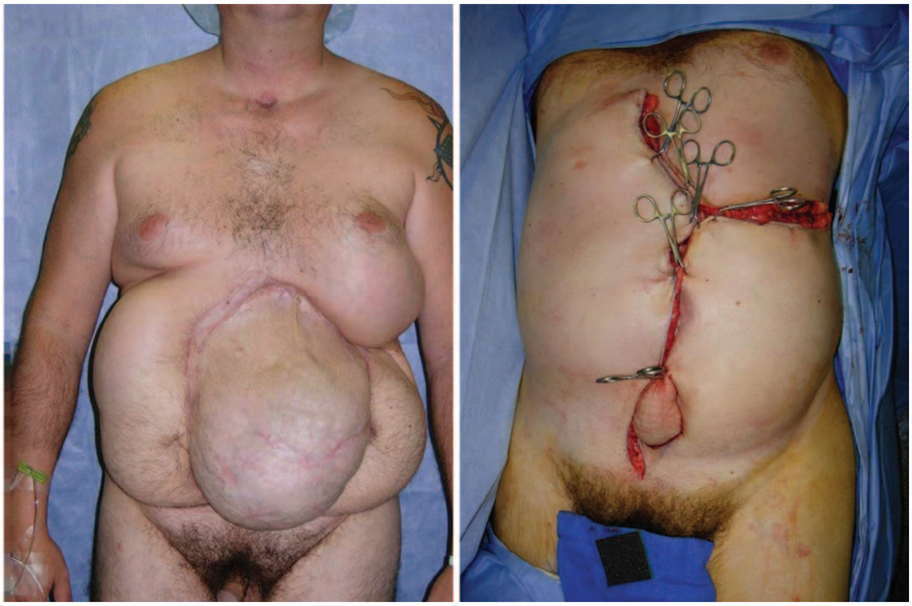

Fig. 2. Posttraumatic ventral hernia.

radial club hand. Given the magnitude of the segmental loss of the radius, 6 cm, and the associated soft-tissue deficiency, free flap transfer of vascularized bone with soft tissue, an osteocutaneous flap, would be the optimal choice. In the posttrauma setting, assessment of the vascular status is essential, because in all likelihood the radial artery has been damaged and lost to use, at least distally, as a recipient vessel. Contemporary computed tomography scanners (multirow detectors) can perform high-quality angiography for visualization of the vessels in the proximal and middle forearm.[14] The reconstructive workhorse in this scenario would be the fibula free flap, although a scapular flap would yield sufficient soft tissue and bone stock and, with adequate preoperative planning, might not require intraoperative position change.

In summary, two victims sustained massive trauma as a result of penetrating injuries from high-velocity missiles. The methods employed by the trauma team, including the plastic surgeon, in the depicted hypothetical scenario (Table 1, by no means exhaustive in scope)were *all* developed since the tragic events of November 22, 1963. Many were developed by plastic surgeons, a fact that serves as a tribute to the integral role that plastic surgery has played in the care of trauma patients.

Table 1. Innovations in Surgery Since 1963

Decompressive craniectomy
Vicryl mesh
Negative pressure wound therapy (vacuum-assisted closure)*
External fixation
Bone spacer
Integra
Bone plates/screws*
Parenteral nutrition
Titanium
Alloplastic reconstruction with computer-assisted design/manufacturing*
Separation components repair of abdominal wall*
Free tissue transfer*

*Innovations developed by plastic surgeons.

EVOLUTION OF THE CARE OF MAXILLOFACIAL TRAUMA

—Larry H. Hollier, Jr., M.D.

The experience of a patient arriving to the emergency room with severe facial trauma is very different today than it was 50 years ago. To begin with, today the patient is more likely to make it to the emergency room alive. The advents of hypotensive resuscitative techniques have improved survival in the transport phase.[15] The plastic surgeon is also much more likely to be involved in the care of the severely injured patients. With the advancements in microvascular surgery, hand surgery, wound care, and craniofacial techniques, we are the go-to experts in most of these areas.

On arrival, as with any trauma patient, airway breathing and circulation are established. Today, patients are much less likely to receive a tracheotomy at the outset for severe facial trauma. Endotracheal intubation is preferred in the vast majority of these cases. However, one must be cognizant of penetrating injuries involving the floor of the mouth. The muscles of the tongue base are prone to massive swelling in such cases, which can result in difficulty in airway management if a tracheotomy has not been placed.

Following arrival, accurate diagnosis is critical. This was very difficult 50 years ago. The standard of care at the time was plain radiographs. Most patients were subjected to a facial series of radiographs, taken after the head was placed in various positions to accentuate different bone contours. The Waters, Townes, and Caldwell were all among the various views. Although step-offs could sometimes be appreciated, the severity of the displacement in three dimensions was very difficult to assess. Subsequent use of tomography helped somewhat. This was done by moving the x-ray machine and plate relative to the patient while taking a series of images on one film.[16] This method created a certain spatial depth to the radiograph. This was a precursor to our modern computed tomographic scanner. First introduced clinically in the Mayo Clinic in the early 1970s and more broadly throughout the 1980s, it gained widespread use. Early machines, however, were slow and frequently had technical problems that shut them down periodically. Current technology for a facial trauma patient often involves a spiral computed tomography scan, which takes mere seconds.[17] The data can then be reconfigured to a simulated three-dimensional representation, something that is very helpful in the more complex panfacial injuries.[18]

Once an accurate diagnosis has been made, timing of surgery becomes a question. In the 1960s, there was a tendency toward more conservative or closed management of facial fractures. This was due in part to the difficulty in diagnosis but also to limitations in surgical techniques and hardware. In many cases, the patient would be brought to the operating room to address life-threatening thoracic or intraabdominal injuries, and care of the facial trauma would be deferred to a later date. Currently, plastic surgery principles dictate that much of the treatment be provided immediately following these general surgical maneuvers. Although not all facial fractures require or should have surgical intervention immediately upon presentation, there is a general appreciation now that overly long delays are detrimental to the patient's outcome.[19] Certainly, in most penetrating injuries with soft-tissue involvement, immediate wash out, débridement, and repositioning of some fracture fragments are generally performed.

With respect to specific injuries, perhaps nothing better demonstrates the advances in care of facial trauma than mandible fractures. In the first edition of Grabb & Smith's textbook on plastic surgery in 1968, there are only three paragraphs on the treatment of mandibular fractures.[20] The only technique of open reduction discussed advocates using 25-gauge stainless steel wire on the bone fragments as an adjunct to intermaxillary fixation for 4 to 5 weeks. In most mandible fractures at the time, closed treatment with intermaxillary fixation alone was typically used. Currently, open reduction and internal fixation are felt to be the standard of care in the vast majority of mandible fractures. Although the technology for internal fixation was first developed in the 1950s and 1960s in Switzerland, largely by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) group for lower-extremity fractures in skiers, it was not until the 1970s that technology had advanced enough to create systems of hardware applicable to the facial skeleton.[21–24] Initially these were made of stainless steel and were quite large, because it was believed that rigid stability was required for the healing of facial fractures. The fact that most of these fractures healed with the use of wire fixation alone should have told surgeons otherwise. In the past 20 years, there has been a trend toward smaller load-sharing fixation. Technology has also moved from stainless steel to lighter, stronger titanium alloys and, in some cases, plates and screws made of resorbing polymers, particularly in the pediatric population.[25]

In the 1960s, midfacial fractures were also typically handled using wire. Suspension wires anchored to cephalic stable points such as the zygoma were also used in severe cases.[26] Unfortunately, this often resulted in midface shortening and retrusion. In the most severe cases, external fixators were sometimes used. These were secured to a plaster head cap with vertical bars extending inferiorly. In current practice, most midfacial injuries are treated open with miniplate fixation. External fixators are currently used in only the most severe mandibular injuries. Orbital injuries were and continue to be some of the most challenging facial injuries.

Concerns over vision and appearance are paramount in these situations. The difficulty facing surgeons 50 years ago was in both diagnosis and treatment. Accurate assessment of the severity of orbital fractures using only plain radiographs is essentially impossible. Technically, the injury is also difficult to treat, because wiring of the small fragments is typically not possible. Into the 1960s and 1970s, packing the maxillary antrum to support the healing of the orbital floor remained quite popular.[27] Subsequently, bone grafting was increasingly used, partly owing to the pioneering work of Paul Tessier in the late 1970s and 1980s. Currently, the vast majority of these patients undergo alloplastic reconstruction of the floor with material such as titanium or high-density porous polyethylene. This work is facilitated in some cases now by intraoperative imaging. Current technology has brought computed tomography into the operating room, allowing scanning immediately after placement of hardware to check positioning. In the most severe cases, intraoperative navigation is also possible. Preoperative computed tomography scan data can be entered into the system, allowing the surgeon to navigate in real time the depths of the orbit to get a sense for reduction and placement of fixation.

Clearly, the average patient presenting with facial trauma today can expect a quite different experience in comparison with 50 years ago. The advances in technology and techniques have improved our results and minimized morbidity. The real question for most surgeons involved in the treatment of craniofacial injuries is what advances to expect in the future. Fixation research has increasingly focused on increasing the speed and ease of application, looking very carefully at bone glues rather than permanent implants. A great deal of work is currently being done on bone replacement as well. Bone morphogenic proteins and bone substitutes are gaining in popularity and application. One might expect that 50 years from today, a patient presenting to the emergency room will marvel at how rudimentary our care was today.

THE BOSTON MARATHON BOMBINGS AND MASS CASUALTY RESPONSE

—Samuel J. Lin, M.D.

Time seems to stand still in the middle of a catastrophic event, either manmade or natural. In the wake of the explosions at the Boston Marathon, we are once again reminded of how fickle life can be. Were it not for the efficiency of multitudes of emergency medical services present at the site, perhaps more lives would have been lost. Mass casualty events generate a large number of victims needing immediate medical attention, and the goal of an organized response is to maximize the number of lives saved; the process for allocating care should be clinically sound and transparent.[28] In this post–September 11th era, the emergency response in the United States has been raised to the level of national consciousness. Around the world, emergency services and hospital protocols are being reviewed and undergoing radical changes to respond to these types of events (such as the July 2005 London bombings).[29] Among numerous other changes, aside from the creation of national and state Departments of Homeland Security, comprehensive strategies have been organized and coordinated to efficiently use and distribute resources to both state and local authorities. Their purpose is to enhance preparedness and to prevent, protect, and recover from acts of terrorism. From driver license security to ammonium nitrate security to border security, all facets of potential security lapses are being examined.[30] As a result of mass casualty events occurring without warning, it is important that providers conform to crisis standards of care; indeed, hospital protocols include disaster drills for these occasions. The reality of the treatment of patients in a mass casualty event is a balancing act. There are patients who will do well with minimal treatment and patients who will not survive despite maximum efforts.[31] The key for the provider is to identify and to triage those patients who will benefit from early surgical intervention.[31] One of the main responses to a disaster situation is rapid evacuation of all casualties from the source of danger when there is potential for further explosions or collapse of surrounding structures. Another is reduction in mortality rate among those who are critically injured, through proper triage so as to avoid inappropriate assignment of constrained resources and allow for proper management.[31,32] Medical resources should be allocated in an organized, equitable, clinically fair, transparent manner to reduce the number of lives lost.[28,33,34] Despite a proper understanding of these fundamental aims, however, overtriage has consistently occurred in previous terrorist bombing incidents. Overtriage occurs when patients with noncritical, non-life-threatening injuries receive immediate care in the setting of a mass casualty event; this might delay care for those who need it most urgently. In one review, the authors studied 220 mass casualty events due to terrorist bombings.[35] As such, a consensus should be established that clearly defines requirements for rapid scene clearance to reduce the occurrence of overtriage. Using a computer-based model, authors have defined quantitative relationships between increasing casualty load and surge capacity at receiving hospitals; the outcomes of this strategy will increase the rate at which casualties arrive at treating institutions, permitting proper use and allocation of resources and providing high-level trauma care.[36]

Fig. 3. Flow chart of all mass casualty patients being treated following the Boston Marathon bombings. Courtesy of Lydia Helliwell, M.D.

From a broader approach, authors have also analyzed caregiver response from mass casualty events associated with natural disasters, widespread infection, and manmade occurrences.[34] From this analysis, numerous plans have been promoted to aid in optimizing the response to a mass casualty event, including early discharge of patients from the intensive care unit, cancellation of elective admissions, meticulous use and reuse of resources, and obtaining resources from stockpiles.[34] Cohen et al. reported that plastic surgery involvement in a mass casualty blast showed a predictable pattern related to patient volume, on the basis of which guidelines might be formulated; the authors note distinct phases of plastic surgery involvement during these events.[37] The Centers for Disease Control and Prevention developed a national guideline called SALT (sort, assess, lifesaving interventions, treatment/transport), which aims to improve the efficiency of triage in mass casualty events; the authors note that the combination of the infrequency of mass casualty events for any given hospital and the lack of a standard measure for triage accuracy limits the ability to define a standard process of triage.[38] The national guideline was evaluated by Lerner et al., who found that it had a higher accuracy rate in comparison with other previously published systems and stated that providers found it easy to use.[39] Other triage systems have been described, such as JumpSTART [a pediatric multicasualty tool incorporating Simple Triage and Rapid Treatment (START) components]. Training of prehospital care personnel in this system for triage of pediatric patients also has resulted in significant performance improvements.[40]

Authors have suggested a theoretical optimal ratio of triage/treatment team members to casualties; using a computer model, Hirshberg et al. reported effective analysis of triage accuracy, suggesting that strategy can be used by hospitals to enhance their response to future threats and that an optimal team-to-casualty ratio can greatly improve triage and treatment.[41] Other modes of disaster preparation have included virtual reality training, war-gaming, and multi-manikin simulations to improve decision-making.[42,43] Nonetheless, though use of a computer model as well as other methods of simulating a disaster situation can prove useful, they are based on casualty arrival rates and flow through the trauma system without providing much knowledge on surge rates, which are important for future disaster planning. The surge capacity of a facility implies the ability to expand care capabilities in response to prolonged demand (e.g., increasing potential patient beds, available space in which patients may be triaged, available personnel of all types, medication, supplies, and legal capacity to deliver health care under situations that may exceed authorized capacity).[29,35,44,45] Authors have recommended a reverse triage strategy to expedite patient discharge, creating a surge capacity for victims and for rapid assessment of the need for continuing inpatient care. Reverse triage involves allocation of hospital resources to those most in need by safely discharging inpatients to facilities that are equipped to care for the less critically ill, such as public health contingency stations or nursing homes. In this study the authors did not find increased clinical risk for those patients who were discharged earlier and those whose planned admissions were cancelled.[46]

It is a tragic irony that the Office of Emergency Management of New York City was based at the World Trade Center complex, with its communication based on One World Trade Center's antennae.[47] One of the most important factors contributing to successful crisis management is adequate communication and coordination; the lack of communication may result in large-scale panic.[47] All members of a hospital have important roles in mass casualty events. During these rare events, the use of case managers has been shown to enhance the efficiency of workup/treatment times and use of resources, thus raising surge capacity. Furthermore, they help to advance patient care by increasing personal accountability, being involved in treatment decisions, and ensuring continuity of care.[48] Delaying nonurgent computed tomography scans and limiting the use of blood typing and cross-matching has also served to save on resources and provide adequate patient care.[29] Authors have suggested the use of focused assessment with sonography for trauma as a triage tool, to aid in management at a lower cost than laparotomy and computed tomography and with more accuracy than clinical observation; analysis of this tool showed sensitivity, specificity, and accuracy of 75 percent, 97.6 percent, and 93.1 percent, respectively.[49]

There are many lessons to be learned from past mass casualty incidents around the world. Boston will never be the same after the events of the 2013 Boston Marathon. For any given hospital, the low likelihood of a mass casualty event and the lack of accepted measures of triage and treatment outcomes have slowed a widespread acceptance of protocol. A consensus has not yet been established to adequately inform providers and policymakers about the best strategies for management of resources during mass casualty events.[34]

The primary goals in the response to a disaster must be proper evacuation of all casualties from the scene of the incident as well as proper and efficient triage in an attempt to reduce the number of critically injured victims and lower the mortality rate. Explicit control of patient flow and proper resource use in the hospital setting will also save lives (Fig. 3). In Boston, the local authorities, the general public, and the surrounding hospitals reacted with utmost competence, implementing lessons learned from past events. In the aftermath of the tragedy, this is a city that continues to heal but is proud in the knowledge that those who could be saved indeed were treated expeditiously. With our colleagues in law enforcement, emergency medical services, and other surgical specialties, plastic surgeons from each medical center and hospital responded immediately and admirably.

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PATIENT CONSENT

The patient provided written consent for the use of her images.

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