Blunt and Penetrating Cardiac Trauma

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KEYWORDS

• Cardiac trauma • Blunt cardiac injury • Penetrating cardiac injury • Cardiac box

KEY POINTS

- Blunt cardiac injury diagnosis requires a high index of suspicion. Treatment is supportive care in almost all instances.
- Penetrating cardiac injuries are highly lethal. The 3-dimensional cardiac box defines anatomic areas that are at highest risk of underlying cardiac wounds.
- Treatment of penetrating cardiac injuries requires emergent surgical intervention. Cardiac surgical support, including cardiopulmonary bypass, may be required.

BLUNT CARDIAC INJURY

The earliest reports of nonpenetrating cardiac injury date back to the seventeenth century; however, the first successful repair would not take place until 4 centuries later.[1] Blunt cardiac injury (BCI) is a challenging clinical entity to fully understand. This challenge is due to a lack of clear diagnostic criteria and further complicated by a lack of a uniform grading system. The American Association for the Surgery of Trauma (AAST) has created an injury scale to define BCI.[2] By the admission of the AAST, this grading is limited by the spectrum of injuries and lack of diagnostic test. Although this grading scale provides some language to discuss these injuries, there is no large-scale validation of this system against mortality.

The best evidence within the body of literature cites an incidence of BCI between 3% and 76% of trauma patients.[3] It may cause as many as 20% of motor vehicle collision–related deaths.[2] Minor injuries may be asymptomatic. Severe injury can manifest as a highly morbid constellation of symptoms making the true incidence impossible to quantify. Autopsy reports suggest that severe cardiac injury may carry a prehospital mortality as high as 95%.[4] The population of patients that survive to hospitalization

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can be divided into 3 groups: (1) hemodynamically stable patients with conduction abnormalities, (2) hemodynamically unstable patients with isolated conduction abnormalities, or (3) those with conduction abnormalities and structural defects.[5,6]

EVALUATION

During the initial evaluation of the injured patient, recognition of a pattern of injuries or symptoms at high risk for BCI is critical but challenging, and the clinician must maintain a high index of suspicion in any patient sustaining chest trauma. Physical examination may demonstrate a "seat-belt sign," subcutaneous emphysema, or obvious deformity of the chest wall.[7] It should not be interpreted that these findings necessarily mandate workup, but rather should be part of the astute clinician's overall gestalt in deciding which patients need further evaluation (Fig. 1). Unfortunately, significant physical examination findings may be absent in a patient with severe BCI, and the clinician must remain vigilant in monitoring their patient's physiologic progression. The difficulty with studying BCI is that there is no clear diagnostic test. This creates significant heterogeneity within the literature.

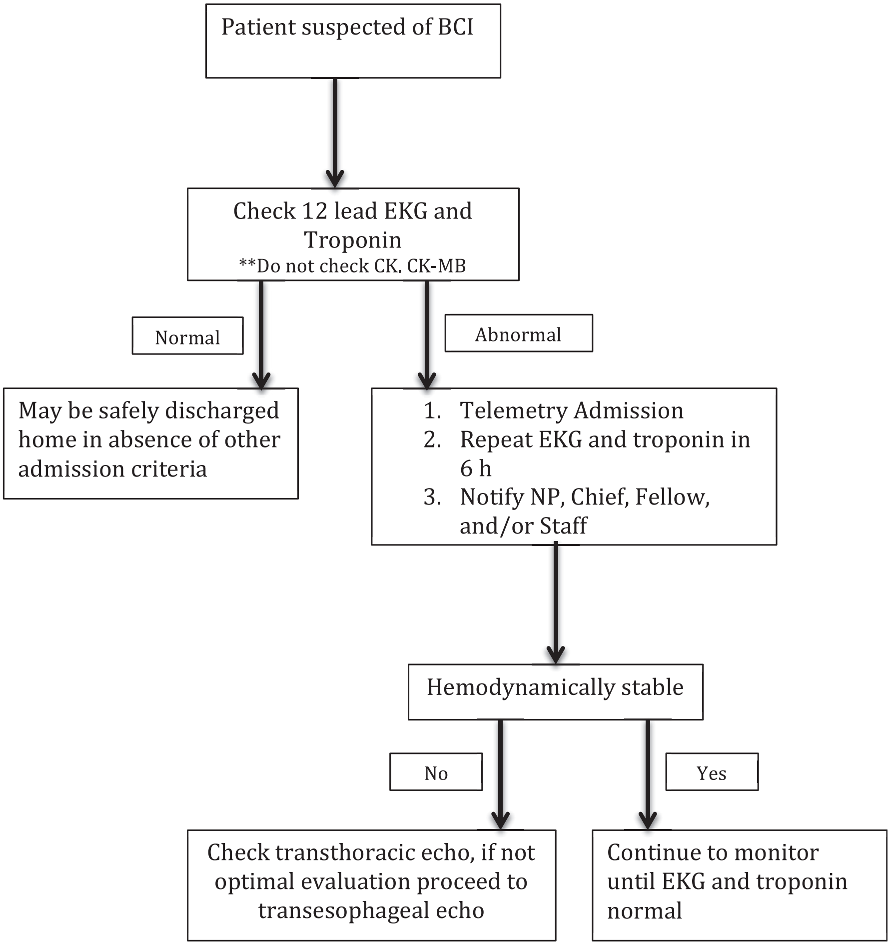

Fig. 1. Suggested protocol for workup for BCI. NP, nurse practitioner.

The most essential screening component in the workup of the patient with suspected BCI is an electrocardiogram (EKG). When performed serially, the sensitivity is reported as high as 89%. The negative predictive value (NPV) of EKG in identifying BCI approaches 98%.[8,9] Discussion remains within the literature that an NPV of 98% may preclude the use of further testing. Nevertheless, with the wide availability of troponin I testing (discussed later), the recommendation remains that EKG should not be used as the sole screening modality.[10]

There is a wide spectrum of electrical disturbances identified on screening EKG. Most studies eliminate sinus bradycardia and tachycardia as being abnormal because of the wide spectrum of causes that may lead to their development in the multiply injured patient.[8] The most common abnormalities identified on EKG are right bundle branch blocks.[11] This abnormality is presumably due to the anterior position of the right heart and its subsequent susceptibility to injury. Of note, it cannot be assumed that all EKG abnormalities will not require treatment. Approximately one-quarter to one-third of all patients with BCI require some intervention, whether chemical or otherwise, for arrhythmia.[9,12]

With the identification of assays for cardiac troponin I (cTnI), the specificity of biochemical assays has improved over creatine kinase (CK), although the sensitivity remains poor.[3,13] The sensitivity of cTnI for significant BCI is 23%. In concert with findings on the EKG, the use of cTnI is synergistic. The sensitivity decreases as the threshold defining "elevated" increases. When defined as greater than 0.1 ng/mL, cTnI only identifies an injury in approximately 8% of cases at presentation and 24% at 24 hours.[14] The troponin T is only slightly better at 10% at presentation and 24% at 24 hours. These data were later confirmed, suggesting that sensitivities of cTnI and T were 23% and 12%, respectively.[9] Regardless, significant cardiac injury can be ruled out within 8 hours of presentation in the setting of normal EKG and cTnI, because this combination has a 100% NPV for significant cardiac injury.[9] These data would suggest that in the setting of significant blunt chest trauma after the initial EKG and serial cTnI need only be checked for 8 hours. If normal, the patient can be safely discharged in the absence of other indications for admission. Although cTnI may be elevated more than 36 hours after injury, there appears to be no benefit in checking serially if the overall trend is downward. After multiple sources demonstrated very little predictive value in terms of actual cardiac injury, the use of CK in BCI has fallen out of favor.[3,13,14] In addition, CK-MB was noted to be elevated in patients with only isolated extremity injuries, bringing into question its utility in polytrauma at all.[14] The current body of literature does not support the use of CK in the evaluation of BCI.

Hemodynamically stable patients with normal EKG and cTnI need no further workup. Those with ongoing arrhythmia or hemodynamic instability after resuscitation or those with elevated troponin require further workup. The use of transthoracic echocardiography is useful in determining structural abnormalities or wall motion defects. The difficulty with transthoracic echocardiography is that it may prove technically difficult or impossible to obtain optimal images in the setting of significant blunt trauma. If so, the use of transesophageal echocardiography can be used successfully, when available.

The use of multidetector computed tomographic (CT) scanners has revolutionized the decision making in the acute trauma setting. Although highly accurate for identification of most osseous and nonosseous injuries, the cardiac motion limits the ability to identify BCI on the initial "traumagram." It may be useful in revealing pericardial effusions, or even pericardial rupture. Traditional dogma is that sternal fractures may necessitate workup for BCI. However, there currently is no indication for workup of

BCI after sternal fracture in the absence of other clinical indicators.[12,15] In fact, there are no radiographic findings that should prompt workup for BCI.

The EKG-gated CT scan, timed by concurrent use of EKG to capture images of the heart without motion artifact, is useful in identifying structural injuries to the heart or differentiating between myocardial infarction and BCI.[16,17] MRI of the heart in a gated fashion is also described and may provide valuable insight regarding diagnostic challenges of acute myocardial infarction or BCI. There is no clear literature to suggest superiority of CT over MRI; however, the speed and accessibility of CT make it likely the favored choice.

TREATMENT

The mainstay of BCI management is supportive care. Vasopressors and inotropes are needed on occasion to support patients through the initial period of myocardial stunning resulting from the injury itself. Surgical intervention is extremely rare. The role of surgery in BCI should be restricted to patients with structural abnormalities, that is, ruptured papillary muscle, valvular abnormalities, cardiac rupture or, more commonly, diagnosis and treatment of pericardial effusions. Patients with pericardial effusions identified on a FAST (focused abdominal with sonogram For trauma) examination in the trauma bay should proceed expeditiously to the operative theater for a subxiphoid pericardial window. The patient should be prepared for the possibility of extending the incision into a formal median sternotomy should the pericardial fluid return sanguineous. It is incumbent on the trauma surgeon to maintain open communication with anesthesia team, such that induction of anesthesia does not occur before the arrival of the surgical team and completion of the standard preoperative preparation and draping. A pericardial window is favored over traditional pericardiocentesis because the latter has a false negative rate as high as 80%.[2] Surgeons proceeding to operative intervention on a presumed BCI should be clear that cardiopulmonary bypass might be necessary in the setting of significant intracardiac injury. Early consultation with cardiac surgery and mobilization of a perfusion team should be initiated in these circumstances. Should a hemodynamically significant lesion be identified, surgical intervention is associated with poor outcomes for atrial or ventricular injuries with mortality between 40% and 70%.[18–21] Mitral, tricuspid, and aortic valve abnormalities may have better outcomes than chamber injuries.[22–24] Pulmonary valve injury is the least commonly reported in the literature, but appears to present late and overall has good outcomes. Valve replacement is more common and generally has better outcomes than repair, although large randomized series are lacking.[25–27] It should also be noted that hemodynamically stable patients with valve injuries may be repaired in a delayed fashion, days or up to years later.

PENETRATING CARDIAC INJURY

History

Of the myriad injuries confronting the trauma surgeon, none may be more daunting than the patient presenting with a penetrating cardiac injury. Battlefield descriptions of injuries to the heart punctuate the Homerian epics as a novel graphic way into the pantheon of Mount Olympus.[28] As early as the first century BC anatomists and surgeons recognized the imminent and nearly universal fatality associated with these injuries.[29] By the nineteenth century, a few rogue surgeons began to experiment with suture repair of the heart in both human and experimental models. Although the early descriptions of these injuries demonstrate technically successful operations, inhospital mortality was extremely high. The earliest series of penetrating cardiac injuries corroborated the expected intraoperative and postoperative lethality of these injuries.[30]

Incidence

Contemporary series have shown a tremendous improvement in outcomes over the past centuries. A recent series from a high-volume center demonstrated that current mortality for penetrating cardiac injuries is approximately 40%,[31] mirroring the current body of literature with survival being reported between 19% and 73%.[32–37] Outcomes within individual centers may vary depending on available institutional resources, including cardiopulmonary bypass capabilities, massive transfusion protocols, and immediate availability of surgical staff.[38]

Secondarily, outcomes from penetrating cardiac injuries are related to the mechanism of injury. Over the last 2 decades, there has been a shift in frequency from knife-based “stab” injuries to gunshot wounds.[31,39] During the 1980s and 1990s, the number of stab wounds nearly doubled the number of gunshot wounds. This gap has closed in many urban centers in the new millennium. The prognostic difference between these injury types is not wholly unpredictable.

Between both mechanisms, the most frequently injured chamber of the heart is the right ventricle (RV).[31,40] This injury pattern has been consistent through history.[30] When combined with left ventricle injuries, ventricle injuries may represent up to 87% of all penetrating cardiac injuries.[31] The location of individual injuries may affect prognosis. RV injuries appear to have the best “to discharge” survival, at nearly 60%, whereas injuries to the right atrium are reportedly half.[34] These data are potentially biased by the difference in frequency of the 2 injuries, with some series demonstrating no difference in mortality.[32] Injury to more than one chamber is increasing with the increase in contemporary gun violence. Some series identify multichamber injury as both an independent predictor of mortality and a unique product of gunshot wounds.[31] Ballistic injuries, overall, are more lethal than stab wounds, and this may be due to the increase in multichamber injury.[31,34,36]

Diagnosis

Diagnosis should begin with physical examination. Penetrating wounds in the anatomic area known as the “cardiac box” should elicit highest levels of concern for penetrating cardiac injury. The “cardiac box” is an area of the anterior thorax bordered superiorly by the clavicles, inferiorly by the xiphoid, and the nipples laterally.[41] Recent literature has identified that corresponding lateral and posterior areas of the thorax are also associated with high rates of cardiac injury.[42] These data, along with the classic anatomic areas of concern, have led to the development of a more inclusive area defining possible injury. This “three-dimensional cardiac box” (**Fig. 2**) represents a modern structure for penetrating wounds that should be of highest concern for cardiac injury. Other clinical findings can suggest cardiac injury as well. Beck Triad of hypotension, jugular venous distention, and muffled heart sounds constitutes the classic clinical presentation of pericardial tamponade. The findings of Beck’s Triad should be considered within the context of a complete workup, as Demetriades[43] demonstrated that these findings may not be present in up to 25% of patients with cardiac injuries.

The increased use of ultrasonography has made early recognition of penetrating cardiac injuries obtainable, even in the prehospital setting. Pericardial tamponade identified preoperatively may be an independent risk factor for survivability of penetrating cardiac injuries.[44] In the trauma bay, the increased use of surgeon-led ultrasonography has led to a decrease in time to operating room for patients with pericardial

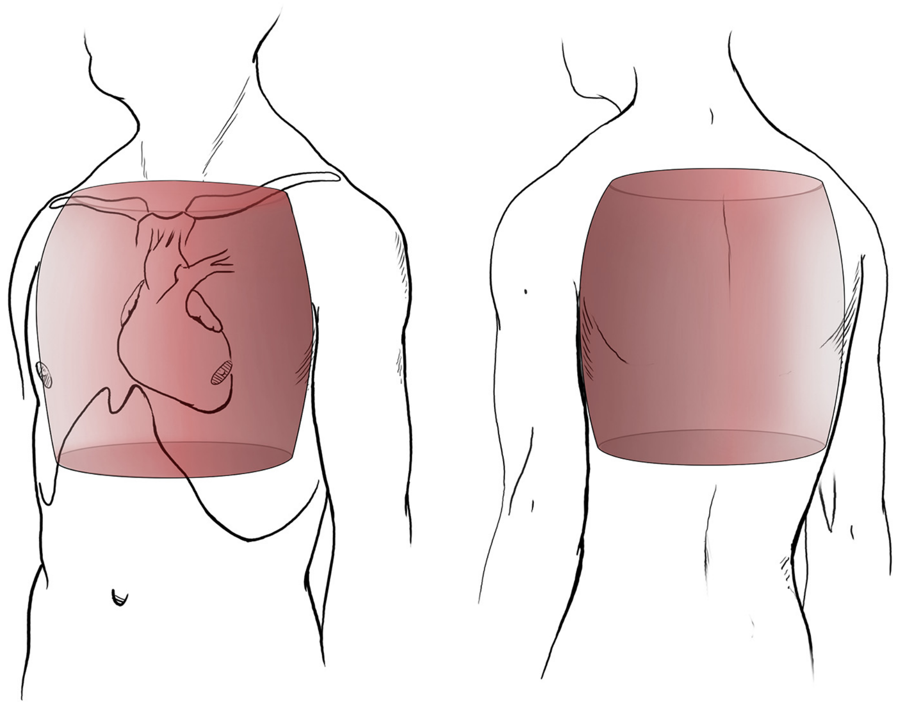

Fig. 2. The 3-dimensional cardiac box. Red gradient indicates likelihood of cardiac injury with brighter red being of higher degree of likelihood.

blood identified on ultrasound.[45] The use of ultrasound may have up to 100% sensitivity in experienced hands.[46] Ultrasound has use beyond identifying hemopericardium. It may also rule out risky operative procedures with narrow therapeutic benefit, like resuscitative thoracotomies.[36] The surgeon-ultrasonographer must always remain vigilant in the setting of penetrating cardiac injury because violation of the pericardium may allow necessitation of blood into the left or right hemithorax, leading to false negative results.[47] Historically, blind pericardiocentesis was performed to identify hemopericardium; however, this practice has largely been supplanted by ultrasound. Ultrasound has many advantages, including reproducibility, minimal false positive rate, and speed.

Chest radiography as part of a ballistic survey may allow some prognostic information of 2-compartment or transmediastinal injury and identify massive thoracic cage hemorrhage. In hemodynamically stable patients, proceeding to the CT scanner is also safe to identify trajectory and characterize potential injured structures.[48] The caveats of CT use in the evaluation of thoracoabdominal ballistic injury are the following: (1) there is no role for CT evaluation of patients that do not respond to resuscitation, (2) CT should not preclude transport of stable patients to a center that is better equipped to deal with cardiac injuries, (3) in the setting of an ultrasound positive pericardial effusion, the surgeon should not delay operative intervention to perform a CT scan. CT findings that correlate strongly with penetrating cardiac injury include primarily hemopericardium and pneumopericardium. Other more subtle findings that suggest cardiac injury include hemothorax with trajectory in close proximity to heart, retained ballistic fragments, hemomediastinum, or pneumomediastinum.[49]

Preoperative Care

As the identification of hemopericardium can be performed rapidly and reliably with minimal equipment, it is a logical conclusion that the envelope would be pushed further in the hope that early relief of tamponade may allow increased survival. This has led to the idea of early implementation of resuscitative thoracotomy in the prehospital setting in some areas of the world.[50,51] Vital signs on arrival to an emergency center are a strong predictor of outcomes in the penetrating cardiac injury. Presumably the restoration of vital signs as early as possible is the rationale for roadside operative intervention; however, this idea is largely disregarded in the America trauma literature, where the trauma system does not allow for a trauma surgeon in the prehospital setting.[40] In fact, patients that suffer cardiac arrest in the field have a survival of 0% in some studies, and even patients who arrest in the ambulance have dismal predicted survival. The window for potential salvage of patients undergoing resuscitative thoracotomy in the setting of penetrating thoracic trauma is approximately 15 minutes. Beyond that timeframe, the yield of performing resuscitative thoracotomy is less than 1.5%.[34,52,53] This is not to say that the performance of a resuscitative thoracotomy is a hopeless procedure. In fact, of all patients undergoing resuscitative thoracotomy, penetrating cardiac injuries portend the most favorable outcomes, with stab victims surviving neurologically intact between 15% and 50% of the time, and gunshot victims about half that.[52,54] These data have remained remarkably consistent over time.[53]

Intraoperative Care

What has not remained consistent is the management of exsanguinating hemorrhage. The advent of damage control surgery revolutionized the approach to the patient arriving in hemorrhagic shock due to injury.[55] However, techniques for damage control surgery to the chest may not be as familiar to the surgeon covering the trauma bay. In principle, the concept of damage control thoracic surgery is the same: abbreviated hemorrhage control followed by resuscitation and planned reoperation. In fact, the use of this technique in thoracic surgery is well accepted and safe.[56] Temporary packing of a thoracotomy or sternotomy wound as a temporizing measure should be performed when the injured patient enters into the triad of death: acidosis, coagulopathy, hypothermia.[56,57] Additional temporizing maneuvers for damage control cardiac surgery include the use of Foley balloon tamponade.[58] This technique however has fallen out of favor according to a contemporary panel of expert opinion.[57] Stapled cardiorrhaphy is another technique that permeates the surgical lore. This technique has proven safe and expeditious in both the preclinical setting and clinical setting for damage control of an exsanguinating cardiac laceration.[59–61] This technique may not be as useful in gunshot wounds with significant tissue loss. When faced with a lacerated coronary artery, suture ligation is a possible maneuver. The heart muscle must be subsequently observed for ischemia. If a focal area of muscle appears to be suffering compromise, the suture should be removed and finger occlusion applied until the necessary technical expertise can arrive. Although distal ligation is usually well tolerated, proximal narrowing or ligation will ultimately require revascularization.

In the setting of hemodynamic stability or after the successful completion of a damage control procedure, the next conundrum facing the trauma surgeon is definitive repair of penetrating cardiac injury. Most lacerations to the muscle of the heart can be repaired with simple interrupted monofilament suture with or without pledgets. When the injury is through or near a coronary vessel in a hemodynamically stable patient, the artery should be spared by placing mattress sutures underneath the bed of the artery using a polypropylene monofilament suture on a tapered needle. Complex injuries involving valves, multiple chambers, or the great vessels require cardiac surgery involvement.

Postoperative Care

In the postoperative period, management of penetrating cardiac injury should focus on the normal sequelae of cardiac operations. These sequelae may warrant echocardiography postoperatively to evaluate function.[31] The exact incidence of postoperative complications is unknown. Improved resuscitation practices, critical care, and trauma systems may have changed the patterns of postoperative complications after penetrating cardiac injuries. In the 1960s and 1970s, the University of Pennsylvania published a series of complications after cardiac repair.[62] The frequency of complication was nearly 50%, with ventricular septal defect (VSD) being the most common. In this series, the secondary lesion was picked up using a combination of EKG, echocardiography, and catheterization for patients with symptoms. The incidence of postoperative complications in a series out of Houston was nearly 30%. Again, patients with symptoms were worked up with echocardiogram and catheterization. The reoperative rate in this series was 20% of symptomatic patients and ~6% of patients surviving their injury.[63]

Because the nature of postoperative complications can likely be predicted based on the location of the injury, the recovery of patients in the intensive care unit should be focused on symptom management. Transient (~72 hour) symptomatic bradycardia and hypotension due to complete heart block are described and may necessitate temporary pacemaker placement.[64] This series also noted the relatively high incidence of VSD in survivors. Extrapolations of these data are difficult given the small number of cases in the series. Reports of complete heart block permeate the literature, however.[65–67] Thrombus formation, well described in BCI, is less frequent in penetrating cardiac injury, although possible.[63,68]

FUTURE DIRECTIONS

Penetrating cardiac injuries continue to be highly lethal. As technology has raced to keep up with cardiac surgery, the availability of adjuncts to support the injured heart has also appeared. Older technology such as extracorporeal membrane oxygenation (ECMO) is finding more and more places to fit in the care of the trauma patient.[69–75] These reports document successful management of many different injury patterns using both venovenous and venoarterial ECMO. Included in these data is a report of the successful use of venoarterial ECMO for a penetrating cardiac injury. All centers may not maintain expertise or interest in an expensive and labor-intensive technology like ECMO, but there is a developing role for this technology in the care of trauma patients. In addition to ECMO, ventricular assist devices may be safe to include in rare well-considered situations of penetrating cardiac injury complicated by acute heart failure.[76]

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