



Penetrating Cardiac Trauma

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INTRODUCTION

Trauma in general represents the third most common cause of death in the United States after neoplasia and cardiovascular disease, claiming more than 150,000 lives each year (1,2). Cardiothoracic injury causes 25% of deaths immediately following trauma, and the majority of these fatalities involve either cardiac or great vessel injury (2). In addition, between 25,000 and 30,000 Americans die from gunshot wounds each year, and 10% of these deaths are the direct result of penetrating cardiac trauma (3). Due to the high prevalence of this type of injury, an understanding of the pathogenesis, manifestations, and management of cardiac trauma is becoming increasingly important to medical personnel. This review article will discuss the historical and clinical aspects of penetrating cardiac trauma and the current approaches to treatment.

HISTORY OF PENETRATING CARDIAC TRAUMA

The earliest known reference to the severity of cardiac wounds dates back several millennia. Hippocrates, Aristotle, and Galen commented on the almost uniformly dismal prognosis of such injuries (4). Up until the end of the 19th century, acknowledged leaders in the fields of science and medicine almost uniformly dismissed the possibility of successful surgical repair of penetrating cardiac trauma. Early in the 18th century, Boerhaave labeled all penetrating cardiac trauma as fatal (5). In 1883, Theodore Billroth stated, "The surgeon who should attempt to suture a wound of the heart would lose the respect of his colleagues" (3). In 1896, Paget stated, "Surgery of the heart has probably reached the limits set by nature to all surgery: no new method and no discovery can overcome the natural difficulties that attend a wound of the heart " (5,6).

Ironically, it was in the very same year that Rehn succeeded in repairing a 1.5 cm right ventricular stab wound to a patient in a Frankford hospital by suturing the heart wall, a procedure referred to as cardiorrhaphy (4,7). This procedure had been previously accomplished for the first time in 1882 by Block in lagomorph models; in 1895, deVecchio was successful in canines (2). The first cardiorrhaphy performed successfully in America was in 1902 by Hill, who repaired a stab wound to the heart of a teenage boy (8). Following Hill's achievement, an increasing number of cardiorrhaphies to treat penetrating cardiac trauma were attempted. Several large studies of such patients were published over the next 30 years with recovery rates ranging from 30-50% (4,7). Cardiorrhaphy slowly became an accepted method for the management of penetrating cardiac trauma.

Pericardiocentesis, the procedure of drawing fluid from the pericardial space, was a non-surgical procedure initially discussed in 1649 by Riolanus (2). Dupuytren performed the first percutaneous pericardial

exploration for the relief of cardiac tamponade (2). Unfortunately, he was able to prolong his patient's life by only a few hours. The first successful pericardiocentesis for cardiac tamponade secondary to a penetrating cardiac wound was accomplished in 1829 by Larrey, surgeon to Napoleon (4,7).

During World War II, pericardiocentesis as a non-operative treatment of cardiac wounds was advocated. Blalock and Ravitch proposed the serial use of pericardiocentesis if tamponade is present followed by observation of the trauma victim (9). While this work correctly highlighted the importance of pericardiocentesis for the treatment of tamponade, its emphasis upon conservative treatment was incorrect. Extensive patient studies over the next 30 years documented that conservative treatment of penetrating cardiac trauma led to suboptimal results; aggressive management of penetrating cardiac trauma, including sternotomy and cardiorrhaphy when indicated, is more appropriate (3,4,7).

As technical sophistication progressed, it became possible to surgically correct increasingly complicated cardiac injuries. Following the perfection of his surgical approach in canine models, Dwight Harkin was able to remove 13 intracardiac projectiles from American soldiers during World War II with no fatalities (10,11). In 1965, Jones and Jahnke performed the first repair of a traumatic coronary artery-cardiac chamber fistula (12,13). Since then, many other advanced surgical techniques have been utilized to improve the outcome of penetrating cardiac trauma victims, including aneurysmectomy, subendocardial resection and cryoablation of arrhythmogenic foci, intra-aortic balloon pumps, and rapid stapling devices (14-16).

ETIOLOGY OF CARDIAC PENETRATION

The anatomic position of the heart in relation to the anterior chest wall is critical in determining which areas of the heart are most commonly affected by penetrating cardiac trauma. In a review of 1,802 cases of penetrating cardiac trauma from 20 reports published between 1967 and 1980, the right and left ventricles were injured 43% and 33% of the time, respectively. For the atria, right-sided lesions were found in 14% of cases and left-sided lesions in 5% of cases. Injuries to the great vessels were found to occur with a frequency equal to that of the left atrium (17). This distribution of injuries is due to the disparate exposure of the cardiac chambers to the anterior surface of the chest. The right ventricle covers the greatest portion of the anterior chest wall and represents 55% of the anterior cardiac surface. The frequency of involvement of the remaining cardiac chambers in penetrating injuries is proportional to the area of the anterior chest wall that they cover (17).

The coronary arteries, involved in 3.1-4.4% of penetrating cardiac injuries, are also potential sites of injury (2,18,19). Due to its anatomically anterior placement, the left anterior descending coronary artery is the most frequently involved, being injured in 87.5% of cases of coronary laceration (2). The right coronary artery is the second most commonly injured vessel (19).

Over the last 30 years, the incidence of penetrating cardiac trauma has increased eight-fold. Classically, the majority of penetrating cardiac trauma cases have resulted from stab wounds in civilian settings and from missile injuries in war time. Missile injuries to the heart now occur with greater frequency than stab wounds in civilian settings (4,17) and are more lethal, with 11% of victims arriving at the trauma center alive compared to 40% of cardiac stab wound victims arriving alive (20).

Prior to 1984, over 80% of missile injuries were caused by small caliber handguns (ranging from .22 to .32) and 75% of victims sustained only single bullet injuries (21,22). Surgeons at major trauma centers today see increasingly larger caliber bullets in gunshot victims and a greater number of bullet injuries per patient. Shotgun injuries currently account for 4% of penetrating cardiac trauma cases and have a mortality rate of nearly 100% (22).

Cardiac stab wounds are most commonly caused by knives, but wounds from items such as ice picks and

screwdrivers are also frequently encountered (17). Iatrogenic cardiac injuries have also been reported, with common causes being pacemaker leads, central venous catheters, and cardiac catheters (3). The majority of these cases result in minimal cardiac injuries.

CLINICAL MANIFESTATIONS

The two most common clinical manifestations of penetrating cardiac injury are hemorrhage and pericardial tamponade (3). Hemorrhage can lead to hemorrhagic shock with tachycardia and decreased systolic and mean arterial blood pressures (23). Pericardial tamponade classically results in the acute cardiac compression triad of Beck, which consists of decreased arterial pressure, increased central venous pressure, and distant heart sounds (24). Although clearly pathognomonic for tamponade, Beck's triad occurs in only 10% of individuals with pericardial tamponade (25).

DIAGNOSIS

The vast majority of individuals experiencing penetrating cardiac trauma will be symptomatic. Surprisingly, among those patients with cardiac penetration arriving at the trauma center, 70% do not exhibit symptoms suggestive of cardiac injury (25). A diagnostic dilemma exists in the evaluation of these stable patients with juxta-cardiac penetrating wounds to the chest. Pericardiocentesis is not considered a reliable method to diagnose occult penetrating cardiac trauma as this method can result in either false positive or false negative results in up to 50% of cases (26). Electrocardiographic changes are also unreliable with false negative rates of up to 89% (25).

Cardiac catheterization can accurately diagnose penetrating trauma to the heart. This technique will provide information about the specific area of the heart involved, whether the cardiac valves or coronary vessels have been damaged, and whether any intracardiac shunts have been created. However, this approach is considered to be too time consuming and is not appropriate for the initial evaluation of the trauma patient (3).

One effective technique is the use of subxiphoid pericardial windows, incisions made in the pericardium by a subxiphoid approach. This is commonly employed in cases of suspected occult penetrating cardiac trauma. Subxiphoid windows represent a rapid method for the accurate diagnosis of such injuries and should be considered as the gold standard for the evaluation of occult penetrating cardiac trauma (25). An alternative approach is to utilize serial echocardiography. In a recent series of patients with juxta-cardiac penetrating chest wounds and stable vital signs, two-dimensional echocardiography was found to be 90% sensitive and 97% specific for the diagnosis of cardiac penetration (25).

MANAGEMENT IN THE FIELD

Most victims experiencing massive penetrating cardiac trauma die prior to reaching the trauma bay. Those who survive will present to the emergency medical personnel with the potentially lethal complications of hemorrhage and cardiac tamponade. The placement of two rapid intravenous infusion lines allows for immediate replacement of circulatory volume. A systolic blood pressure greater than or equal to 90 mmHg is desired.

Pericardiocentesis, to prevent cardiac tamponade, may be performed in the field by trained personnel if an adequate systolic blood pressure cannot be maintained. The removal of as little as 30 cc of fluid from the pericardial sac can improve left ventricular diastolic filling enough to support the patient's circulatory status in most cases. Pericardiocentesis may be repeated as needed to maintain systolic blood pressure en route to the trauma center. Minimal cardiac injuries are not uncommon during pericardiocentesis, but these injuries usually seal themselves. A more serious condition could result, however, if a coronary vessel is lacerated. Fortunately, this situation is highly uncommon. To prevent exsanguination, any stabbing weapons still present

in the chest should not be removed before reaching the trauma bay (3).

MANAGEMENT IN THE TRAUMA BAY

In the trauma bay, the patient undergoes rapid primary and secondary assessment and is further stabilized through the maintenance of airway and blood volume (3). A central venous pressure line should also be established in these patients (2). Further management is dependent on their vital signs; if stable, patients can receive a chest roentgenographic examination, nasogastric tube placement, and further evaluation for other injuries. Patients with either a large pneumothorax or hemothorax should receive a chest tube in the trauma bay.

Patients with bright red blood per nasogastric aspirate should be managed according to the severity of the injury. If less than 500 ml of blood are evacuated, the patient is stable, and penetrating cardiac injury is not strongly suspected, the patient may then be admitted for observation. If drainage from the chest tube continues beyond 500 ml, the patient should be transported to the operating room for thoracotomy in order to arrest bleeding (17).

Those patients with suspected cardiac penetration or who cannot be stabilized, however, should be transported immediately to the operating room for subxiphoid pericardiotomy and possible thoracotomy if such transportation is possible. If patient deterioration is too rapid, then emergency pericardiocentesis, pericardial window, or thoracotomy may be performed in the trauma bay (17).

Patients with a completely negative work-up, but in whom an occult penetrating cardiac injury is highly suspected, may be evaluated by either 2-D echocardiography or proceed to the operating room for a subxiphoid pericardiotomy under sterile conditions (17,25).

SURGICAL MANAGEMENT

The induction of the patient represents a particularly critical time because of increased susceptibility to decompensation as positive pressure ventilation decreases blood return to the heart. A pericardial window may be created if the diagnosis of penetrating cardiac trauma is still uncertain and subxiphoid pericardiotomy has not been performed in the trauma bay. The approach to the heart is usually via either a median sternotomy or a left anterior thoracotomy. The former is considered the standard approach but may be more time consuming than the latter, which does not necessitate any special surgical instruments (4).

Once adequate exposure has been obtained, the pericardial sac may be incised and cleared of clotted blood and fluid. Digital pressure is usually sufficient to control any active hemorrhage from the cardiac chambers. Following cardiac decompression, the heart should be allowed to reestablish proper perfusion prior to cardiorrhaphy. Tissue perfusion may be monitored by serial blood gas evaluation. The anesthesiologist must be prepared for the treatment of cardiac arrhythmias which can result from manipulation of the myocardium. The arrhythmias most likely to persist subsequent to myocardial manipulation include profound bradycardia and ventricular tachycardia (2).

Small lacerations of the myocardium may be repaired with interrupted 2-0 or 3-0 silk or synthetics (2,4). Teflon felt pledges are usually used to assist in anchoring the sutures and to prevent the sutures from causing further myocardial damage (4). If the laceration occurs in or near a coronary vessel, a horizontal mattress suture should be used. The suture should run through the myocardium beneath the vessel to prevent compromise of the coronary blood supply (2). Small coronary vessels which have been lacerated may be ligated (4). Larger coronaries will require either direct repair or bypass. Suitable sources for bypass material include the internal mammary artery and a reversed portion of the saphenous vein (2,27). Large myocardial wounds may require the placement of the patient on cardiopulmonary bypass and the use of a synthetic graft

to cover the wound (2). Injuries such as severe valvular damage or large intra-cardiac defects necessitate immediate repair; fortunately, such injuries are quite rare (4). If missiles are present within the myocardium, they should be removed when possible (2); intraoperative fluoroscopy may be helpful in precisely localizing such missiles (4).

PROGNOSIS

Penetrating cardiac injuries have been generally classified into three categories based upon their initial clinical presentation (Table 1). First described over 20 years ago, this is a simple classification system which requires no additional assessment beyond that normally accomplished within the trauma bay (28). In one study of 64 patients classified with this system, overall survival was 23% for Group I, 79% for Group II, and 100% for Group III (29).

Ivanbury has published a highly quantitative system for describing the severity of penetrating cardiac trauma, the Penetrating Cardiac Trauma Index (PCTI). This correlates well with survival and is able to separate survivors from nonsurvivors at a statistically significant level ($p < .05$) (30). While elaborate systems of measuring severity of injuries undoubtedly improve the interpretation of clinical series, there is rarely sufficient time to classify patients into such systems in the trauma bay (30). A more qualitative system such as the one presented in Table 1 is often not only sufficient, but also more applicable to rapid patient description and patient care. On a more pragmatic level, patients with penetrating cardiac trauma generally present with primarily either pericardial tamponade or hemorrhagic shock. This initial dichotomy is usually sufficient to dictate the immediate patient intervention necessary (31).

DISCUSSION

Penetrating cardiac trauma represents an increasingly important form of traumatic injury, especially in large urban centers. In the 19th century, cardiac injuries were considered to be inoperable, and as recently as the middle of this century conservative management of cardiac injury was advocated. Tremendous progress has been made in the management of cardiac injury over the last fifty years, made possible by the pioneering work of Dwight Harkin, who undertook the removal of intracardiac projectiles from allied soldiers during World War II with a 100% success rate (10,11). Aggressive management, including cardiorrhaphy when indicated, is currently recognized to lead to more optimal results than conservative management (3,4,7).

Trauma bay and emergency medical services are essential for the treatment of penetrating cardiac trauma. Future efforts may be directed towards increasing the rapidity of patient transport to trauma centers and increasing the speed with which sternotomy, when indicated, can be initiated.

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