INTRODUCTION

Background

Trauma is the leading cause of death in young adults. Despite continuous innovation in trauma care, fatal trauma remains a significant medical and socioeconomic problem. [1, 2] Thoracic trauma comprises 10-15% of all traumas. [3] It directly accounts for approximately 25% of trauma related mortality and is a contributing factor in another 25 %. [4]

Penetrating thoracic trauma accounts for almost 33% of total chest trauma. It is mostly attributed to violence and it has a higher mortality rate than blunt chest trauma. Penetrating thoracic traumas, including gunshot and stab wounds, are the major causes of cardiac injury. [5, 6]

Blunt thoracic trauma may injure the sternum, ribs, lungs, pericardium, myocardium, valves or sub-valvular apparatus, coro0ry arteries, or the great vessels. [7] Road traffic accidents (RTA) are the most common cause of blunt traumas. The severity of the impact predicts the clinical course and it`s outcome. [8]

Cardiac injuries

Cardiac injuries associated with non-penetrating chest trauma are uncommon. The two commonly reported mechanisms of cardiac injury in blunt trauma are transmission of the kinetic force in direct impact to the chest wall, causing compression of the heart between the sternum and the spine, and compression of the lower extremities and abdomen with rapid increase in intra thoracic hydrostatic pressure. [9] Shear force during blunt trauma may lead to lacerations to the pericardium, and this could lead to a pericarditis-like picture. In sudden deceleration injuries, the myocardium can be injured leading to cardiac rupture. More than 50% of cardiac rupture injuries involve the right atrium due to the thin walls and the large diameter, and 25% the left atrium.[7] Recoil of the intercostal muscles keeps the architecture of the rib cage intact preventing subsequent injuries to the thoracic organs in most patients.[8]

On the other hand, penetrating cardiac injuries are associated with high mortality rates. The majority of patients die on scene despite aggressive resuscitation attempts. Moreover, even those who do survive the initial assault pose a difficult challenge to trauma surgeons. [10] Emergency physicians working in high volume Trauma Centers are expected to diagnose cardiac tamponade and to perform emergency thoracotomy (ET) to decompress the pericardium. Specific training in the procedure should be undertaken. [11-12]

Surface anatomy

The cardiac diamond is bounded by the sternal notch superiorly, the nipples laterally, and the umbilicus inferiorly. Any injury with an entrance wound within this area must draw the attention to the possibility of cardiac injury. The cardiac diamond must also be considered projected onto the back and in particular the left side where the descending thoracic aorta can be injured (Figure 1). [13]

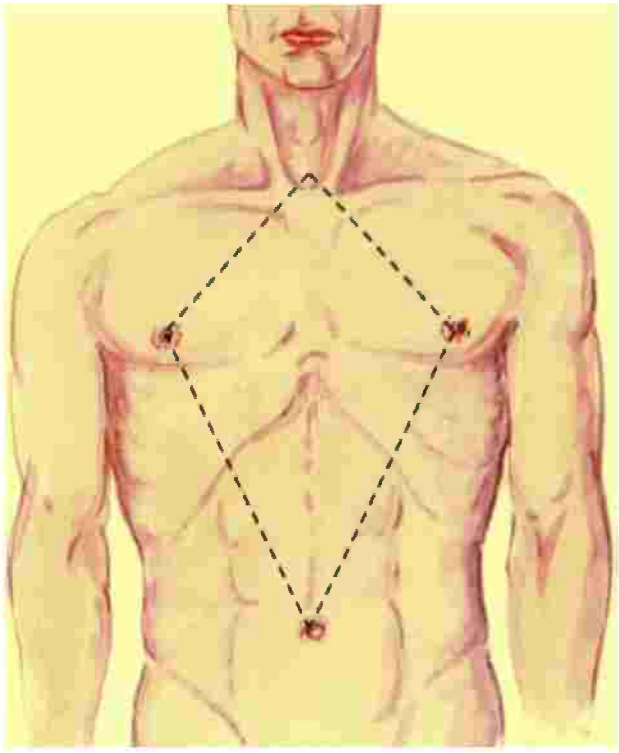

Figure 1: The cardiac diamond

(Niall M, Kieran M. Penetrating thoracic trauma. Surgery 2011; 29: 227-30.)

The right ventricle is the most vulnerable chamber to penetrating trauma as it is comprising the majority of the anterior surface of the heart, while the left atrium is the least frequently injured, as it is smaller and almost entirely posterior structure. James, [14] reported that the frequency of injury to the right ventricle is (43%), left ventricle (34%), right atrium (18%) and left atrium (5%). Injuries are classified as complex if they create shunts, disrupt valves or disrupts papillary muscle apparatus, or lacerate coronary arteries (~5% of injuries).

The survival rate of penetrating cardiac injuries has been improved because of advances in: Pre hospital care (PHC), fast transportation to trauma-referenced facilities, and advances in preoperative trauma surgery. [15]

Pre-hospital care:

Pre-hospital resuscitative interventions by Advanced Life Support (ALS) units performed for penetrating trauma patients may lengthen on-scene time but do not significantly increase total pre-hospital time. Moreover, these interventions did not appear to benefit the rapidly transported penetrating trauma patients. [16]

A universal trauma Cardio-Pulmonary Resuscitation CPR-algorithm is needed. This algorithm should raise the awareness of the underlying reasons in Trauma Cardiac Arrest TCA. Algorithm training and education has to involve methods, which help to recognize these reasons and provide the techniques to successfully resolve them, (Figure 2) [17] and (Figure 3). [18]

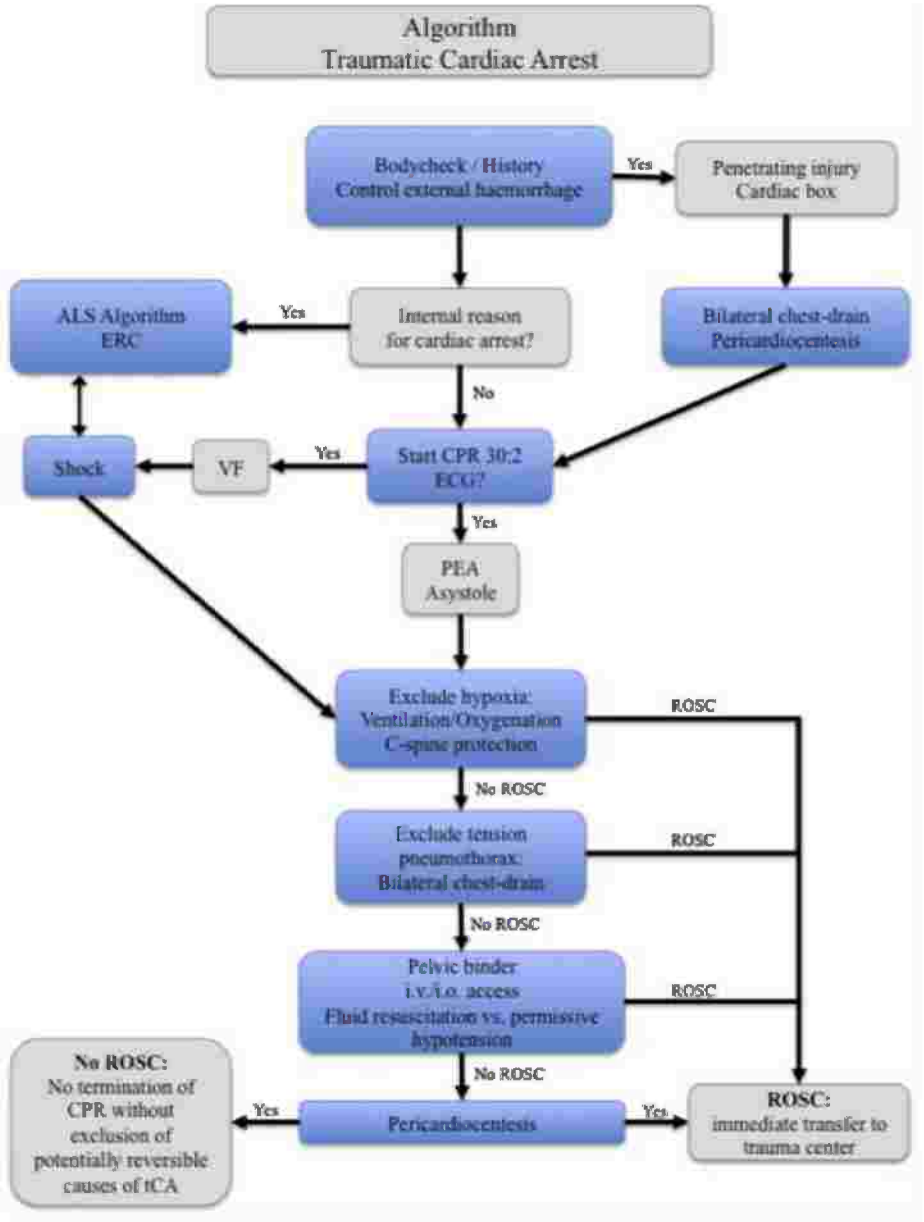

Figure 2: Suggested algorithm for traumatic cardiac arrest

CPR: cardiopulmonary resuscitation; ECG: electrocardiography; PEA: pulseless electric activity; ROSC: return of spontaneous circulation; VF: ventricular fibrillation, ALS: advanced life support, ERC: European Resuscitation Counsil.

(Klebera C, Giesecke MT, Lindner T, Haas NP, Buschmann CT. Requirement for a structured algorithm in cardiac arrest following major trauma: Epidemiology, management errors, and preventability of traumatic deaths in Berlin. Resuscitation 2014; 85: 405-10)

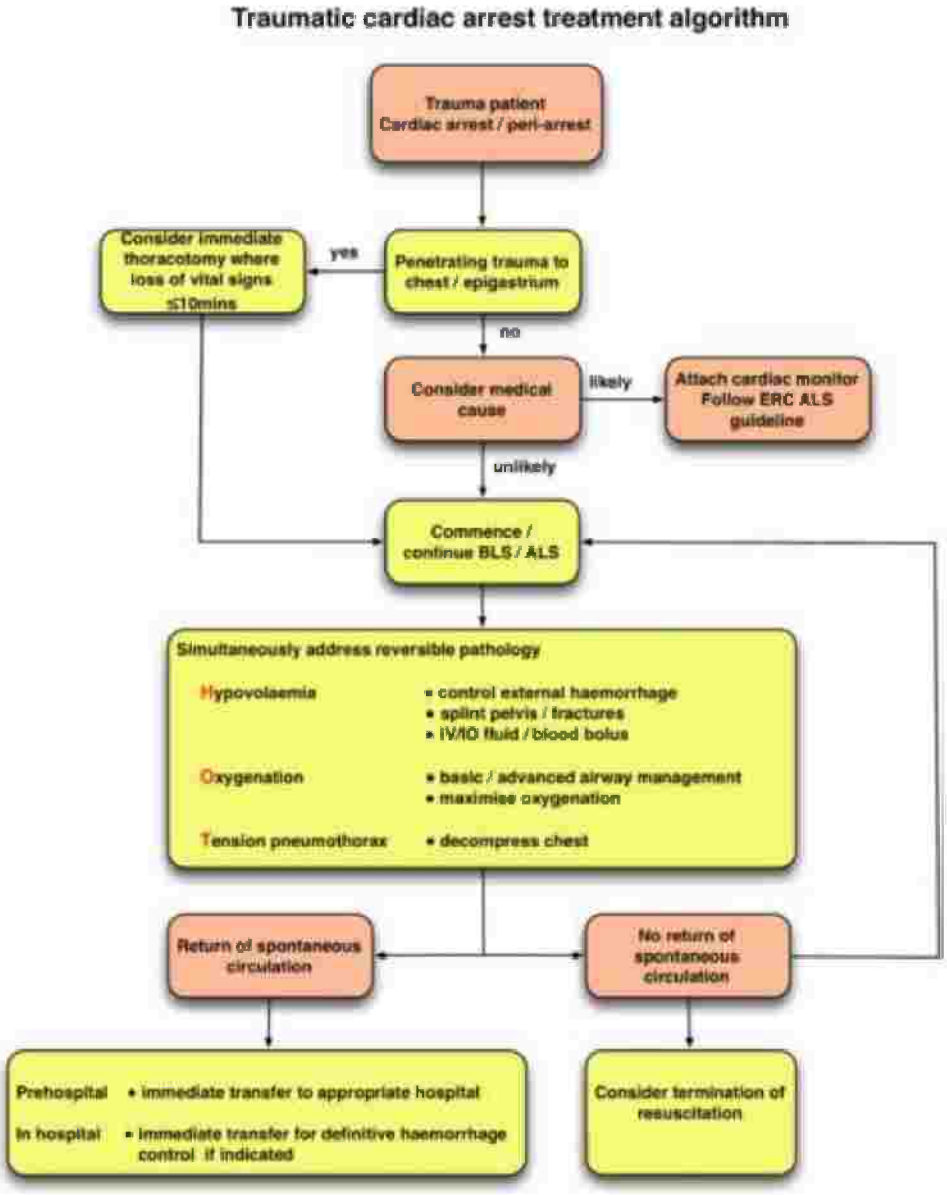

Figure 3: Traumatic cardiac arrest treatment algorism

(Lockey DJ, Lyon RM, Davies GE. Commentary and concepts Development of a simple algorithm to guide the effective management of traumatic cardiac arrest. Resuscitation 2013; 84: 738-42.)

Factors affecting the outcome:

Authors have documented several factors that could affect the outcome in trauma patients. These factors included the mechanism of injury, physiological parameters of the patient on emergency department (ED) admission, early recognition and the timing of treatment of life threatening injuries, associated injuries, and better resuscitative techniques. These factors can significantly affect outcomes in these patients. [5, 15]

1- Mechanism of injury

Generally, penetration with sharp objects is associated with a better outcome than penetration that results from gunshot and non-penetrating injuries because they often exsanguinate and have a high probability of associated intra thoracic injuries. [19]

2- Physiological parameters of the patient

The clinical presentation ranges from hemodynamic stability to acute cardiovascular collapse and fatal cardiopulmonary arrest. About one third of the patients with penetrating cardiac injuries are haemo-dynamically stable. Signs and symptoms may be intermittent (due to clotting and re-bleeding) or masked by hypotension. Finally, tamponade can develop hours after initial presentation, making the diagnosis difficult in the ED. [19]

Kang *et al.* [20] reported that non-specific signs of shock such as agitation, tachycardia, tachypnea, hypotension, diaphoresis and cool extremities may dominate the clinical picture. Despite these obvious deleterious effects, cardiac tamponade has also a protective effect by limiting bleeding and thus preventing exsanguination.

3- Life threatening presentations

Cardiac tamponade is a life-threatening consequence of cardiac injury. The classic physical signs referred to as Beck's triad (hypotension, elevated jugular venous pressure and muffled heart sounds) are reported in only a minority of patients. [16] An exaggeration of the normal 3 to 6 mmHg drop in systolic blood pressure with inspiration may be observed. This is called pulsus paradoxus when the inspiratory systolic decrease is greater than 10 mmHg is another characteristic feature of tamponade. [20]

Exsanguination is another major cause of death. Less commonly, penetrating injuries to the heart may cause cardiac dysfunction as a result of coronary, myocardial or valvular injuries. Defects in the walls separating the left and right sided chambers create intra cardiac shunts as traumatic VSD. Embolism of retained intra cardiac projectiles is an important threat to those patients. [20-21]

4- Associated injuries

Depending on the phase of respiration and diaphragmatic position at the time of injury, intra-abdominal viscera may be penetrated. Similarly, cardiac injury with abdominal penetrating injuries should be considered. [14] Survival is greater for cardiac injuries compared to chest injuries, while abdominal injuries have a worse prognosis. Multiple injuries have greater mortality rate. [12]

5- Resuscitative techniques

Early and balanced use of blood products appears to be lifesaving and reducing total blood use. Better and safer tools for hemorrhage control and resuscitation as needle decompression of a tension pneumothorax may be enough to change an emergency into a stable situation, but should be followed by formal chest drains. Decompression of pericardial tamponade and control of external bleeding can save more lives. [13,17, 22]

Diagnostic modalities

By the turn of the past century, treatment has been moved from simple clinical observation to surgical intervention. The diagnostic procedures have been advanced from a clinical physical examination to include Focused Assessment Sonography for Trauma (FAST), cardiac echocardiogram (Echo), and multi slice computed tomography scan (CT) scan. [23]

1- Chest radiography

The initial evaluation of a penetrating chest trauma includes physical examination and chest radiography. The sensitivity and specificity of both examinations for diagnosing cardiac injury is relatively low. [10] Chest X-ray may be misleading since the cardiac silhouette is unlikely to be enlarged in acute tamponade, at least 250 ml of pericardial fluid must be present to detect heart enlargement radiographically [14-20] (Figure 4). [24]

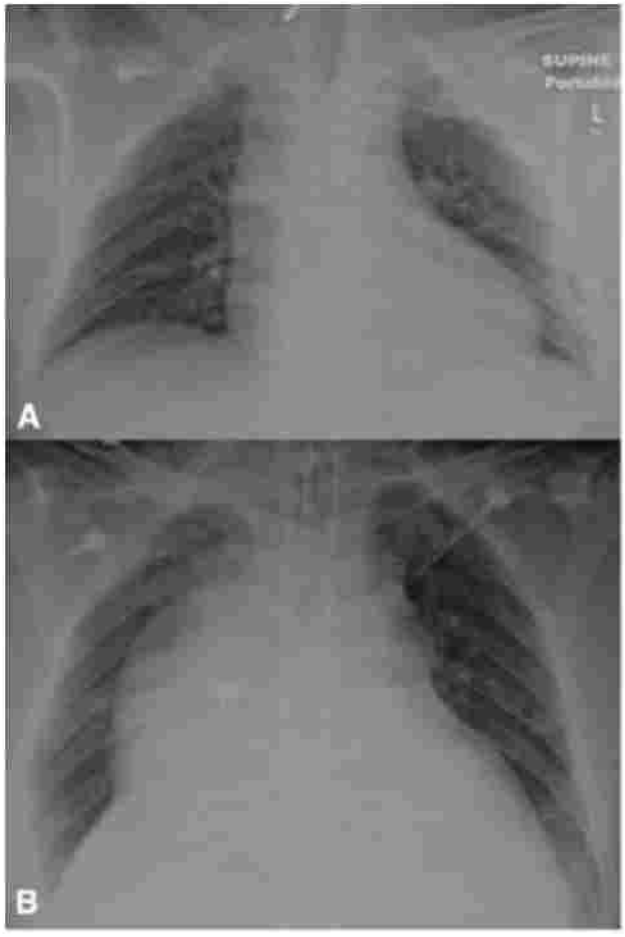

Figure 4: Chest radiographs. A: Initial supine chest radiograph in a trauma patient. B: Repeat chest X-ray study 22 h later demonstrating significant increased density involving the right hemithorax, believed to represent mediastinal blood.

(Levine M, O'Connor AD, Tasset M. Methemoglobinemia after a mediastinal stab wound. The Journal of Emergency Medicine 2013; 45 e153-56.)

Retained intra cardiac foreign bodies may occasionally be seen. Signs of non-cardiac injury such as pneumothorax or pneumo-peritoneum should be sought. Occasionally, pneumo-pericardium may be detected. [14-20] Classic clinical sign of a pneumo-pericardium is the mill-wheel murmur or bruit de Moulin that was originally described by Bricheteau in 1844 in a patient with a pyo-pericardium. [25]

Although the absence of pericardial fluid rules out tamponade, it may miss significant cardiac injuries that decompress to adjacent cavities. Thus, a high index of suspicion for cardiac injuries should be raised in patients with pericardial stab wounds with haemothoraces or blood in the peritoneal cavity, [10] (Figure 5). [26]

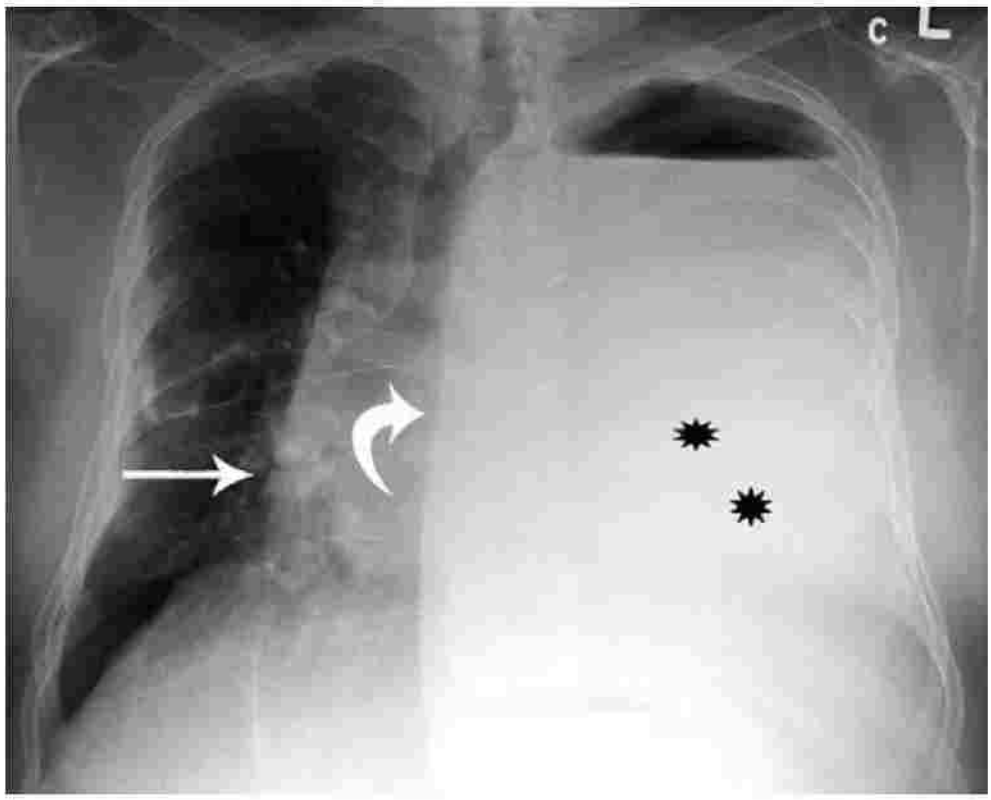

Figure 5: Heamothorax at the left side with mediastinal shift to the right side

(Pool KL, Munde RF, Vaporciyan A, O'Sullivan PJ. Review Radiographic imaging features of thoracic complications after pneumonectomy in oncologic patients. European Journal of Radiology 2012; 81: 165-72.

2- Focused Assessment Sonography for Trauma (FAST)

FAST is currently the most widely practiced method for diagnosing traumatic haemo-pericardium in the Emergency Department (ED). It has the desirable qualities of being rapid, non-invasive, readily available and repeatable. However, FAST is both operator and patient dependent. Appearances can be deceptive when there is a loculated collection of clotted blood or when there is associated haemo-pneumothorax (Figure 6). [20]

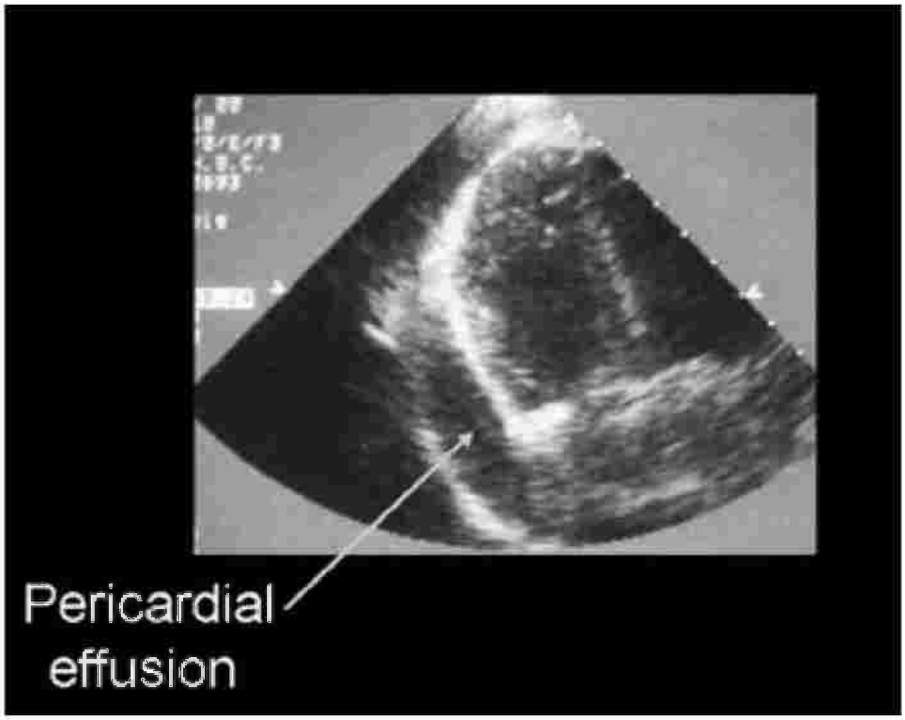

Figure 6: FAST scan showing echo-free space around the heart consistent with haemopericardium.

(Kang N, Hsee L, Rizoli S, Alison P. Penetrating cardiac injury: overcoming the limits set by Nature. Injury. 2009; 40: 919-27.)

3-Echocardiography (Echo)

Echocardiography (Echo) is recommended as the gold standard of care in stable patients with penetrating cardiac injury. [27] It is able to show myocardial wall dysfunction and provides a direct view of wall motion abnormalities. In addition, it may show associated valvuar injuries, intra-cardiac shunts or thrombosis, pericardial effusion, cardiac tamponade and ventricular dilatation. Other important advantages of a cardiac echocardiogram are its non-invasive nature and its ease of use both at the bedside and in the emergency unit. [15] Trans-esophageal echocardiogram (TEE) can clearly show more detailed information such as Loculi of the tamponade, heart function and more importantly the internal structures and condition of the great vessels of the heart. It is ideally performed pre-operatively, [28] (Figure 7). [29]

Figure 7: Transthoracic four-chamber echocardiographic view showing the large pericardial fluid (marked with arrow).

(Bogdanovic A, Radcjkovic M, Tomasevic RJ, Pesic I, Petkovic TR, Kovacevic P, Rancic Z. CASE REPORT Presentation of pericardial hydatid cyst as acute cardiac tamponade. Asian Journal of Surgery 2013; 20: 1-3.)

4- Computed Topography (CT)

CT can detect significant injuries with 100% sensitivity and 97% specificity. It is particularly useful in reconstructing the course of a penetrating object and its possible migration. However, only patients who are hemo-dynamically stable enough to leave the emergency department should be evaluated using this tool. Unstable patients with clear signs of tamponade or hemodynamic instability should be taken immediately to the operating room for urgent surgical intervention, [27] (Figure 8). [30]

Figure 8: Large pericardial effusion at CT scan.

(Sochala M, Aïssou L, Sorbets E, Pop N, Sleiman C, Goudot FX, Meune C. Letter to the Editor Delayed cardiac tamponade following management of a massive hemothorax related to a penetrating thoracic trauma. International Journal of Cardiology 2014; 172: e69-e70.)

5- Electrocardiogram (ECG)

Electrocardiogram (ECG) has become a prominent part of the work up of a patient admitted with a penetrating chest injury that may have resulted in cardiac damage. [32] Low voltage tracings and pointed T-waves can be observed in the ECG by a pericardial rub. [33] In the case of a patient with a negative ultrasound but the presence of a J wave on the ECG, further investigations should be performed to exclude a pericardial collection prior to the discharge of the patient to home. The presence of a J wave appeared to be closely associated with the presence of an occult cardiac injury even in the presence of a negative ultrasound (Figure 9). [31]

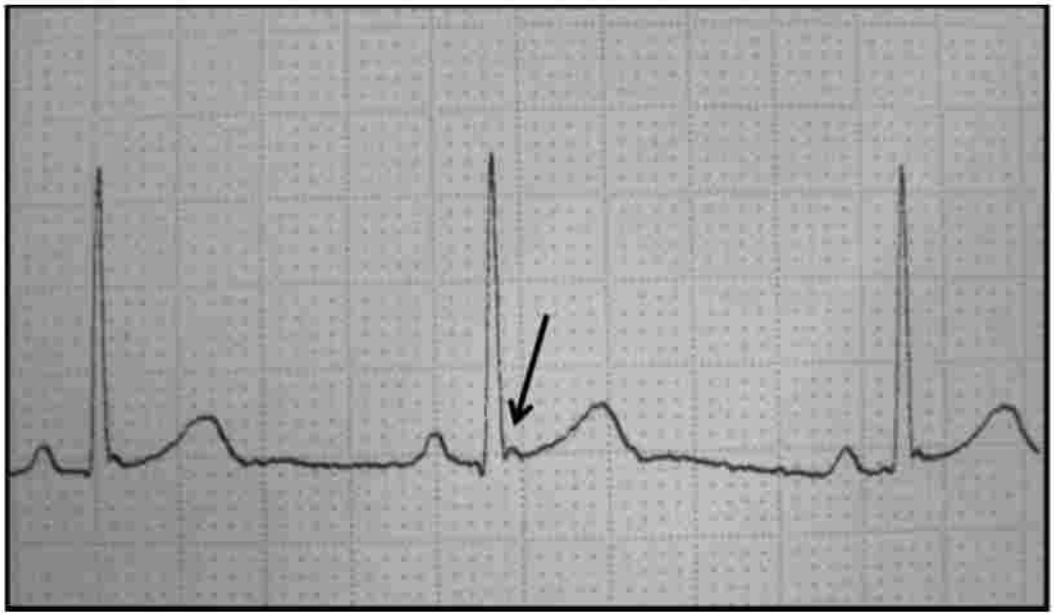

Figure 9: J wave on the ECG (J-wave indicated by the arrow).

(Andrew JN, Pradeep HN. The J-wave: A new electrocardiographic sign of an occult cardiac injury. Injury, Int. J. Care Injured 2014; 45: 112-15.)

Treatment

1- Tube thoracostomy

Most penetrating chest injuries can be treated with tube thoracostomy. [32] It is required to allow the lung to re-expand and to drain any intra-plural collection. [13]

2- Pericardiocentesis

Pericardiocentesis was not suggested because penetrating into a cardiac chamber may yield a false-positive result, while clotting of the blood in the pericardial cavity may yield a false-negative result. Furthermore, drainage of the pericardial blood is often incomplete and tamponade may persist or recur. [32] It also may induce dysrhythmias or lacerate myocardium or coronary arteries. [14]

3- Surgery

Surgery should be considered immediately in cases with initial chest tube output 1500 ml or initial output 1000 ml then continued output of 250 ml/h for 3 successive hours; hemodynamic instability; massive hemothorax associated with shock, signs of pericardial tamponade, injury to the diaphragm, massive air leak, or radiographic evidence of a large hemothorax (Figure 10). [32]

Emergency Thoracotomy (ET) is performed shortly after the trauma in patients who have objective signs of life: pupillary response, spontaneous ventilation, carotid pulse, palpable blood pressure, movement of extremities and electrical activity in the ECG. Survival for blunt injury is significantly lower than for penetrating injury due to conditions such as cardiac contusion, cardiac rupture, and aortic rupture. It is only performed in cases where previously witnessed cardiac activity (prehospital or in-hospital) and unresponsive hypotension (SBP < 70 mm Hg) despite vigorous resuscitation. In general, ET is contraindicated in patients with blunt injury without witnessed cardiac activity, penetrating abdominal trauma without cardiac activity, severe head trauma, severe multisystem injury, improperly trained team and insufficient equipment. [12]

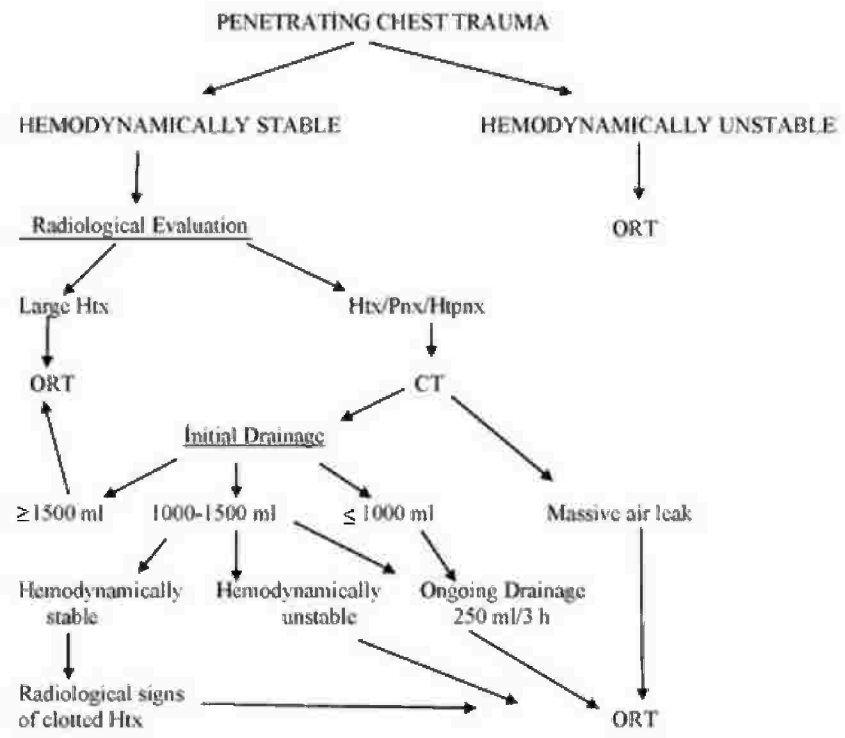

Figure 10: Indications for thoracotomy

ORT: operation room thoracotomy, Htx: heamothorax, Pnx: pneumothorax, Htpnx: heamo-pneumothorax, CT: chest tube

(Serdar O, Refik U, Alper A, Gungor A, Cemal O. Urgent thoracotomy for penetrating chest trauma: Analysis of 158 patients of a single center. Injury, Int J Care Injured 2011; 42: 900-4.)

A left antero-lateral thoracotomy should always be performed on patients who are hemodynamically unstable, [33] (Figure 11). [13] This antero-lateral incision is most often used in emergency departments for resuscitative purposes. A median sternotomy is the incision of choice in patients with some degree of hemodynamic stability. [33]

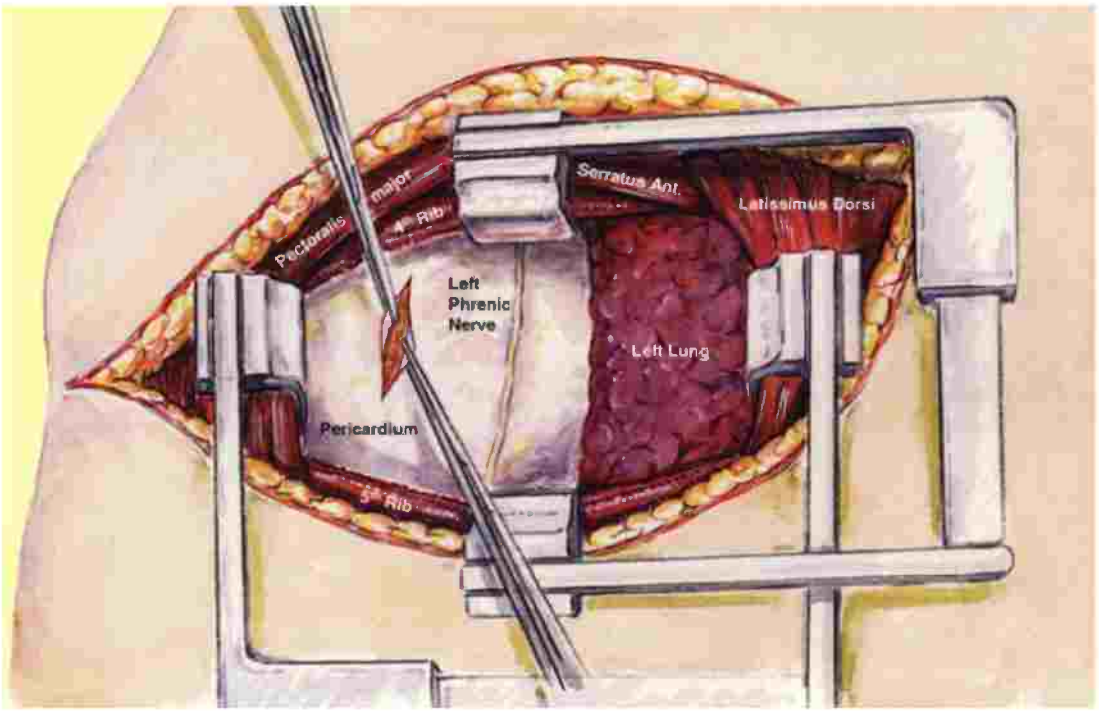

Figure 11: Antero-lateral thoracotomy, opening of the pericardium to relieve tamponade by incising the pericardium anterior to the phrenic nerve.

(Niall M, Kieran M. Penetrating thoracic trauma. Surgery 2011; 29: 227-30.)

4- Subxiphoid pericardial window (SPW)

The sub-xiphoid pericardial window (SPW) is a useful technique at laparotomy to identify cardiac injuries in patients with penetrating thoraco-abdominal injuries. [34] The procedure showed 100% sensitivity, 96% specificity and 97% accuracy. [14] The indication for performing a subxiphoid pericardial window include: Positive ultrasound for fluid, equivocal ultrasound (poor visualization), Pneumo-pericardium, Continued clinical suspicion. [26]

Patients with a penetrating chest injury with a pneumo-pericardium who are unstable require emergency surgery. A delayed tension pneumo-pericardium developed in 10% of patients who were initially stable. It is recommended that all stable patients with a pneumo-pericardium after penetrating chest trauma should undergo a SPW. A sternotomy is not required in stable patients with no evidence of active bleeding at SPW, as the underlying cardiac injuries if present has sealed. [24]

Volume restoration should proceed simultaneously with surgical intervention, preferably using whole blood or packed red blood cells. Internal cardiac compressions should be performed if the heart is not beating and arrhythmia should be treated with

internal defibrillation (begins at 20 joules and increases to 40-50 joules. Avoid touching the coronary arteries with the paddles) and medication. [32]

Cardio-pulmonary bypass should be always ready for use, before exploration of cardiac injury. However, depending on the preoperative findings, cardio pulmonary bypass is best avoided, as it causes bleeding from other organs in patients with poly trauma. [35]

Complications

Complications are common and may occur immediately. The most common early complications are respiratory in nature, such as atelectasis, residual pneumothorax, pneumonia, empyema, residual hemothorax and lung abscess. Multiple organ dysfunction related to hemorrhagic shock may also occur. [32]

Late sequelae and postoperative complications include intra-cardiac shunts, valvular decompensation (which is manifesting as hypotension, pulmonary edema, and new murmurs), disruption of conduction pathways, ventricular false aneurysm, fistulae between coronary arteries and cardiac chambers (coronary-cameral fistulas) and septic complications (suppurative pericarditis, endocarditis). Intra-cardiac thrombus can occur after both blunt and penetrating trauma and should be included in the list of possible complications following cardiac repair. [13, 19, 20, 36]

Fibrothorax is one of the late complication that will cause breathlessness on exertion. This may be compounded by chest wall pain (intercostal neuralgia). This is usually due to injury to an intercostal nerve by a knife or bullet, but may be difficult to avoid in an emergency thoracotomy or chest drain insertion. [13] Touching on the incision site, little press on the thoracotomy region, talking to the patient about pain was stated to provide pain relief to him. [37]

Those patients may also develop post-cardiac injury syndrome. Presentation of this syndrome is ranging from simple uncomplicated pericarditis to a more complicated presentation with pleuro-pericarditis, cardiac tamponade or massive pleural effusion. Treatment is based on empiric anti-inflammatory therapy with the possible adjunct of colchicine for prevention of recurrences. The overall prognosis of the post-cardiac injury syndrome is benign but recurrences are possible. Long-term follow up is warranted in such patients. [38]

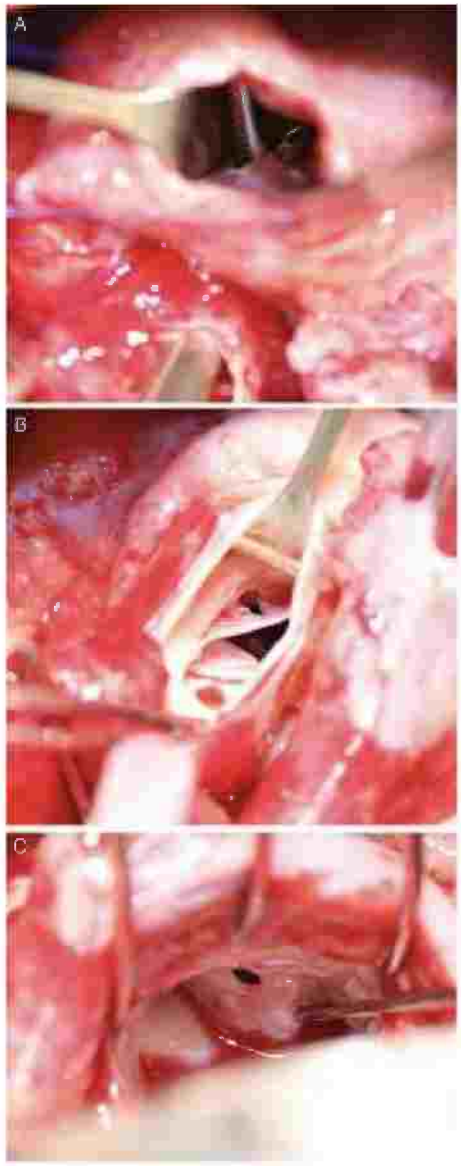

Figure 12: **(A) An instrument passed through the aortic root emerges in the right ventricular outflow tract, confirming the presence of a defect in the fibrous outlet ventricular septum, (B) associated with a perforation of the right coronary leaflet of the aortic valve and (C) a perforation of the anterior mitral leaflet. This lesion pattern reflects the trajectory of a single anterolateral to posteromedial cardiac stab injury.**

(*Reddya D and Muckartb DJJ. Holes in the heart: an atlas of intracardiac injuries following penetrating trauma. Interactive CardioVascular and Thoracic Surgery. 2014; 1-8*)