PENETRATING CARDIAC INJURY

J O'Connor[1], M Ditillo[2], T Scalea[3]

[1]Associate Professor Surgery, University School of Medicine, Director Thoracic And Vascular Trauma, R Adams Cowley Shock Trauma Center, Baltimore, Maryland USA, [2]Trauma Critical Care Fellow, R Adams Cowley Shock Trauma Center, University of Maryland School of Medicine Baltimore, Maryland USA, [3]Physician in Chief, R Adams Cowley Shock Trauma Center, Francis X Kelly Professor of Trauma Surgery, Director, Program in Trauma, University of Maryland School of Medicine, Baltimore, Maryland USA.

Abstract

It is understood that penetrating cardiac trauma is a highly lethal injury and those surviving to hospital have an overall mortality approaching 80%. Reported mortality figures vary widely and are extremely dependent on mechanism of wounding, cardiac chambers involved and possibly the presence of cardiac tamponade. Despite significant advances in pre-hospital care, operative techniques, and intensive care management, the mortality has not changed over several decades. This article will review the anatomic regions of concern for a cardiac injury, clinical presentation, and physical findings. The need for an expeditious evaluation and modalities available including, plain radiographs, sub-xiphoid window, and echocardiography will be considered. Options for surgical exposure, technical details of repairing cardiac injuries, and special circumstances such as injury adjacent to a coronary artery and intra-cardiac shunts are discussed in detail. Outcome data and future directions in managing this challenging injury are also examined.

Introduction

Penetrating cardiac trauma presents formidable surgical challenges. Rapid transport and evaluation coupled with expeditious operative intervention yield the most favorable results. Cardiac injuries resulting in tamponade, rather than exsanguination, have improved survival. Throughout history operative repair of cardiac injuries was considered to be impossible and the first successful cardiorraphy was performed just over a century ago.

History

The earliest description of a penetrating cardiac injury is in the *Iliad*. In Book XV Homer dramatically describes the death of Sarpedon, a son of Zeus, by Patroclus, the result of a spear to the heart. Zeus sends Hypnos (Sleep) and Thanatus (Death) to carry the body off the battlefield [1]. Hippocrates believed cardiac wounds were uniformly fatal and that was the prevailing belief over several subsequent centuries. Ambrose Pare, arguably the preeminent surgeon of his generation, described cardiac wounds and their prognosis. In the 19th century prominent surgeons such as Paget and Billroth cautioned against repairing cardiac wounds. The first successful cardiac repair was in 1896 by Rehn who closed a right ventricular stab wound. Subsequently Beck described the physiology and clinical signs of cardiac tamponade. In spite of sporadic reports of successful cardiorraphy, even as late as the Second World War serial pericardiocentesis was still practiced [2].In the latter half of the 20th century improvements in patient transport, volume resuscitation, anaesthesia, critical care and adult cardiac surgery have all combined to improve the outcome of those with penetrating cardiac injuries [3,4].

Demographics and Outcome

Penetrating cardiac injury is highly lethal and survival has not demonstrably improved over several decades [5-10]. Comparing the various studies describing penetrating cardiac injury is complicated by disparate definitions, study methods and outcome end-points. Mandel and Sanusi [11] reviewed a single institution's 24 year experience and found cardiac injuries occurred in 6.4% of penetrating thoracic injuries. In a retrospective, population based study of 20,181 consecutive trauma admissions over seven years, Rhee and colleagues [8] determined the incidence was 1 per 100,000 man years and 1 per 210 admissions. The overall survival was 19.3% with only modest improvement over time. Naughton and associates [7] examined penetrating cardiac injury over a one year period, including autopsy findings. Their results demonstrated the victims were predominately male [86%], knew their assailant [83%] and assaults occurred more often in the evening in spring and summer. Over half were dead at the scene and another 26% were dead on hospital arrival. Another autopsy study determined death at the scene was most often related to haemorrhagic shock not tamponade [12].

Several studies have attempted to define factors predictive of survival. In a retrospective review of 48 patients the overall mortality was 56%; cardiac chamber injured and weapon used were no different in survivors and non-survivors [9]. In another retrospective study of 50 patients the mortality was 44% and surprisingly those in shock had improved survival [10]. In a larger retrospective examination of 302 patients, Tyburski and coauthors [6] found gunshot wounds were more lethal than stab wound with respective mortalities of 77% and 42% and had not improved over the 20 year study period. Haemodynamic stability on admission, stab wounds and tamponade all were associated with improved survival. In a one year prospective study, Asensio and colleagues [5] reported their results on 60 patients with penetrating cardiac injury. The overall mortality was 63%; 86% for gunshot wounds and 32% for stab wounds. Mechanism of injury and sinus rhythm when the pericardium was opened predicted survival while anatomic site of injury and tamponade did not confer a survival benefit.

Corresponding Author: Dr J O' Connor, Associate Professor of Surgery, University of Medicine, Baltimore, Maryland, USA
Email: joconnor@umm.edu

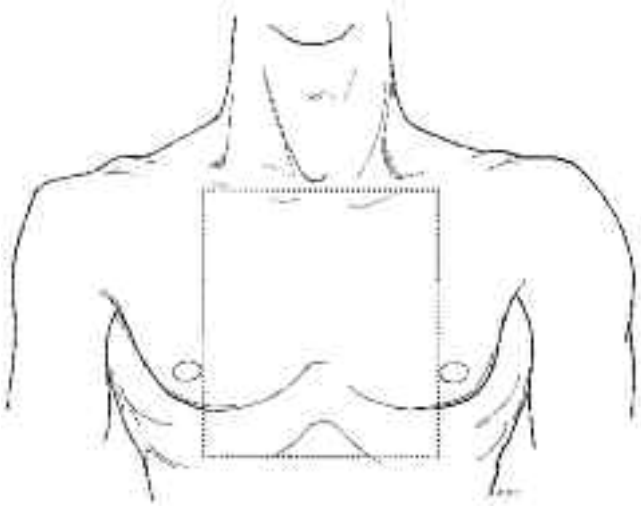

Figure 1: The Cardiac Box.
Penetrating injuries within these borders should raise awareness of a possible cardiac injury. Wounds outside the confines of the "cardiac box" do not exclude cardiac injury.

In a review of 70 patients presenting with penetrating cardiac injuries, unconsciousness and systolic blood pressure less than 50mmHg on admission were independent predictors of mortality [13].

Presentation and Evaluation

While any penetrating injury to the thorax may be associated with a cardiac trauma, those within the "cardiac box", defined as inferior to the clavicles, superior to the costal margin and medial to the midclavicular line, are the most worrisome **[Figure 1]**. This does not imply a cardiac injury can be excluded if the wound lies outside the confines of the "box" [14]. Of note, cardiac injury resulting from stab wounds outside of the precordium had a higher mortality than those within its boundaries [15]. A plausible explanation is, given the location of the wound, cardiac injury was not initially considered.

The clinical presentation of penetrating cardiac trauma covers the spectrum from haemodynamic stability to cardiac arrest. The role of emergency department or resuscitative thoracotomy is discussed in detail in the previous edition. As with all trauma patients a rapid, yet thorough, physical examination is mandatory. Location of wounds, assessment of cardio-respiratory status, heart and lung sounds and, in haemodynamically stable patients, a portable chest radiograph can be expeditiously performed. Penetrating cardiac trauma may result in exsanguinating haemorrhage or cardiac tamponade. With the former, survival depends on swift transport, evaluation and treatment. In the latter, prompt diagnosis and treatment are essential. The rapid accumulation of even a small amount of blood causes increased intrapericardial pressure resulting in decreased venous return, decreased cardiac output, hypotension and, ultimately death. Beck's triad of muffled heart sounds, hypotension and jugular venous distension is the classic description of the signs of cardiac tamponade but is infrequently present. The data on the survival benefit from tamponade remains discordant. While some studies demonstrated increased survival with tamponade [6, 16], other reports have shown no benefit [5, 17]. Transport time and degree of haemodynamic instability are clearly confounding variables when comparing different studies.

Historically, sub-xiphoid window was the gold standard to evaluate for haemopericardium however, echocardiography has now become the modality of choice. Early studies of echocardiography reported sensitivity 56%, specificity 96% and accuracy 90%. Both sensitivity and specificity improved in patients without haemopneumothorax [18]. A prospective study evaluating occult haemopericardium compared echocardiography to sub-xiphoid window. It found echocardiography had a sensitivity, specificity and accuracy of 90%, 97%, 96% respectively [19]. In a prospective, multicentre study of ultrasound in patients with possible cardiac wounds Rozycki and colleagues [20] reported 100% sensitivity, 97% specificity, 97% accuracy and mean time from study to operation of 12 minutes. Subsequent studies have confirmed these findings when the procedure was performed by surgeons [21] or when FAST [Focused Assessment with Sonography in Trauma] was used [22]. The use of either echocardiography or FAST is a rapid, non-invasive, physican performed modality which accurately diagnoses haemopericardium. This results in expeditious, definitive surgical repair and obviates the need for a pericardial window.

A pericardial window can be performed to diagnose haemopericardium if ultrasound is not available or the results are equivocal. Multiple studies have confirmed the accuracy of this technique [23, 24] and, it is also useful in occult cardiac injuries [25]. While some authors advocate a thoracoscopic approach to create a pericardial window we see little utility in the technique

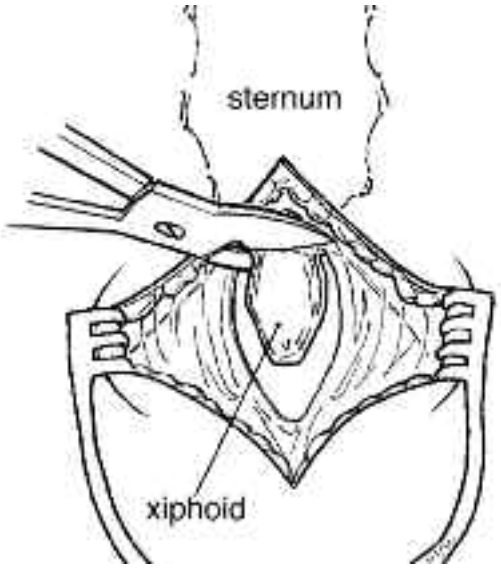

Figure 2: Sub-xiphoid pericardial window I.
Excision of the xiphoid facilitates exposure.

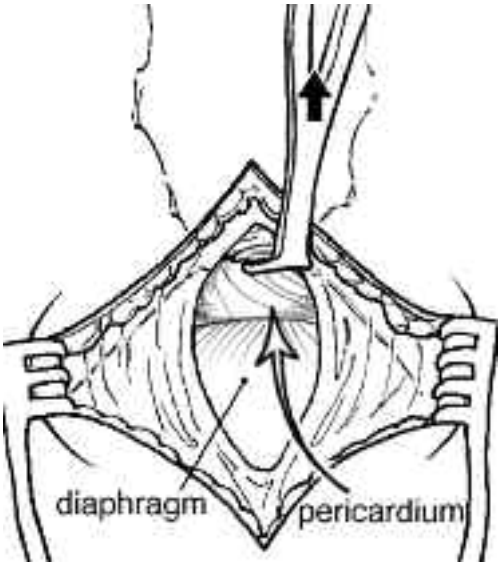

Figure 3: Sub-xiphoid pericardial window II.
Upward traction applied to the distal sternum allows identification of both the diaphragm and pericardium. In larger patients, Trendelenburg's position improves exposure of the pericardium.

[26, 27]. A pericardial window should be performed under general anaesthesia in the operating room. The midline is incised over the xiphoid and it is our practice to excise it as it facilitates further dissection. With the distal sternum elevated with a retractor, the diaphragm is identified and using blunt dissection the pericardium is found **[Figure 2, 3]**. The pericardium is then grasped with Allis clamps or smooth forceps and incised; if blood or clot are encountered a sternotomy is immediately performed. One note of caution needs to be emphasized. Adequate pre-load is essential to prevent further decompensation following haemopericardium and tamponade. The induction of general anaesthesia and positive pressure ventilation tends to decrease pre-load and may result in cardiac arrest. Therefore, in hypotensive patients it is our practice to fully prep and drape prior to the induction of anaesthesia. If haemodynamic collapse were to occur, an incision can be rapidly performed with relief of tamponade.

Incisions and Exposure

Several incisions can be utilized to expose the heart and mediastinum. Each has attendant advantages and disadvantages, and the choice may be influenced by the surgeon's experience and facility with each. While a postero-lateral thoracotomy affords excellent exposure of pleural cavity it allows only limited cardiac exposure. Another disadvantage is it may exacerbate haemodynamic instability, since the lateral decubitus position can result in worsening hypotension. For these reasons we do not use this approach for penetrating cardiac injuries. If an emergent thoracotomy is required it is our preference to divide the sternum and carry the left antero-lateral incision into the right pleural space as a "clamshell thoracotomy". It can be done rapidly, allows adequate exposure of the heart and mediastinum and can be performed by a general surgeon **[Figure 4, 5]**. The main disadvantages of this

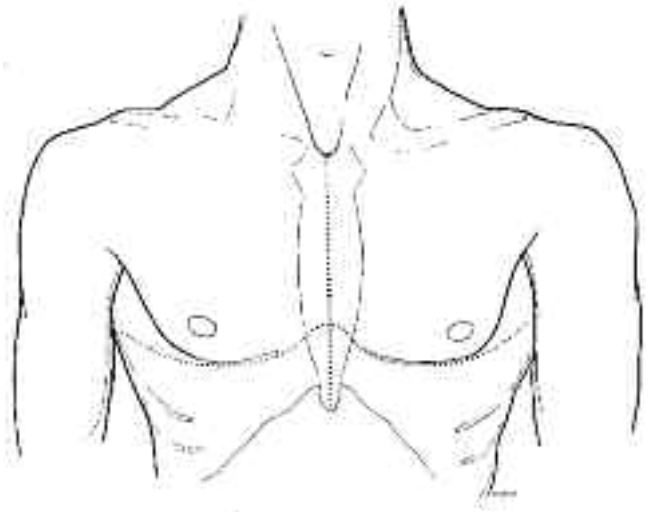

Figure 4: Median sternotomy and clamshell incisions.
The individual surgeon's comfort with a particular incision and the patient's haemodynamics will influence the choice of incision. Note the clamshell incision is carried across the body of the sternum not the xiphoid.

Figure 5: Clamshell incision for damage control
Following significant blunt force trauma and post-resuscitation, the lungs and heart are edematous, preventing primary closure. A modified VAC dressing was placed and the thorax closed two days later. Note the modified VAC for temporary abdominal closure for a concomitant, emergent splenectomy. (Author's photograph – JVO).

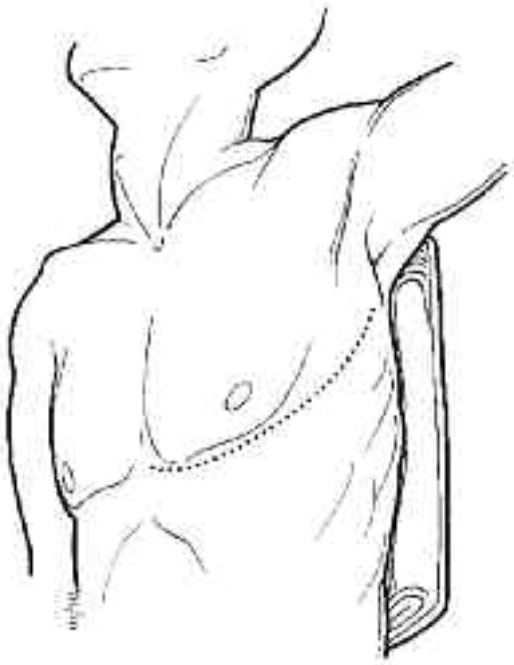

Figure 6: Correct positioning for a left anterolateral thoracotomy.
The incision is made over the inframammary fold and, the placement of a roll or bump under the back greatly improves the exposure especially posterior, toward the ipsilateral axilla.

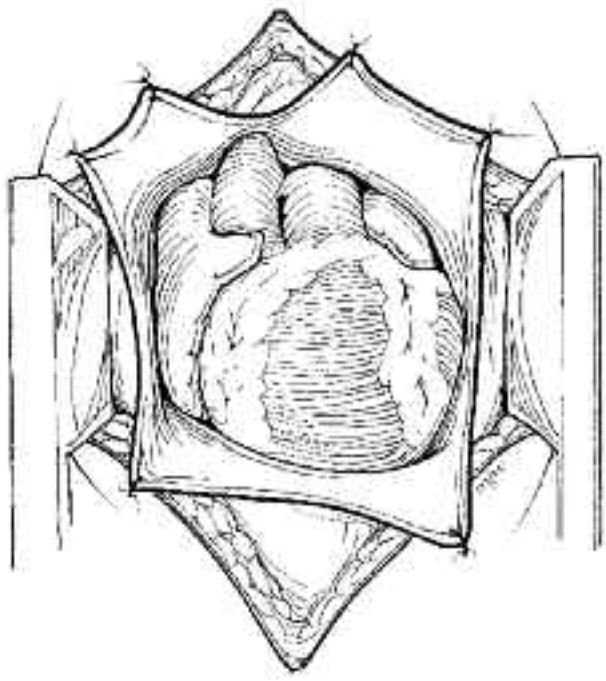

Figure 7: Pericardial sling.
A pericardial sling can be easily constructed by suturing the cut ends of the pericardium to the skin and affords superb exposure of cardiac structures.

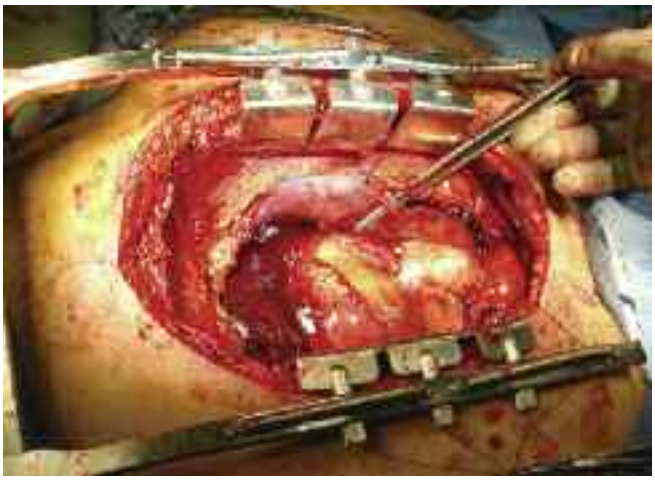

Figure 8: Sternotomy with clotted haemopericardium.
The patient's head is towards the right and a pericardial sling has been constructed. The forceps are through a rent in the pericardium secondary to a stab wound. There was a large right atrial laceration which was primarily repaired. [Author's photograph –JVO]

approach are the incision is often place too inferiorly, and both sternal and thoracic closure may be problematic. The antero-lateral incision should be placed over the inframammary fold and placing a bump of about 20 degrees under the left chest facilitates extension to the ipsilateral axilla **[Figure 6]**. Median sternotomy affords optimal mediastinal exposure, can be performed rapidly and allows repair of the cardiac injury. While cardiothoracic surgeons have more experience with this approach, a well trained general surgeon is more than capable of using this approach to treat cardiac injuries [28].

Whichever incision is chosen, once the mediastinum has been exposed the pericardium must be opened. If an antero-lateral incision is employed, the pericardium is incised anterior to the phrenic nerve. If a median sternotomy is performed the pericardium is opened widely and a pericardial sling can be constructed by tacking the edge of the pericardium to the skin **[Figure 7]**. Following pericardiotomy any haemopericardium can be evacuated **[Figure 8]**. Several techniques are available to achieve temporary control of the cardiac injury including digital control, placement of a Foley catheter and the use of skin staples [29]. The placement of a Foley catheter, while an ingenious idea, has significant limitations, the most serious is the possibility of enlarging the cardiac injury. Once the balloon is inflated and gentle traction applied, it is difficult to secure and easy to dislodged, thus enlarging the wound. Skin staples have also been used successfully to gain temporary closure of cardiac wounds [30, 31]. We favour digital control since it is a simple and direct method. It need not completely stop cardiac bleeding but rather decrease it and facilitate definitive repair

Cardiac Repair

Atrial wounds are often easier to repair than ventricular since the former are low pressure chambers and the injury may be controlled with a vascular clamp. After the vascular clamp is applied the repair is performed with 3-0 or 4-0 Prolene* using either a simple running or horizontal mattress. The thin atrial walls, which are prone to tearing, require precise suture placement and for that reason we favour a mattress repair. Injuries to the left atrium while infrequent present a challenge given its posterior location. Likewise, injuries at the junction of the right atrium and inferior vena cava are also difficult to manage. Temporary control can occasionally be obtained by sequentially placing Allis clamps and then repairing the vessels [32]. Ventricular injuries resulting from stab wounds can be repaired with 3-0 Prolene either as a simple running suture or an interrupted horizontal mattress. Larger wounds, especially those resulting from gunshot wounds, are closed with interrupted horizontal mattress sutures. A larger curve of the needle facilitates engaging the tissue at right angle and it is essential to drive the needle following its curve. We believe most cardiac injuries can be closed without Teflon pledgets and use them if the ventricular wall is friable, as they more evenly distribute tension when the suture is tied. Three other important technical details are to take an adequate bite of the myocardium. There is a tendency, especially among inexperienced surgeons, to take a small myocardial bite with the suture. If a superficial bite is taken, the risk of tearing the tissue increases. While it may seem counterintuitive, a larger myocardial bite will yield a more secure repair. The second is timing the suture to ventricular contraction, as this will also minimize myocardial tearing. Finally, while the right ventricle is generally a low pressure chamber, it has less myocardial wall thickness than the left and is more prone to tearing if inadequate tissue bites are employed.

Adjuncts and Special Circumstances

Several adjunctive measures are available to assist cardiorraphy including, temporary in-flow occlusion, methods to facilitate repair of posterior cardiac injuries, adenosine infusion and the use of cardiopulmonary bypass for post-cardiorraphy resuscitation [33-37]. Although temporary inflow occlusion appears an attractive option it is of limited value in a hypotensive, acidotic patient [33]. Posterior cardiac wounds present a problem as they require lifting the heart, which often leads to profound hypotension, bradycardia and possibly arrest. The approach we have adopted is to lift the heart, assess the injury and return the heart to its normal position. The same technique is used to place the sutures, often they can not be tied when they are placed, and the heart is again returned to its normal anatomic position. After a period of recovery the heart is again lifted and the sutures tied. This technique demands patience on the part of the surgeon and close cooperation with the anaesthesia team. The infusion of adenosine causes temporary asystole thus facilitating cardiac repair and is particularly useful when precise suture placement is required, as in proximity to coronary arteries or conduction system [35]. Slowing the heart rate by infusion of a β-blocker, while an option, must be carefully considered because of its negative inotropic effect on already compromised myocardial function

Injuries in proximity to the coronary arteries require special attention. Clearly the danger is that the suture placed to repair the myocardial injury may compromise or occlude coronary blood flow. Therefore the sutures need to be placed precisely, deep to the coronary artery itself [4, 38]. In this circumstance we avoid using pledgets as they may increase the likelihood of compromising coronary flow. If the coronary artery is lacerated, several alternatives are available. If the coronary is a small branch or if the laceration is in the distal third, ligation is an option. If the proximal coronary artery is lacerated, particularly the left anterior descending, coronary artery bypass is needed which may or may not require cardiopulmonary bypass and cardioplegic arrest [4, 39]. Cardiopulmonary bypass has also been used for haemodynamic support after cardiorraphy [36-37]. Cardiac injuries which have the potential to cause septal or valvular damage also demand specific consideration. Occasionally a left to right shunt, from a septal injury or aorto-pulmonary artery fistula, can be detected at the time of operation. The pulmonary artery may be distended and have a palpable thrill. Most post-traumatic valvular lesions present as insufficiency but, unless they are profound are generally not diagnosed at the time of cardiac

* Polypropylene suture. Ethicon, Inc Somerville, New Jersey, USA

repair. We have found intra-operative transoesophageal echocardiography to be an excellent diagnostic modality [14].

The last special circumstance is damage control. Occasionally after cardiac repair the thorax can not be closed without significant haemodynamic compromise. The additive effects of hypotension, acidosis, volume resuscitation and cardiac distention may prevent chest or sternal closure. The temporary use of a modified vacuum closure minimizes the risk of worsening hypotension and increasing airway pressure. Following the initial surgery, resuscitation continues in the intensive care unit. When physiologic parameters have normalized, definitive closure is accomplished usually within 48 hours of the damage control operation [40, 41]. Following resuscitation, and if the haemodynamics allow it, diuresis greatly facilities closure. Occasionally it is only possible to close the skeletal thorax and not the chest wall musculature. In these instances we employ a Vacuum Assisted Closure [VAC] over the bony thorax and staged closure of the muscle.

Future Therapy

There is interesting and potentially revolutionary research using therapeutic hypothermia in the treatment of haemorrhagic shock resulting in arrest. Therapeutic hypothermia has been effective and advocated in the treatment of non-traumatic cardiac arrest [42-45]. The application of this therapy to the treatment of exsanguinating trauma patients is a natural extension of the concept of damage control [46, 47]. Uncurbed haemorrhage is lethal and inducing hypothermia, with its protective physiologic effects, allows precious time to control the exsanguinating bleeding. Several experimental studies, with various animal models subjected to exsanguinating haemorrhage, have demonstrated its efficacy [48-51]. In spite of the use of different animal models and slight differences in the degree and duration of hypothermia, it is clear that emergency therapeutic hypothermia is an extremely useful modality in the treatment of exsanguinating haemorrhage. The application of this technique in humans is but a matter of time.

Conclusions

Penetrating cardiac injuries, with its attendant mortality, presents formidable clinical challenges. There is no other injury which demands expeditious diagnosis, rapid surgical exposure and adherence to precise technical principles. If these tenets are followed in treating this deadly injury, reasonable survival can be achieved.

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