THE CURRENT MANAGEMENT OF PENETRATING CARDIAC TRAUMA

A Dissertation presented by

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Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any other university for a degree.

Signature:

Date:

SUMMARY

The vast majority of patients with penetrating cardiac injuries do not reach the hospital alive as the pre-hospital mortality rate for these injuries is in the region of 86%. The patients that do reach the hospital alive are potential survivors and it is obviously crucial that any cardiac injury is detected and managed appropriately. Most of these injuries present with either cardiac tamponade or hypovolaemic shock and are relatively straightforward to diagnose and require immediate surgery. There is, however, a group of patients that are relatively stable with an underlying cardiac injury and it is in these patients that a potential or occult cardiac injury needs to be identified.

Dr Ken Mattox, doyen of international trauma surgery, stated in 1989 that; "Today's controversy relates to two issues. One, detection of occult heart injuries in a stable patient, and second, the choice of an incision or other test to detect that occult and maybe innocent injury." This thesis is primarily aimed at an attempt to answer these two questions as well as a number of other questions pertaining to cardiac injuries that have plagued me in my role as a trauma surgeon working in a Trauma Center with a high volume of penetrating chest injuries.

The current screening tests that are being used to detect cardiac trauma have been examined. There appears to be a move away from the clinical assessment of patients to the use of pericardial ultrasound. Ultrasound does indeed play a very important role and is extremely useful but like any test, it has its limitations. It is possible that we as clinicians are missing cardiac injuries from an over-reliance on cardiac ultrasound. In this study a number of clinical parameters were examined and found to be extremely useful in the diagnosis of a cardiac injury. The central venous pressure measurement, the chest x-ray and the electrocardiogram were found to play a valuable role in the screening of cardiac trauma. Several studies were devised to look specifically at these clinical parameters in order to determine if they can improve the sensitivity in diagnosis. In particular, these studies have shown that a central venous pressure of greater than 12cm H20, a new radiological sign on chest x-ray called the "left straight heart border", and a new diagnostic sign on the

electrocardiogram called the “J wave”, are all present in a hemopericardium and will improve diagnostic acumen.

The current surgical thinking is that all patients with a hemopericardium after penetrating cardiac trauma should undergo immediate surgery and repair via a median sternotomy. This algorithm is absolutely essential for the patient presenting lifeless, critically unstable or with cardiac tamponade. But what of the patient who is completely stable? In South Africa, as in many parts of the world, intensive care beds are in great demand and emergency theatre lists are under pressure. This has often led to delays in these stable patients reaching theatre. The question as to whether another management option existed was thus raised. We observed during clinical practice that this particular select group of cardiac injuries could potentially be managed with a subxiphoid pericardial window performed within 24-hours after admission. The pericardial window is undertaken to determine if there is any active bleeding from the heart (unstable clot) or not; in the presence of active bleeding, a median sternotomy is performed and the cardiac injury repaired. In the absence of active bleeding the patient can be safely managed with a pericardial drain in a post-operative high care unit without the need for a sternotomy. This hypothesis was tested in a prospective, randomized clinical trial, the first of its kind in the literature on penetrating cardiac trauma.

The other issues considered in this thesis is the diagnosis of occult cardiac injuries in patients with thoracoabdominal penetrating wounds in the proximity of the heart, who require a laparotomy for an acute abdomen. In addition, the management of the pneumopericardium in hemodynamically stable patients was prospectively studied. A new management algorithm based on the findings of a high proportion of patients with a tension pneumopericardium was devised. The problem of the missed cardiac injury was also studied and the most appropriate management determined. The thesis has been completed with a recommended screening protocol for cardiac wounds.

I feel confident that this thesis will contribute to the knowledge and aid in the diagnosis and management of penetrating cardiac trauma.

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FOREWORD

The evaluation and comparison of the numerous clinical reports on penetrating cardiac injuries proved to be a difficult task. There were a number of reasons for this. The vast majority of cardiac trauma studies reported in the literature were retrospective in nature and comprised information that in many cases had been collected over a period of 10 to 20 years. There were only a total of 15 prospective studies in the literature on penetrating cardiac trauma and 4 of these were related to the role of ultrasound in screening for cardiac trauma (table 1).

Table 1. Prospective studies conducted in the literature on penetrating cardiac injuries.

Author	***Year***	***Number of Cardiac Injuries***	***Topic***
Heller et al[1]	1974	27	Post traumatic cardiac complications
Michelow et al[2]	1987	9	Conservative management
Hirshberg et al[3]	1989	14	Pitfalls in management of chest trauma
Jimenez et al[4]	1990	9	ECHO versus SPW for screening
Buckman et al[5]	1993	66	Factors affecting the resuscitation
Ordog et al[6]	1994	4	Stab wounds to the chest
Ma et al[7]	1995	6	Ultrasound screening
Meyer et al[8]	1995	9	ECHO versus SPW for screening
Rozycki et al[9]	1995	6	Ultrasound screening
Rozycki et al[10]	1996	10	Ultrasound screening
Asensio et al[11]	1998	60	Predictors of outcome
Asensio et al[12]	1998	105	Predictors of outcome
Rozycki et al[13]	1998	22	Ultrasound screening
Rozycki et al[14]	1999	29	Ultrasound screening
Taval et al[15]	2004	8	Ultrasound screening

Furthermore, the prospective studies that had been conducted were limited by very small numbers of actual cardiac injuries, with most including less than 30 patients and only 3 having numbers greater than 60 patients. The studies that looked at the role of ultrasound (US) for screening did not confirm their true negative results of the US with surgical findings, but considered the finding a true negative if the patient did not return to the hospital. It is for this reason that all the clinical studies in this thesis have used a subxiphoid pericardial window (SPW) as the gold standard for a comparison of the various screening modalities in their ability to detect a hemopericardium.

There have been no randomized clinical trials conducted in patients with penetrating cardiac trauma, with respect to either screening or surgical management. The management guidelines for penetrating cardiac injuries have been based predominantly on these retrospective series from centres that are mostly seeing less than 20 cardiac injuries per year.

In addition, there is a lack of standardization with regard to the nomenclature used in the literature. For example, cardiac tamponade, which should normally apply to cases of the clinical scenario arising from compression of the heart by blood/clot in the pericardium, is often used to describe the mere presence of blood in the pericardial sac.

The pre-hospital mortality rate for penetrating cardiac injuries is extremely high. Countries with efficient trauma systems and rapid transportation have a higher in-hospital mortality rate than those countries without these systems in place as a result of the most severe cases arriving alive in the hospitals. This makes an evaluation of survival rates between institutions difficult. Studies on mortality that include the pre-hospital deaths report a very low overall survival rate.[16]

The physiological status on the patient on arrival is of vital importance with respect to survival. Although a physiological grading system has been proposed in the literature this has not been universally adopted.

It is well recognized that gunshot wounds to the heart have a much higher mortality than stab wounds and an analysis of any series needs to look closely at the mechanism of the trauma. Studies that are predominantly stab wounds have higher survival rates than those where gunshot wounds predominate.

All these factors have to be considered when examining the results of the studies on penetrating cardiac injuries (PCI). “Only with serious scientific enquiry based on prospective collection and analysis of data can we extend the frontiers in the management of devastating injuries, much like Cappelen, Farina and Rehn did over 100 years ago.”[17]

ABBREVIATIONS

AAST	American Association for Surgery in Trauma
ATLS	Advanced Trauma Life Support Course
BP	Blood Pressure
CIS	Cardiac Injury Score
CT	Computerized Tomography
CVP	Central Venous Pressure
ECG	Electrocardiogram
ECHO	Echocardiogram
ERT	Emergency Room Thoracotomy
DSTC	Definitive Surgical Trauma Care Course
GSW	Gunshot Wound
Hb	Hemoglobin
ICU	Intensive Care Unit
PCI	Penetrating Cardiac Injury
PI	Physiologic Index
RCT	Randomized Controlled Trial
RTS	Revised Trauma Score
SLHB	Straight Left Heart Border
SPW	Subxiphoid Pericardial Window
US	Ultrasound

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SECTION A

HISTORICAL PERSPECTIVE

> "When a patient comes under observation after a severe injury to the chest caused by a fall, or from being run over, kicked by a horse, gored by an ox, transfixed by the pole of a van or a carriage, shot accidently by a friend, designedly by an adversary, or intentionally by himself; stabbed in a fit of jealousy, or in a civil broil, or in revenge, and in one or other of a thousand and one ways in which such injuries are produced, it remains for the surgeon to decide whether the heart is injured, and if the heart has received serious injury."[18]

John Bland-Sutton in 1908.

Surgeon at the Middlesex.

CHAPTER 1

HISTORY OF CARDIAC TRAUMA SURGERY

The history of surgery is not only fascinating but also provides an insight into the various treatment modalities that have been tried with respect to penetrating cardiac trauma. There was a time when simple conservative management of a cardiac wound provided a better survival than surgical intervention. Pericardiocentesis was the treatment of choice for decades and yet today the majority of trauma surgeons condemn the practice. Immediate surgery has now become the management algorithm of choice for all cardiac wounds. It is important for us to interrogate how this came to be established and examine the evidence behind the shift from conservative to emergency surgical intervention.

The ancient Egyptians, although realizing the importance of the heart, were at the forefront of developing an aura of mysticism and superstition that enveloped the heart for centuries. The Egyptian Book of the Dead (ca 1567 B.C) provides a description of the underworld judgment scene. [19, 20] On entry to the underworld the jackal-headed Anubis weighed the heart of the deceased against a statue of the goddess of truth and justice. If the double pan balance was evenly balanced there was admission ……"to the company of Osiris and the blessed; if not, if his heart was heavy and laden with sin, it was cast to the devouring beast Ammit." [21]

Homer was the first author to narrate a cardiac injury in the classical epic the Iliad (ca. 950 B.C), when the Greek commander, Idomeneus, killed the Trojan, Alkathoos.[22]

> " Idomeneus smote him with a thrust of his spear full upon the breast, and clave his coat of bronze around him, that aforetime ever warded death from his body, but now it rang harshly as it was cloven about the spear. And he fell with a thud, and the spear was fixed in his heart, that still beating made the butt thereof to quiver."

The Iliad and the Odyssey contain numerous references to cardiac injuries.[23] Achilles best friend, Patroclus, killed Sarpedon, the son of Zeus, with a spear to the heart.

> "The prostrate prince, and on his bosom trod;
> Then drew the weapon from his panting heart,
> The reeking fibers clinging to the dart;
> From the wide wound gush'd out a stream of blood,
> And the soul issued in the purple flood."

Hypnos (sleep) and Thanatus (death) were sent by Zeus to carry Sarpedon's body from the battlefield to be buried in Lycia.[24]

Hippocrates recognized their fatal nature but made no other mention of cardiac injuries except to confirm their lethality. "A severe wound of the bladder, of the brain, of the heart, of the diaphragm, of the small intestine, of the stomach and of the liver is deadly."[25, 26]

Aristotle (384-322 B.C.) wrote that "The heart again is the only one of the viscera, and indeed the only part of the body, that is unable to tolerate any serious affection. This is but what might reasonably be expected. For, if the primary or dominant part be diseased, there is nothing from which the other parts which depend upon it can derive sucour." [27, 28]

Celsus (1st century A.D.) recognized the clinical features of shock associated with a cardiac injury when he wrote in De Medicina that "When the heart is wounded much blood is lost, the pulse weakens, pallor becomes extreme, a cold and foul sweat arises from the stricked body, the extremities become cold and speedy death follows."[26, 29]

Pliny the Elder (23-79 A.D.) felt that the heart "is the only one among the viscera that is not affected by maladies, nor is it subject to the ordinary penalties of human life; but when injured, it produces instant death."[26, 30]

Claudius Galen (130-200 A.D.) expressed his sentiment of the hopelessness of a cardiac wound.

> "When a perforation penetrated in one of the cardiac ventricles, they (the gladiators) died on the spot, mainly by blood loss, and even faster if the left ventricle was injured. When the penetrating object did not pass through the cardiac cavity but stopped at the cardiac muscle, some of the wounded gladiators lived through the very day on which they were wounded as well as the following night; they eventually died later because of an inflammation." [21]

Ambrose Pare described cardiac wounds but made no suggestions with respect to treatment. He considered the heart to be the harbor of the soul. "The heart is the chief mansion of the soul, the organ of vital faculty, the beginning of life, and the fountain of the vital spirits, and so consequently the continued nourisher of the vital heat, the first to live and the last to die." [31,32, 33]

Boerhaave and Fallopius (1523-1562) were adamant of the fatality associated with cardiac injuries. Fallopius is quoted as saying that "wounds of the heart are always followed by sudden death. When wounded it cannot heal, being too firm, always in motion, and of inflammatory heat."[26, 34, 35]

The teaching of Hippocrates, Aristotle, and Galen that all heart wounds were fatal was adhered to until the 16th Century until Cabriolanus contradicted this teaching. In 1604 Cabriolanus discovered in autopsy studies on hanging victims a case of a healed scar of the heart and in a second victim an unhealed cardiac wound.[32, 36] The idea that not all cardiac wounds were fatal was also suggested by Holerius.[26, 37]

Morgagni in 1761 was the first to recognize cardiac tamponade from an injury of the coronary artery and that blood in the pericardial sac could compress the heart and restrict its movement.[38]

The nihilism surrounding cardiac injuries continued and in 1804 John Bell published his "Discourses of nature and care of wounds" declaring that "there is so little to be done …..and the signs and consequences are so clear, that it is a waste of time to speak longer of wounds of the heart." [23, 39]

There is a dispute as to who shall be named as the first cardiac surgeon of our time. The two contenders are the extremely well-known Baron Larrey and the almost unheard of Catalonian surgeon called Francisco Romero. It would appear that these two men performed the first open pericardiotomy at approximately the same time.

Francisco Romero of Barcelona performed an open pericardiotomy on a patient with a pericardial effusion around 1810. He presented his memoir entitled "Observatio experimentis confirmata, pro hydrope pectori, pulmonum anasarca, et hydropericardio Cognoscendis; et nova methodus dittos morbos operandi" in 1815 to the Society of the School of Medicine in Paris in 1815. An incision was made over the costal cartilage of the 6th rib and after opening up the pericardial sac the fluid was allowed to drain into the pleural space. These open surgical procedures were viewed at the time as being unnecessarily aggressive and the Society did not endorse his ideas.[40]

Baron Dominique Jean Larrey, the Surgeon-in-Chief of Napolean's Imperial Guard, made a number of contributions to trauma surgery. He invented the "Flying amubulance" to rescue the wounded from the scene of battle whereas previously casualties were considered to be a nuisance. He introduced a

system of triage to manage patients according to the severity of their wounds and also successfully decompressed the pericardial sac of a patient with a wounded heart by catheter drainage. A sound was passed and 7 beakers of wine colored fluid was drained via a catheter. He was also able to demonstrate on dogs that cardiac injuries were not always fatal.[41, 42]

The pericardiotomy that was performed by Baron Larrey was conducted on Bernard Saint-Ogne, a 30-year old infantryman who had attempted suicide after being accused of an offence that he did not commit, on the 18th March 1810.[43]

> " Larrey's patient was a man, aged 30, who stabbed himself with a knife in the left side of the chest; the pericardium and the left lung were wounded, the knife passed through the fifth costal cartilage and was still in the wound when he was brought into hospital. Frothy blood escaped in jets with each systole. The knife was withdrawn and the wound dressed with plaster; the patient tore off the dressing and it was reapplied. The pulse was rapid and there was grave dyspnoea. Bleeding gave some relief. Some improvement took place, but later on he became worse, and in great distress requested Larrey either to open his chest or to give him a narcotic strong enough to send him to sleep. Operation 45 days after injury, incision through the skin and cellular tissue in the fifth space below the nipple, carefully carried deeper until pericardium felt. With the left index finger on the pericardium as a guide an incision into the pericardium was made with a bistoury, the finger inserted, and the apex of the heart felt. About a liter of fluid with some blood clot escaped. Great relief. In ten days the wound closed and the symptoms recurred. Wound reopened with a probe, 4 oz. of pus escaped. Considerable improvement. Death 68 days after injury and 23 after the operation. Autopsy: Suppurative mediastino-pericarditis."[32]

Despite the advent of these open surgical approaches, the management of cardiac injuries in the beginning of the 19th Century consisted of venesection, leeches, absolute quiet and an attempt to evacuate fluid by passing a sound into the wound.

In 1854 Baron Dupuytren stated in his book that,

> "Only a few years ago it was considered an incontrovertible fact that wounds of the heart are instantly fatal. Latour, in his "History of essential and proximate causes of Hemorrhage", (vol . i., p. 75), reported a very singular case of a soldier, in whom, six years after his cure, a ball was extracted from the right ventricle, near to the apex of the heart, and partly covered by the pericardium. Finally, individuals have recovered, in whom there was every reason to suppose from the symptoms, that the heart had been injured. These facts, and others I shall adduce, prove that wounds of the heart are not instantly fatal, and even that, under certain circumstances, they may be cured. Indeed this conclusion is generally admitted by educated surgeons, as regards wounds penetrating the ventricles or auricles……"[44, 45]

In a publication by Georg Fischer of Hannover in 1868 on 452 cases of cardiac injury treated by pericardial aspiration and venesection the mortality rate was 85% with 15% of these patients having a spontaneous cure.[46]

Billroth in 1875 condemned both pericardiocentesis and any surgical attempts at repairing the wounded heart. "Paracentesis of the pericardium is an operation which, in my opinion, approaches very closely to that kind of intervention which some surgeons would term a prostitution of the surgical art and other madness."[31] He also remarked that "A surgeon who tries to suture a heart wound deserves to lose the esteem of his colleagues."[33, 47, 48]

In 1876 Gottard Bulau of Hamburg developed the system of the underwater drainage of the pleural cavity. This was a huge milestone in the progress of managing penetrating chest trauma and overcoming the inherent problem of the associated hemopneumothorax and allow for re-expansion of the lung.

In 1896 Paget wrote that: "The surgery of the heart has probably reached the limits set by nature to all surgery; no new method and no new discovery can overcome the natural difficulties that attend a wound of the heart. It is true that heart suture has been vaguely proposed as a possible procedure and has been done on animals, but I cannot find that it has ever been attempted in practice."[49]

In 1889 Valerius Idelson wrote in an editorial in the Annals of Surgery that cardiac injuries were considered not really to be amenable to surgery and as a result they received very little attention in the medical literature.[50] However, there was about to be a radical shift to surgical management.

De Vecchio demonstrated the feasibility of cardiac repair in dogs by showing a healed wound in the heart of a dog to the Eleventh International Medical Congress in Rome in 1895.[51]

Ansel Cappelan of Norway then performed the first unsuccessful suture of the human heart in 1895. [52] The patient was a 24-year old male who had been stabbed in the left chest in the 4th intercostal space and had presented with symptoms of cardiac tamponade. He was anesthetized with chloroform and a 4th and 5th rib resection was performed and the pericardium was distended with blood. This was opened and a 2cm injury to the left ventricle was sutured with chromic catgut and the left anterior descending coronary artery was ligated. The patient died 2 days later from what was considered to be a pericarditis and anemia.[24, 26, 53, 54]

Dr Guido Farina of Rome sutured the right ventricle in a 30-year old man who had been stabbed in the left chest with a fine dagger at the Spedale della Consolazione in March of 1896. The 5th costal cartilage and rib were removed and five silk sutures were placed into a 7mm wound of the myocardium. On the 8th post-operative day the patient died from a bronchopneumonia but at autopsy the heart was found to be perfectly healed.[18, 55]

The first successful cardiac repair was performed by Dr Ludwig Rehn of Frankfurt on the 9th September 1896.[56] A 22-year old man, Wilhelm Justus, was brought to the hospital after sustaining a penetrating wound in the fourth interspace in a state of collapse. Stimulants were administered

which was followed by improvement but 24-hours later his condition was so much worse that the patient was operated upon. Ether was used for narcosis.[57] A resection of the 5th left rib was undertaken and the pleura was cleared of blood.

Dr Rehn describes the operation further;

> "There is continuous bleeding from a hole in the pericardium. This opening is enlarged. The heart is exposed. Old blood and clots are emptied. There is a 1.5cm gaping right ventricular wound. Bleeding is controlled with finger pressure……I decided to suture the heart wound. I used a small intestinal needle and silk suture. The suture was tied in diastole. Bleeding diminished remarkably with the third suture, all bleeding was controlled."

The post-operative period was complicated by a pneumothorax and chronic infection but the patient made a complete recovery and returned to work.[28, 58]

In his address to the German Society of Surgery, Rehn said "the feasibility of cardiorrhaphy no longer remains in doubt……..I trust that this case will not remain a curiosity, but rather, that the field of cardiac surgery will be further investigated. Let me speak once my conviction that by means of cardiorrhaphy, many lives can be saved that were previously counted as lost."[21, 58]

Duval described the median sternotomy in 1897 and many of the French success in dealing with thoracic injuries during the great-war was due to this technique.[59] The need to prevent entering the pleural cavity resulted in the development of a number of extrapleural approaches to the heart.

Walter Kirchner, a surgeon from St Louis successfully repaired a stab to the left ventricle approached interpleurally via a left sternal flap and read before the Southern Surgical and Gynecological Association in 1909 that; "one must be convinced that injuries to the heart can no longer be considered as invariably fatal, but that the heart may be manipulated and treated surgically just as any organ of the body."[60]

In 1909 Charles H. Peck of New York reported the successful suture of an injury to the right auricle in a 24-year old girl that presented with cardiac tamponade with the pulse returning after the pericardial sac was excised and 300cc of blood evacuated. He tabulated 161 cases of primary suture of the heart in the medical literature from America, France, Germany, Spain, Italy, Canada and England with no surgeon having reported more than three cases. The overall operative mortality of sutured heart wounds was in the order of 64%.[61]

Brewster in 1911 coined the term cardiac tamponade; "as the hemorrhage increases, the pericardial opening sometimes becomes occluded and the condition known as cardiac tamponade arises."[62] Luxembourg emphasized the clinical feature of cardiac tamponade that a patient with symptoms of air hunger, shortness of breath and pain will obtain relief by adopting a sitting posture.[63]

Between 1912 and 1914 there were more than 75 cardiac operations and the mortality rate appeared to be diminishing with an overall rate of around 45%.

Claude S. Beck from Cleveland, Ohio made a number of contributions in our understanding of the management of penetrating cardiac injuries. In 1926 he described the physiology and clinical signs of cardiac tamponade.[26]

Pericardiocentesis was still being practiced by a large number of surgeons. Singleton in 1933 aspirated 250cc of blood from the pericardium of a patient with a stab wound and affected a cure without operative intervention.[64]

The technique of elevating the superior vena cava with a finger to stop the bleeding thereby allowing the vein to be sutured was described by Bigger and Wilkinson in 1933.[65] Olim and Hughes reported in 1939 the ligation of the mid-portion of the left anterior descending artery and vein after a stab wound to the left ventricle adjacent to the coronary artery. There was evidence of a myocardial infarct on the electrocardiogram but the patient survived.[66]

In 1943 in a paper entitled; “Further observations on stab wounds of the heart,” Beck described the traction suture for hemorrhage control, the technique of mattress repair of a wound adjacent to a coronary artery and conducted animal experiments showing the lack of effect of intravenous fluids on arterial blood pressure with cardiac tamponade.[67] He described his technique of stopping bleeding from the heart; “The best way to stop bleeding from a ventricle is by placing a finger *upon* and not *in* the wound. It is difficult, or impossible, to keep the finger on the wound because of movement. It slides off and there is a squirt of blood. However, it can be kept on the wound fairly well, if a suture steadies the heart. Placing a suture in the apex of the heart can do this and holding this suture between the thumb and third finger of the left hand while the index finger of that hand is placed upon the wound. In this way the hand moves with the heart and you do not get so many squirts of blood.”

The apex was selected for the traction suture as it is quickly accessible to the surgeon and is far away from the major coronary arteries. The heart wound can then be repaired. Griswold also acknowledged the advantage of inserting the traction suture in cardiac wounds; “There is nothing more disconcerting than to hold in one’s hand a writhing, jumping heart and blindly attempt to find a wound deep in a gushing whirlpool of blood. The insertion of a traction suture converts this stage of the operation from futile blundering into an orderly process. The traction suture steadies the jumping organ so that a finger may be placed over the opening to temporarily staunch the flow.” [68]

Elkin adopted the method of cardiac repair of placing a temporary suture under the finger and across the wound with traction on this suture providing hemostasis.[23]

A United Sates surgeon based in London, Dr Dwight Harken, removed 134 missiles from the mediastinum, which included 13 from the heart, during the Second World War without any mortality.[69] He wrote of his experience;

> “ To remove the missile, the heart was often split wide open, with tremendous blood loss. Rapid, massive, blood transfusions were needed

> to keep the patient alive. Whole blood was often administered, under pressure, at rates up to one and a half liters per minute. Penicillin, which was just beginning to make an impact on thoracic surgery, was often given in 10,000 unit injections." [28, 70]

Cardiac tamponade was noted by Paul Samson, an American surgeon based at a forward hospital during the Second World War, to be an unusual presentation in war wounds in stark contrast to civilian cardiac injuries as the missiles were larger and the wide pericardial tears allowed for drainage of the pericardial sac into the chest.[71]

The Second World War saw a step back towards conservative management of cardiac wounds. This was due to the perception of a high mortality associated with cardiac repair (between 25-30%) and the fact that a number of selected cases recovered without operative intervention. An era of conservatism returned to the surgical management.[72, 73] Dr Alfred Blalock introduced pericardiocentesis as the definitive treatment for cardiac wounds presenting with tamponade. In 1943 Blalock and Ravitch described the survival of 3 out of 4 patients treated conservatively.[74] In 1949 they reported the survival of 7 patients with cardiac tamponade with aspiration of the pericardial sac. [75] Blau in 1945 reported on 27 cases of penetrating cardiac injuries. The mortality rate of 17% achieved with aspiration alone compared favorably with the operative intervention rate of 24%.[76]

The majority of surgeons adhered to this conservative view operating only when there was external hemorrhage into the thoracic or peritoneal cavity, when there was a failure of pericardiocentesis to relieve symptoms or when the tamponade recurred. There was, however, a small body of surgeons that maintained that there should be immediate surgical intervention in these injuries regardless of the circumstances.[77-79]

In 1951 Elkin et al from Atlanta, Georgia were still recommending a trial of aspiration of the pericardial sac in all cases of cardiac injury while the operating room was being prepared. In selected cases careful observation would be continued if the patient responded positively to the

pericardiocentesis. They managed 18 patients with stab wounds to the heart with this protocol and surgery was only undertaken in one patient. Of the 17 patients treated conservatively there was one death for a mortality rate of 6%.[73] Cooley et al in 1955 wrote that they were in complete agreement with Ravitch, Blalock and Elkin in their recommendation that the initial treatment of a penetrating injury to the heart should be non-operative and that attempted cardiac repair should be reserved for those patients that do not respond.[80]

In the early 1950's rarely was a patient operated upon in most centers until there had been several attempts made at pericardiocentesis.[81] Towards the end of the decade there was a progressively increasing tendency to early thoracotomy in unstable patients after a single aspiration of the pericardial sac. This move towards early operation may well be attributed to the advent of cardiac surgery and the beginnings of the development of a trauma service in the USA.

In the 1960's mandatory surgical exploration versus conservative management with pericardiocentesis remained a controversial issue.[82] In 1966 in the Journal of the American Medical Association, Wilson reviewed 200 penetrating wounds of the pericardium from Wayne State University College of Medicine in Detroit and concluded that cardiac repair should be performed rapidly on all patients except those patients who maintain normal vital signs after pericardiocentesis. In their series, nine patients out of the 200 (4.5%) had sufficient improvement after pericardiocentesis so as to avoid any further surgery. One of these nine patients died. [83]

The majority of surgeons were convinced at this time that the best form of therapy for severe hemorrhage from a cardiac wound was cardiorrhaphy but doubt still remained about the management of cardiac tamponade. Many felt that those patients with the diagnosis of what was termed a "pure" tamponade could be reasonably managed with pericardiocentesis alone. A "trial of therapy" was starting to be adopted by a number of centers but then it was being documented in several series that the outcome of patients was poor if they had undergone cardiac repair only after responding poorly to pericardiocentesis.[84]

A number of studies in the 1960's stressed the danger of a delay in cardiac surgery. In Wilson's study the patients operated on within 30 minutes had a mortality of 10% versus 26% in those whom had surgery at a later time. Beall et al reported a dramatic increase in mortality from 27% to 63% resulting from time delay caused by a failure of pericardiocentesis to relieve a tamponade.[81, 85]

In 1968 Yao et al published their series of 80 penetrating cardiac injuries. They had managed cardiac injuries between 1959 till 1965 with pericardiocentesis. If the patient responded then nil else was done. Only if there was no clinical response to pericardiocentesis or there was recurrent accumulation was a thoracotomy undertaken. This management protocol changed dramatically after 1965 when all patients with the diagnosis of stab wound to the heart were managed with an emergency thoracotomy. Nineteen out of their 80 patients died (24%) and this mortality dropped to 5% between 1965 to 1967 when all patients were taken to thoracotomy with or without pericardiocentesis. They attributed this drop in mortality to more rapid triage with the development of a trauma service and an increased interest in traumatic injuries. This is indicative of the quite dramatic shift in the management of penetrating cardiac trauma from pericardiocentesis to operative intervention.[82]

Symbas et al compared the management of their penetrating cardiac injuries between the years 1964 to 1974 and found that the mortality rate for patients presenting with cardiac tamponade was 5% on patients operated on immediately versus 17.5% in patients managed initially with pericardiocentesis with surgery reserved for patients that did not respond or where the tamponade recurred.[86]

This shift from conservative to surgical management is beautifully illustrated in the three papers published from Baylor University (1955, 1966 and 1972). There was no change in the overall operative mortality but gunshot wounds were becoming predominant in the USA. The mortality from stab wounds to the heart dramatically decreased from 22% to 13%.[21, 81]

By the 1970's the continued advances in cardiovascular surgery and presence of trained personnel combined with the reduction in mortality resulted in immediate cardiorrhaphy becoming the

universal treatment of choice.[87] Subxiphoid pericardial window or transdiaphragmatic exploration at laparotomy was becoming valuable in the diagnosis of suspected cardiac injuries.

Paget's opinion that surgery to the heart had reached its limit must serve as warning, as stated by William Halstead, against the limits of surgery and any blindness towards future developments.[21]

SECTION B

LITERATURE REVIEW

"By these signs you may know that the heart is wounded: If a great quantity of blood gush out, if a trembling possess all the members of the body; if the pulse be little and faint, if the colour become pale, if a cold sweate and frequent sowning assayle him, and the extreme parts become cold…."

Ambrose Pare (1509-1590)

The Workes of That Famous Chirurgion Ambrose Parey.[31]

CHAPTER 2

CLINICAL PRESENTATION OF CARDIAC TRAUMA

There are a numerous modes of presentation of penetrating cardiac trauma ranging from hypovolaemic cardiac arrest to complete hemodynamic stability.[17] The clinical presentation of a cardiac injury is dependent upon the mechanism of injury, the severity of the cardiac wound, time from injury to arrival in hospital, and the presence of associated injuries. Gunshot wounds differ from stab wounds in that more than half are asystolic on arrival compared to 10% of the stab wounds.[5] GSW to the heart tend to present more frequently with bleeding than stab wounds (34% vs 9% respectively).[86] The patency of the pericardial laceration is the determinant of whether the patient will present in hemorrhagic shock or tamponade and whether a pericardial effusion will be present on the ultrasound.

(a) Incidence and prevalence

A cardiac injury occurs in about 3 to 19% of all patients with thoracic stab or gunshot wounds.[71, 88-92] Madiba et al[93] published a series of 589 penetrating chest injuries treated at King Edward Hospital VIII and this included 8 cardiac injuries for an incidence of 1.4% after penetrating trauma. This incidence will obviously also depend on the number of gunshot injuries included which are more likely to result in a penetrating cardiac injury (PCI). In another prospective study from Durban there was a 6% incidence of a PCI after penetrating chest trauma from a cohort of 234 patients.[3] In a population based study conducted in Seattle, there was 1 cardiac wound for every 210 admissions to a level-1 Trauma Center.[92] At Groote Schuur Hospital Trauma Center the heart and intrapericardial great vessels are injured in 3-12% of patients after penetrating thoracic trauma.[94]

A major change occurred in South Africa in the 1980's with respect to the mechanism of trauma. Prior to this period stab wounds had predominated in Trauma Centers but in the decade following, gunshot wounds increased by 873% accompanied by a 30% reduction in stab wounds.[95, 96]

The prevalence of penetrating cardiac trauma appears to be decreasing in South Africa[97], which is in direct contrast to Europe where there appears to be an increase in penetrating trauma.[98] In the United Kingdom there is an epidemic of urban violence that has made chest stab wounds a common entity.[99]

In the United States there has been a trend of gunshot wounds increasing in frequency as a cause of cardiac trauma from the 1970's whereas previously it was predominantly stab wounds.[81, 86, 100-106] Gunshot wounds have become the commonest cause of penetrating cardiac injury in the USA with gunshots now outnumbering stab wounds by a ratio of 2 to 1.[1045, 12, 91, 107-112]

(b) Demographics

The demography of penetrating cardiac injuries in the United States over a 1-year period was reviewed by Naughton et al.[103] These same demographics seem to apply to the majority of countries with a large trauma burden in that 86% of victims were male, 83% knew their assailant, and the majority of injuries were related to domestic or social disputes. They occurred most frequently on weekends, after 6:00 PM and were more common in spring and summer. A similar situation exists in South Africa with 73% of PCI occurring during the summer months and 61% of operations taking place after 20h00 hours.

(c) Aetiology

Penetrating cardiac injuries have been caused by a whole variety of instruments. While stab wounds, gunshot and shotgun dominate, there have been numerous reports of injuries caused by; nails, ice picks, a bodkin (suicide attempt) and foreign body impalement. Iatrogenic injuries have occurred from central venous lines, pulmonary artery catheters, intercostal drain insertion and pericardiocentesis. Cardiac injuries have also been reported to occur in 0.6% of coronary artery interventions and in 6% of radiofrequency ablation of arrhythmias.[28, 113-116]

(d) Pre-hospital Mortality

A penetrating cardiac injury is an injury with an extremely high pre-hospital mortality rate. The causes of immediate death are due to massive hemorrhage, tamponade, injury to coronary vessels and conduction systems, and major valvular disruption.[103] Less than one-third of patients will reach the hospital alive.[117, 118]

Kulshrestha et al[90] in a clinical and autopsy profile of cardiac injuries in India found that 32% of these patients died at the scene of the injury, 57% died during transportation and only 11% would reach the hospital alive. A study from Alabama in the United Sates showed a pretreatment mortality rate of 80% with 54% of patients dying at the scene and 26% dead on arrival at hospital. In Seattle, USA, the pre-hospital mortality rate for cardiac injuries is 55% even in the presence of a well organized trauma system.[92, 119] A retrospective 3-year clinical and forensic analysis of penetrating cardiac trauma from Durban, South Africa, revealed that of the 1198 patients, 94% were taken directly to the mortuary. Only 70 (4%) of patients reached the hospital alive and the mortality rate for these patients was 50%.[120] This figure is similar to that found in Cape Town where the pre-hospital mortality for a penetrating cardiac injury is 86% and 92% for thoracic vascular injuries.[94, 121]

The commonest cause of death at the scene of the assault would appear to be hemorrhagic shock rather than cardiac tamponade.[122]

(e) Site of the Chest Injury

Two-thirds of patients with PCI will have a wound present between the left axillary line and the left sternal border due to the fact that most of the assailants are right-handed.[123] This still leaves a third of patients with PCI and as a result there have been attempts to define the area from where a PCI may occur so as to alert the physician to the possibility of a cardiac injury.

The "danger zone" was proposed by Sauer and Murdock in 1967 and this comprised the area bounded laterally by the left mid-clavicular line and a line through the right medial 1/3rd of the clavicle, superiorly by the sternal notch, inferiorly by the epigastrium.[124] They recommended a "thoracotomy on suspicion" for any penetrating wound within this zone.

The cardiac "silhouette" or "box" is frequently mentioned in the literature as being the high-risk area for thoracic penetrating trauma (diagram 2.1). The problem is that there are no standard definitions as to what anatomical regions these encompass. Grewal[125] defines the cardiac silhouette as the; "the area encompassed by the nipple lines, manubrium and xiphoid." It has been documented that if a wound overlies the cardiac silhouette, there is a greater than 60% chance that the pericardium and heart are injured.[2, 126] The vast majority (84%) of cardiac injuries will have a wound sited in the cardiac silhouette or box.[94]

The cardiac "box" is defined as being the area below the clavicles, above the costal margins and medial to the midclavicular line (diagram 2.2).[17] The high incidence of cardiac injuries medial to the midclavicular line is a well documented phenomenon but injuries do occur outside of these markers.[127]

The term “cardiac proximity” is also used in the literature. Meyer[8] defined this as the presence of an entrance wound in an area with the boundaries comprising the sternal notch superiorly, xiphisternum inferiorly, the left nipple line and the right parasternal line (diagram 2.3).

Diagram 2.1. The Cardiac Silhouette surface markings.

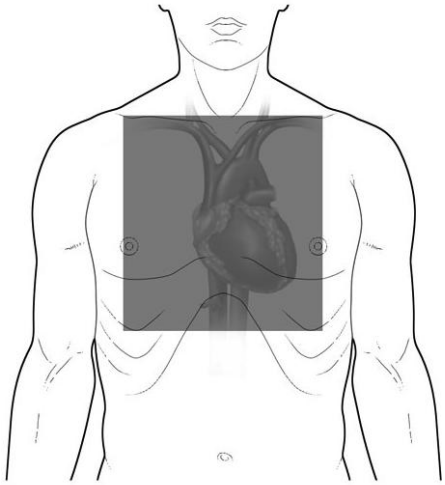


Diagram 2.2 The Cardiac Box surface markings.

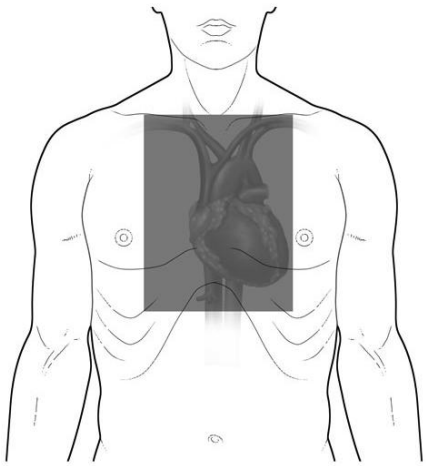
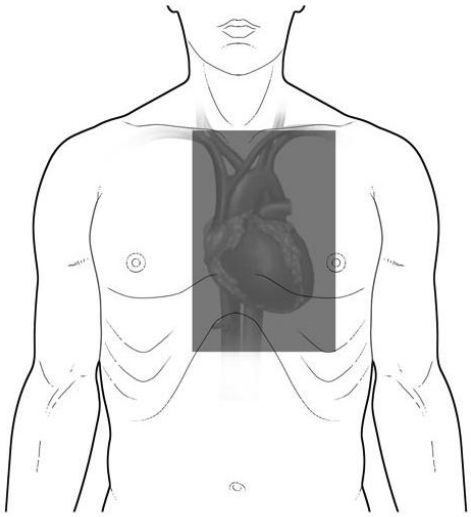


Diagram 2.3. Cardiac Proximity surface markings.



Jimenez[4] refers to "juxta-cardiac" penetrating thoracic wounds as being at high risk for a cardiac injury. This area was defined as being bounded by the manubrium, the subcostal line and the left and right midclavicular lines.

The term "precordium" is also frequently used when discussing wounds that have resulted in a cardiac injury. The "precordial zone" is most often considered to be the area between sternal notch and the xiphoid process and the nipples laterally.[5]

It has, however, been well reported that stab wounds outside of these areas have been implicated in penetrating cardiac injuries. The neck and the posterior chest wall can also result in a cardiac injury and also one has to look at the trajectory involved in gunshot wounds to the thoracic and thoracolumbar areas. In a 15- month postmortem study of penetrating cardiac injuries in Cape Town in 1986, a total of 507 wounds in the thorax resulted in 240 cardiac injuries and of these 33% were in the "cardiac shadow" but 23% were from the posterior chest wall.[128] In patients presenting to hospital with cardiac injuries, the percentage of patients with posterior chest wall stabs drops down to 7% from the 23% in post-mortem studies and this is regarded as being due to the high mortality associated with thoracic aortic trauma.

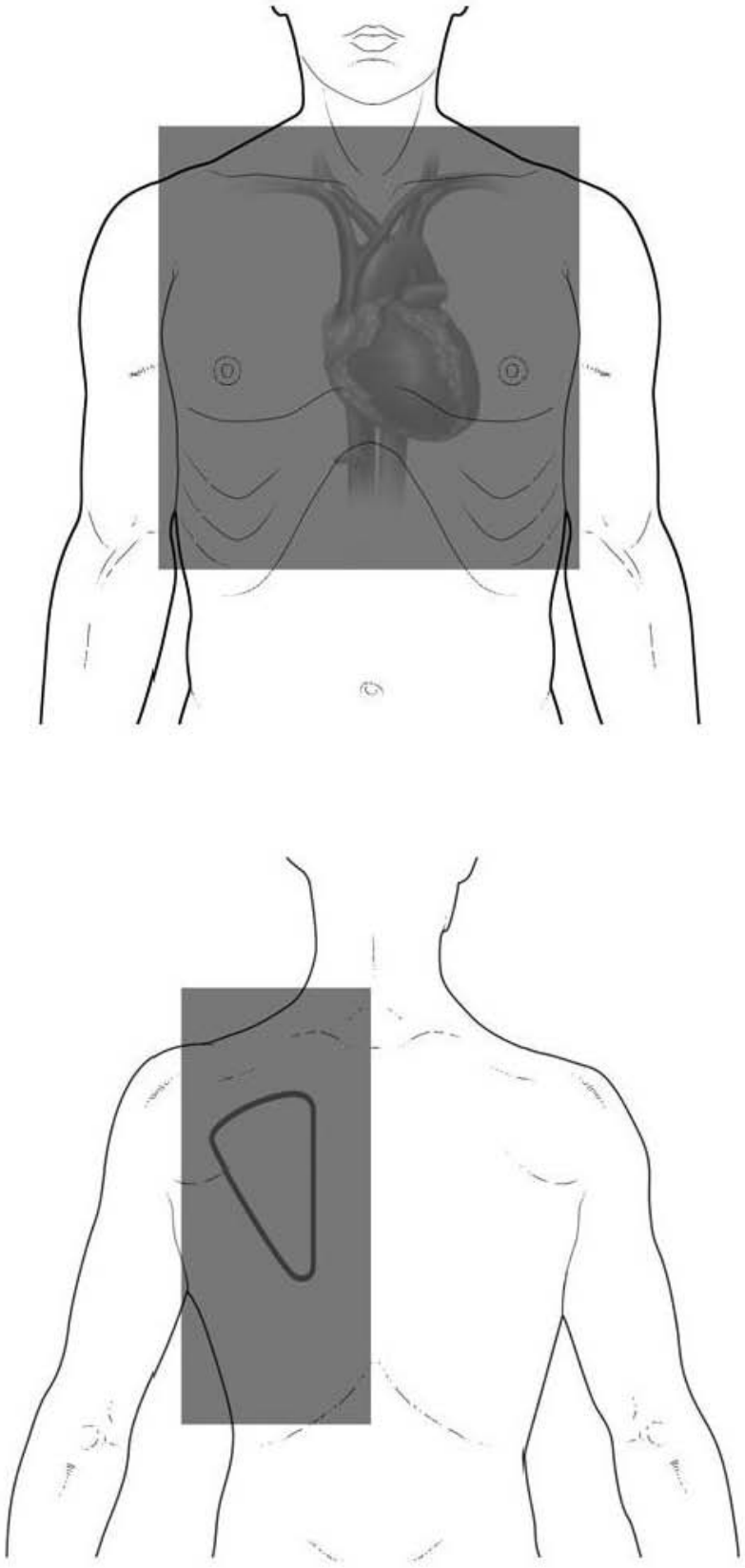
Evans et al[112] also make the observation that cardiac injuries may occur when the entrance wound is in the posterior chest wall or in the subcostal or subxiphoid abdominal regions.

There are numerous case reports in the literature that warn of cardiac injuries occurring from remote sites.[99, 129] A prospective study of 66 patients by Buckman et al showed that the probability of a cardiac injury varied according to the mechanism of trauma.[5] They found that 80% of stab wounds with associated PCI were located in the precordium but only 46% of gunshots. In fact, the heart was injured by bullets entering the lateral chest, back, flank and the shoulders and any gunshot wound of the torso carried the potential of a cardiac injury.

This certainly makes one aware that there is a danger in this limitation of the area that may result in a cardiac injury. Degiannis[97] showed that there is a higher mortality for cardiac stab wounds that lay outside of the precordium (25%) than where the stab wound was sited in the precordium (4%). This may be due to the fact that there is a delay in management of patients where the wound is out of the box as a cardiac injury is not initially considered.

The area that should be considered to be the high-risk cardiac area for stab wounds is the region extending from the right anterior axillary line across to the back of the left chest to the vertebral line with the superior margin being the supraclavicular areas and the inferior margin being the costal margins, inclusive of the epigastrium.[130] The author has called this area the cardiac zone (diagram 2.4). Any gunshot wound to the neck, shoulders, chest, back and abdomen should be considered to have a possible cardiac injury.

Diagram 2.4. The Cardiac Zone – the High Risk Area for a penetrating cardiac injury.



(f) Classification

It is strikingly obvious when examining the publications on penetrating cardiac injuries, the varied classifications systems used by the authors to describing the clinical presentation of patients. A single classification system is required so that a comparison with respect to management can be made between facilities as there are a large number of factors that affect the ultimate survival of the patients.

Rao Ivatury[131] from the United States of America has developed a scoring system to quantify both the physiological and anatomic injury to the heart in order to allow such comparisons. He highlights a number of reasons that impact upon survival after a cardiac injury such as; pre-hospital care, clinical status on presentation, severity of the trauma, mechanism of injury and the effectiveness of the management. In this scoring system the clinical status of the patient on admission is categorized into 4 graded groups called the Physiologic Index (see table 2.1) with each group assigned a numerical value from 5 to 20.

Table 2.1. The Physiologic Index Ivatury et al 1987

Clinical Status on Admission	***Score***
Unconscious No vital signs No respiratory effort No physical activity but some sign of life in transit to hospital	20
Semiconscious Thready pulse Gasping respiration No measurable blood pressure	15
Conscious Systolic BP of 80mmHg or less	10
Stable	5

This classification system was validated in a retrospective study from Sao Paulo and the physiologic index, as well as the penetrating cardiac trauma index and penetrating thoracic trauma index, were shown to be a good predictors of outcome.[132]

There are numerous examples of the varying classification systems that are being used. David Harris[133] from Tygerberg Hospital in Cape Town, South Africa, reviewed 128 cardiac injuries and identified 4 groups of patients after resuscitation. (table 2.2)

Table 2.2. Harris et al Classification of cardiac injury presentation.

Group	***Clinical Status***
GROUP 1:	No vital signs
GROUP 2:	Agonal Systolic blood pressure remains < 90mmHg
GROUP 3:	Compensated shock Systolic blood pressure > 90mmHg
GROUP 4:	Stable

A further classification has appeared from China and this also divides penetrating cardiac trauma presentation into 4 distinct types namely; type 1 cardiac tamponade, type 2 hemorrhagic shock, type 3 combined and type 4 occult cardiac injuries.[134]

Roger Saadia[135] proposed a classification system for penetrating cardiac trauma in 1994. The presentation is divided into 5 groups comprising; lifeless, critically unstable, cardiac tamponade, thoracoabdominal injury and the benign presentation (table 2.3).

Table 2.3. Clinical classification system for penetrating cardiac injuries.[135]

Classification	*Clinical Features*
Category 1: Lifeless	Unconscious with no signs of life.
Category 2: Critically unstable	Profound hypotension and impending cardiac arrest.
Category 3: Cardiac tamponade	Hypotension and elevated CVP.
Category 4: Thoracoabdominal injury	Presence of an obvious associated abdominal injury.
Category 5: Benign presentation	Hemodynamically stable.

Degiannis[97] has used this more clinically orientated approach and linked it with surgical management in a drive for early definitive surgery. This would appear to be more in line with rational clinical acumen and decision making.

(i) Lifeless

The incidence of patients presenting lifeless varies considerably in the various published series. Velamhos et al[118] quoted a figure of 9% of PCI that will present to hospital without signs of life. In Campbell's series[120] 37 out of 70 patients (54%) with PCI presented with an unrecordable blood pressure or no signs of life on arrival. The management of such patients will be endotracheal intubation and immediate emergency department thoracotomy.

(ii) Critically unstable

The immediate management will be endotracheal intubation, chest drainage if required and aggressive resuscitation. If the patient shows evidence of improvement, then the thoracotomy is best performed in theatre; but if any transfer will cause a delay of least 10 minutes or if it is felt that the patient will not survive the next 10 minutes, then an emergency department thoracotomy should be undertaken.

(iii) Cardiac Tamponade

This is the one of the classic presentations of a penetrating cardiac injury and occurs when the pericardial laceration becomes sealed thereby preventing hemorrhage into the pleural cavity. The pericardium in the acute trauma setting is unyielding and bleeding into the sac quickly overwhelms the pericardial capacity to stretch. The filling pressure of the heart is the myocardial transmural pressure and this is derived from the intracardiac pressure minus the intra-pericardial pressure.[136, 137]

Bleeding into the pericardial sac results in an increase in intrapericardial pressure that obstructs the filling of the right side of the heart. There is a reduction in right ventricular stroke volume that causes the left ventricle to underfill and this results in an adrenergic induced tachycardia and increased contractility in an attempt to improve cardiac output. There is no ischemic component in cardiac tamponade as coronary flow, although reduced, is maintained with respect to operational requirements.[138]

Cardiac tamponade is more frequently encountered with stab wounds than gunshot injuries (80% versus 20% respectively) and this may be due to the fact the pericardial rent in a gunshot wound is larger thereby allowing drainage to occur.[5, 139]

The clinical presentation of cardiac tamponade is the presence of elevated neck veins in the presence of hypotension and muffled heart sounds. These signs also vary in frequency in the literature but may well be present in over 90% of cases.[123] One of the classic signs of cardiac tamponade that we have all experienced is the patient presenting that is highly agitated and disruptive and refusing to lie supine. This inability to lie supine is a sign that the patient is tamponading.[97, 140] Pulsus paradoxus is only reportedly present in about 10% of cases.

A tension pneumothorax should always be considered in the differential diagnosis and if there is hyperresonance to percussion on the affected and evidence of tracheal deviation, then a chest drain should be inserted rapidly.

It is apparent that cardiac tamponade may be due to extra-cardiac causes without an associated cardiac injury. In a postmortem study conducted in Cape Town on 304 patients with cardiac tamponade, seventy-two cases were caused by extra-cardiac sources of bleeding; most commonly encountered were the ascending aorta and the pulmonary artery.[128]

(iv) Thoracoabdominal Injury

This is encountered in patients presenting with thoracoabdominal wounds or where the epigastric wound is close to the precordium. The surgeon may encounter a dilemma relating to these injuries with respect to which cavity should be entered first, is a subxiphoid pericardial window indicated, and should this be done before or after the laparotomy.

(v) Benign Presentation

JK Trinkle wrote in 1979 in an article entitled "Affairs of the wounded heart" that patients with penetrating cardiac wounds may present in one of two distinct clinical syndromes – cardiac tamponade or hypovolaemic shock.[141] However it is well recognized that patients with potentially life-threatening chest wounds may present to the resuscitation room relatively asymptomatic.[106, 142] There is the concern that stable patients may have a cardiac injury that is undiagnosed until they suddenly deteriorate.[89]

The reported incidence of clinically undetected cardiac injuries after penetrating trauma varies between 18-20% of patients. These patients are normotensive on admission, normal CVP measurements and no overt clinical signs.[143, 144]

In a prospective study over a 15-year period, Ordog et al[6] found 4 documented cardiac injuries in a series of 4106 patients presenting with no major symptoms or signs and an initial normal chest x-ray to the emergency room. There was a 50% mortality rate associated with these 4 missed cardiac injuries that were operated on with a delayed thoracotomy.

The proportion of patients arriving at hospital with a cardiac injury who do not show any symptoms or signs varies between 15 to 30%.[89, 133, 134, 143, 145, 146] In this stable group of 43 patients Harris et al found that 90% had either a CVP of greater than 12cm H20, an enlarged heart on chest x-ray or at least one clinical sign of cardiac tamponade. However, in 7 patients the only feature of a cardiac injury, was a penetrating chest wound and a CVP of greater than 10cm H_20.

Gao et al in a retrospective series from China on 82 cases of penetrating cardiac injury collected over a 16-year period had the following clinical presentations; hemorrhagic shock 19 (23%), cardiac tamponade 24 (29%), a combined presentation 27 (33%) and occult cardiac injuries in 12 (15%).[134]

(g) Clinical Signs

Becks' triad was observed in 30 of the 46 patients with cardiac trauma (65%) as reported by Evans. Only 25 patients (35%) presented with the complete triad in the retrospective series conducted by Yao with 87% of patients having one or more features of the triad.[82]

In the study conducted by Meyer, clinical signs such as distended neck veins and muffled heart sounds were present with increased frequency in the 9 patients with a cardiac injury than in those without.[8]

Grewal et al[125] in 1995 retrospectively analyzed the clinical features that might have suggested a cardiac injury in patients that were hemodynamically stable with a penetrating chest injury. They found that on univariate analysis there was significant differences in the location of the injury, presence of shock and the CVP in patients with and without a cardiac injury. There study was, however, limited by the fact that there were only 26 patients with a positive pericardial window out of 122 patients. They did not look at the value of the chest x-ray and the electrocardiogram in the diagnosis of cardiac trauma.

(h) Scoring Systems

There are two trauma scoring systems that have been formulated to apply to penetrating cardiac trauma. These comprise the American Association for the Surgery of Trauma- Organ Injury Scale: Heart Injury Scale (table 2.4)[147] and the Penetrating Trauma Cardiac Index (table 2.5).[12]

Table 2.4. Heart Injury Scale (AAST)

Grade	***Description of Injury***
1	Penetrating pericardial wound without cardiac injury, cardiac tamponade or cardiac herniation.
2	Penetrating tangential myocardial wound up to, but not extending through endocardium, without tamponade.
3	Penetrating cardiac injury with septal rupture, pulmonary or tricuspid valvular incompetence, papillary muscle dysfunction, or distal coronary arterial occlusion without cardiac failure. Penetrating tangential myocardial wound up to, but not extending through, endocardium with tamponade.
4	Penetrating cardiac injury with septal rupture, pulmonary or tricuspid valvular incompetence, papillary muscle dysfunction, or distal coronary arterial occlusion

	producing cardiac failure. Penetrating cardiac injury with aortic or mitral valve incompetence. Penetrating injury of the right ventricle, right atrium or left atrium.
5	Penetrating cardiac injury with proximal coronary arterial occlusion. Penetrating left ventricular perforation. Stellate wound with < 50% tissue loss of the right ventricle, right atrium or of left atrium.
6	Penetrating wound producing > 50% tissue loss of a chamber.

Advance one grade for multiple wounds to a single chamber or multiple chamber involvement.

The AAST Organ injury scale was found to be a predictor of outcome in a single center prospective series of 60 PCI. The mortality rates for a grade 4 injury were 52%, grade 5 injury 75% and grade 6 injury 100%.[12]

Table 2.5. The Penetrating Trauma Cardiac Index[12]

AAST Grade	***Description***
1	No cardiac injury but pericardial laceration.
2	Tangential cardiac wound
3	Tangential cardiac wound with tamponade
4	Penetrating wound to RV/RA/LA
5	Penetrating wound to LV

RV = right ventricle RA = right atrium LA = left atrium LV = left ventricle

The scoring systems described have not been universally adopted. This is a pity as at least there is some attempt to standardize the extent of the injuries. A major limiting factor with the scoring systems proposed is that they do not score a major intrapericardial vessel injury that is often a cause of mortality.

CHAPTER 3

THE CURRENT SCREENING MODALITIES

A pre-hospital mortality rate of 86% for penetrating cardiac injuries wound indicate that the patients who arrive at hospital alive are potential survivors. It is essential that clinicians recognize these injuries by performing a clinical examination aided by the currently available screening modalities comprising the chest roentgenogram, the central venous pressure (CVP), the electrocardiogram (ECG), ultrasound (US) and echocardiography (ECHO).

A number of studies have, however, found no correlation between the positive or negative findings at subxiphoid pericardial window (SPW) and the blood pressure, CVP, electrocardiogram and chest x-rays.[148] Jimenez in a prospective study on 73 hemodynamically stable patients with juxta-cardiac penetrating trauma, only 1 of the 9 patients with a proven cardiac injury demonstrated any evidence of pulsus paradoxus, ECG changes or an elevated CVP.[4] It is obvious from these studies that a very close inspection is required of these screening modalities and the role they play in the diagnosis of a hempericardium after penetrating thoracic trauma.

(a) Chest Roentgenographic Study

The majority of centers will obtain a chest x-ray as an adjunct to the primary survey in the resuscitation of the patients with penetrating chest trauma unless the patient is so unstable that an emergency department thoracotomy is required or there is massive hemorrhage and immediate exploration needs to be undertaken.[149] However, a chest x-ray is considered by most authorities to be not particularly useful and is felt to be seldom diagnostic of a penetrating cardiac injury.[150]

A retrospective study from Grady Memorial Hospital in Atlanta, Georgia reported in 1976 that the chest x-ray was of limited value in diagnosing a penetrating injury to the heart.[86] Arom reported in a five year retrospective study on 50 patients who underwent a SPW that the "emergency room chest roentgenogram is often misleading."[148] Duncan et al[143] stated in their retrospective study on the SPW that "predictably, chest x-rays were noncontributing in making the diagnosis of cardiac injury." Kang et al[28] felt that the chest x-ray may be misleading since in acute tamponade, the heart size was unlikely to be enlarged and this could lead to a misdiagnosis.

In what was the largest prospective study involving 4106 patients with a stab wound to the chest and stable vital signs, Ordog reported that the accuracy of the chest x-ray in predicting pathology was 95% with a specificity of 99.9%.[6] There were, however, only 4 documented cardiac injuries in this series so that one cannot comment on the sensitivity of the chest x-ray for detecting specifically a cardiac wound.

The local experience with the management of PCI has lead to a contrary view to other units that have stated that roentgenograms are of limited value to diagnose a cardiac injury.[86, 142, 143, 151] We would agree that in the patient who presents with cardiac tamponade or with major hemorrhage, the usefulness of the chest x-ray may be limited, however they do certainly aid in the diagnosis in the patient who presents in a stable state.

Cardiomegaly is regularly mentioned as a sign of PCI (figure 3.1) but is not considered to be particularly sensitive.

A further sign of a PCI in the stable patient has not been previously described in the literature and this is the sign of the straight left heart border (SLHB). In this sign the aorto-pulmonary window is filled in, changing the normal concave indentation to a straight line. (Figure 3.2) This sign should only be elicited in an erect chest x-ray. This new sign suggestive of a cardiac injury is discussed in depth in Chapter 9.

Figure 3.1. Chest x-ray demonstrating cardiomegaly from a hemopericardium after penetrating chest trauma.

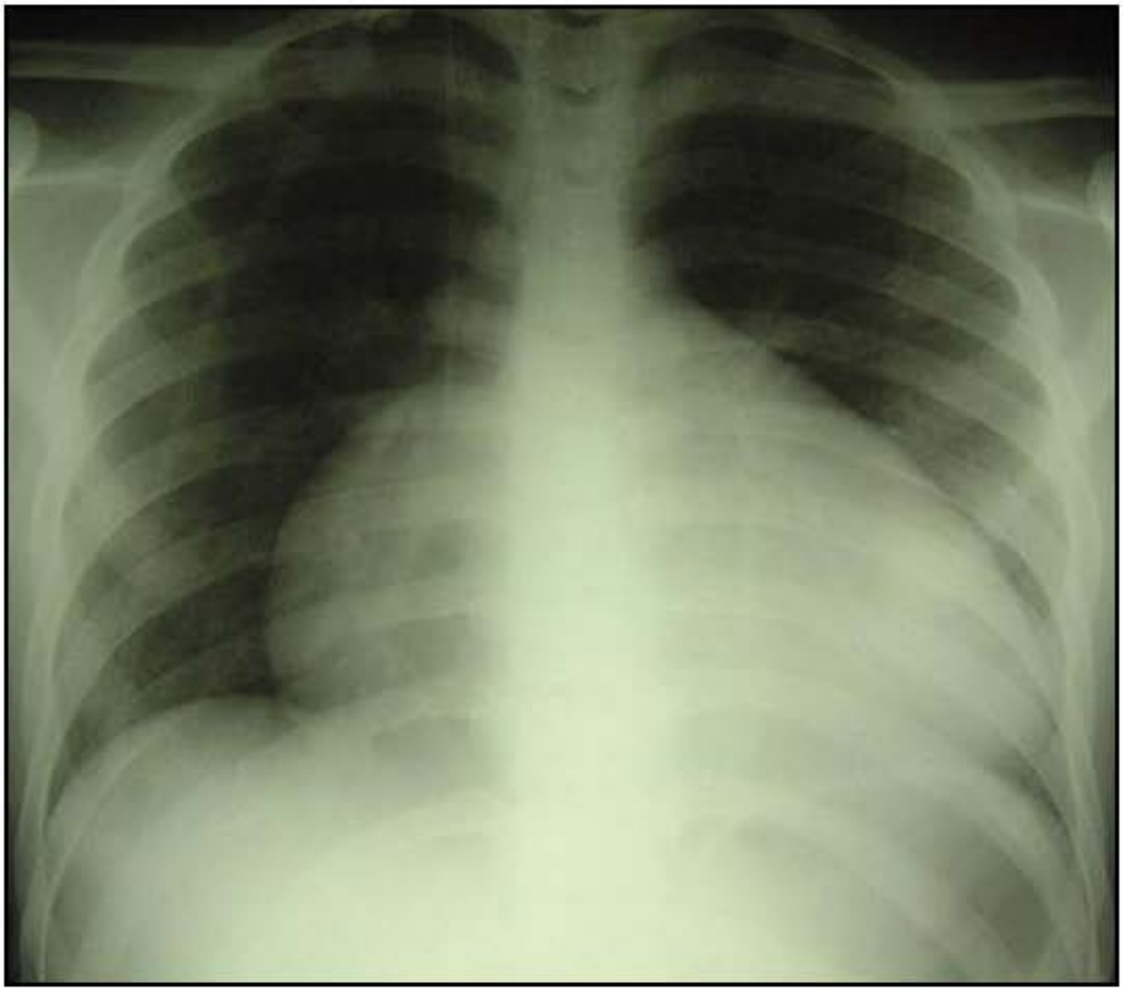


Figure 3.2. A chest x-ray of a patient with a hemopericardium demonstrating the sign of a “Straight left heart order”. Staples mark the site of the stab wound.

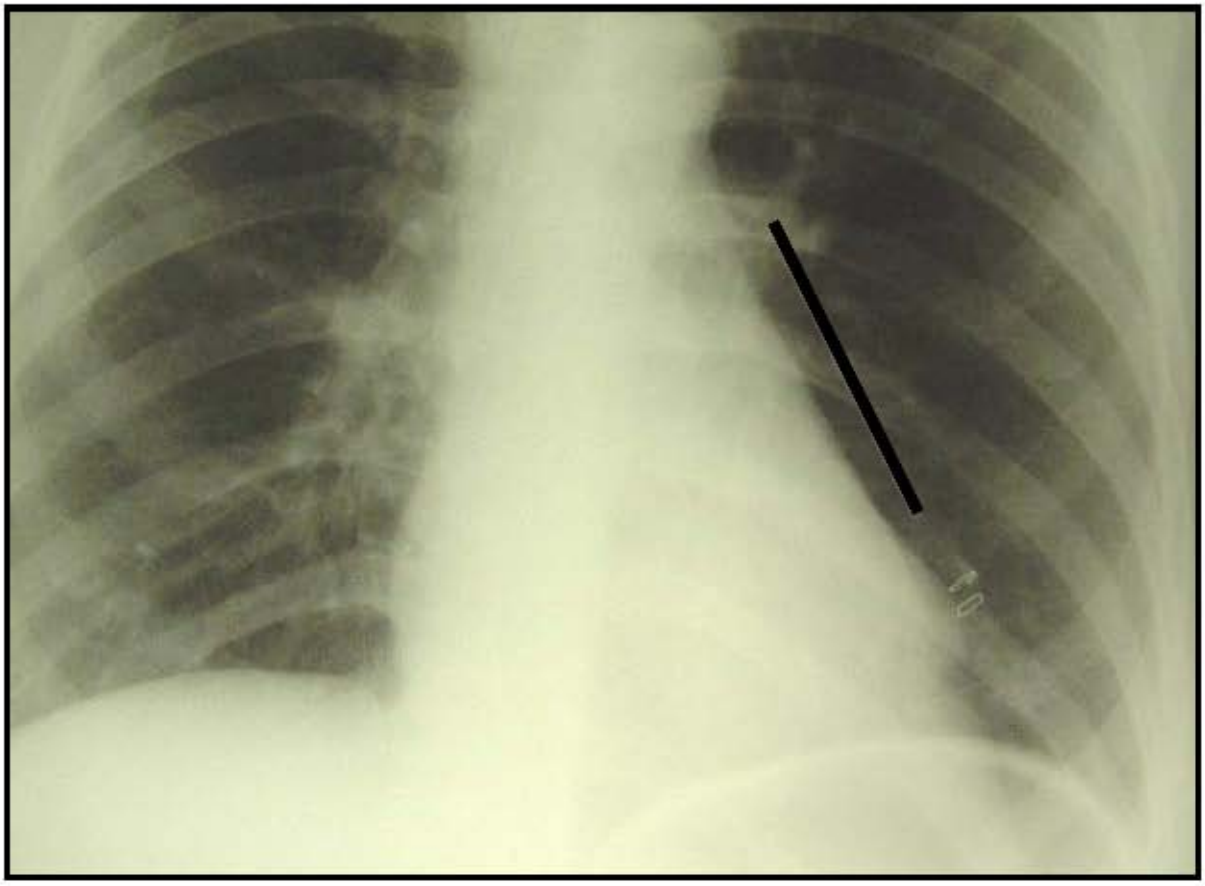


Figure 3.3. A normal erect chest x-ray depicting the concave appearance of the aorto-pulmonary window.

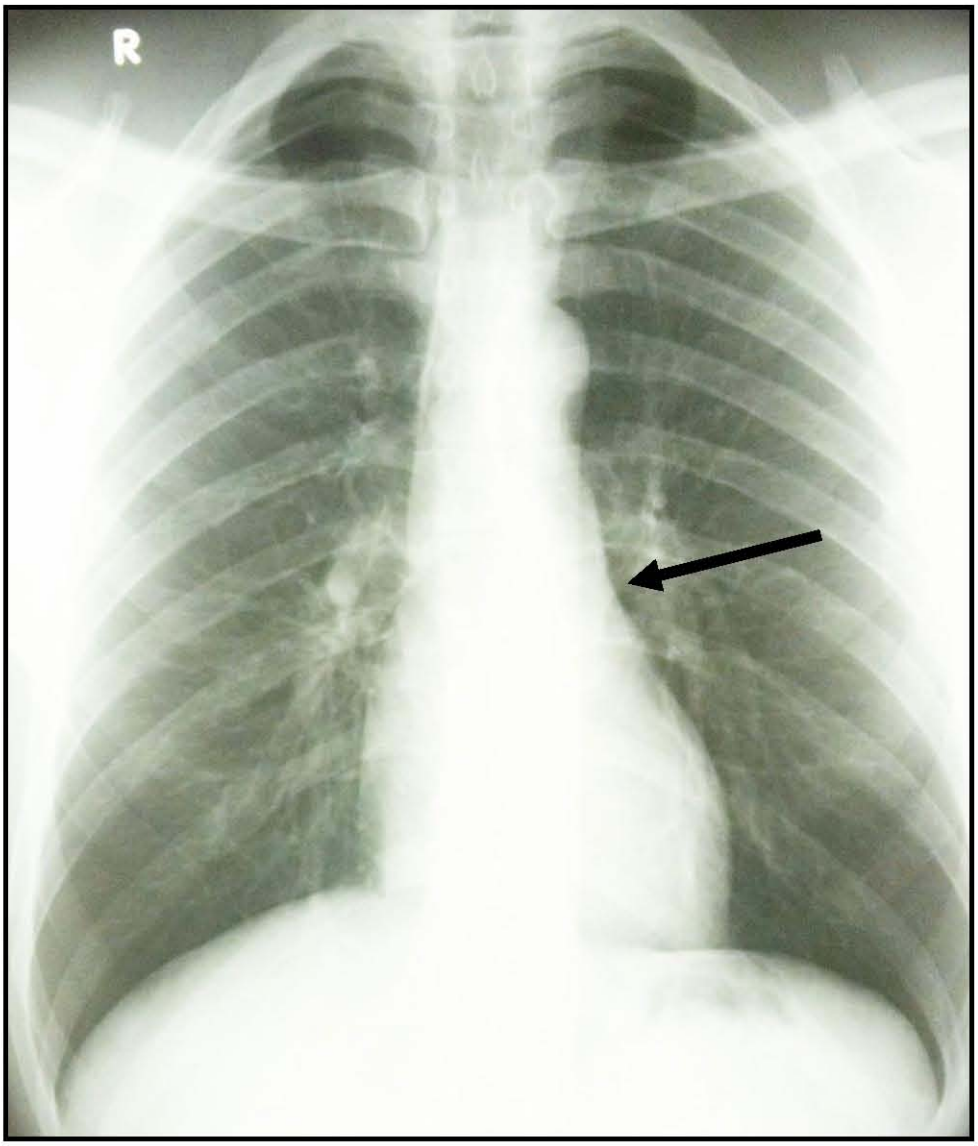
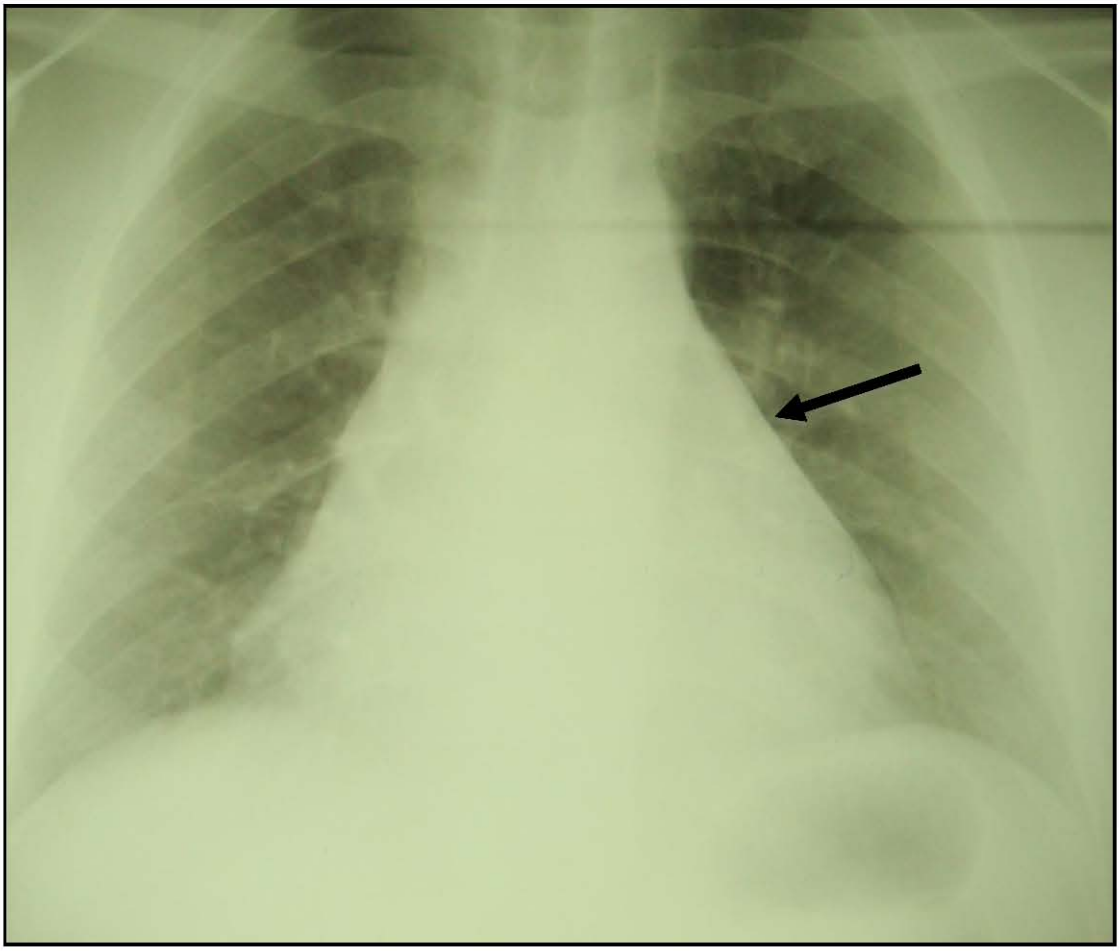


Figure 3.4. A second patient demonstrating the sign of a “Straight Left Heart Border” following a thoracic stab wound.



(b) Central Venous Pressure Measurement

The central venous pressure measurement appears to have its protagonist and its antagonists with respect to its role in aiding the diagnosis of cardiac trauma. There are numerous reasons why patients admitted with a penetrating thoracic wound may have an elevated CVP and these include; overenthusiastic transfusion, shivering, catheter malposition, line blockage and straining. What is particularly useful is an elevated CVP measurement in a shocked patient as a very quick guide to the diagnosis of cardiac tamponade and the need for immediate surgery.

Symbas et al, in a retrospective study over a 10-year period on 102 cardiac injuries, found that neck vein distension and/or a CVP measurement of greater than 12cm of H_20 were strongly suggestive of cardiac tamponade.[86]

Johnson et al[152] documented their clinical experience with 79 PCI over a 13-year period. Fifty-three of the 79 patients with PCI underwent placement of a preoperative CVP line and 41 (77%) had a central venous pressure greater than 20cm H_20. In the subgroup of patients presenting hemodynamically stable with normal vital signs, Buchman found that the CVP was greater than 20 cm H_20 in all 8 of these patients.[89]

In a study by Meyer[8] published in 1995, only 14% of patients with cardiac trauma had a CVP of greater than 12cm H_20. There were only 9 cardiac injuries in this study but the CVP was statistically higher in the group ($p < 0.05$) with the cardiac trauma (14cm) versus the uninjured heart (8.3cm). They felt that the range of these values overlapped so much that the CVP was most likely not a reliable diagnostic tool.

Arom[148] in their series of 50 patients described how cardiac tamponade was falsely diagnosed in cases of an elevated CVP, which was primarily due to shivering or guarding from peritoneal or pleural

irritation. They also noticed that 3 patients with a CVP above 20cm H_20 all had negative subxiphoid windows.

Ken Mattox does not believe that the CVP is helpful as patients without cardiac tamponade may have an elevated venous pressure from overtransfusion and a patient with cardiac tamponade may have a reduced CVP due to reduced blood volumes.[153]

It would appear as if the jury is still out with respect to the role of the CVP in diagnosing occult cardiac trauma.

(c) The Electrocardiogram

The medical literature is somewhat ambivalent about the usefulness of the electrocardiogram (ECG) to help diagnose a cardiac injury. Opinion appears to vary as the ECG being of no diagnostic value to being a useful diagnostic aid.

Johnson reported in 1995 that ECGs generally showed non-specific changes when obtained.[152] In only two out of eight proven cardiac injuries (25%) did the ECG show evidence of inferior ischaemia in one and 3rd degree atrioventricular block in the other. There were two patients with proximal coronary trauma that had normal pre-operative ECGs without any acute changes.

Meyer et al[8] conducted a prospective study on 105 patients with a penetrating chest injury in the cardiac silhouette who were haemodynamically stable. All patients underwent a SPW and if this was positive either a sternotomy or a thoracotomy was done. There were 9 patients identified with a significant cardiac injury. The ECG tracings were not significantly different between those patients with or without a cardiac injury.

A SPW was performed in hemodynamically stable patients because of the close proximity of the injury to the heart in 51 patients. The SPW was positive in 12 patients (23%) and the ECG failed to show any signs of ST segment changes in these 12 patients.[143]

There were also a number of articles that indicated that the ECG may be useful in screening. A report on 46 patients with a positive SPW after penetrating trauma found that 13 out of these 46 patients had positive findings of S-T segment elevation on the ECG.[148] Brewster found in a series of 28 documented cardiac injuries that 57% of these patients had an abnormal ECG.[145] The most common abnormality was S-T segment wave changes present in 38% of the injuries consistent with the diagnosis of a pericarditis. Mattox et al also found that ST segment changes were the commonest abnormality with 32% of patients with proven cardiac injuries exhibiting this phenomenon, and right bundle branch block present in 16%, ischemic changes in 5% and completely normal ECGs in 47%.[87]

The majority of series have reported abnormal ECGs ranging from 30 to 60% of patients with cardiac injuries.[82, 123] This would suggest that the ECG may be suggestive of a cardiac injury but a normal ECG does not exclude any injury.

Joshi et al[154] looked at the electrocardiographic manifestations of penetrating cardiac injury on 50 patients with penetrating cardiac injuries admitted to the intensive care unit after the cardiorrhaphy has been performed. This post-operative study is useful as it classifies the electrocardiographic changes that may occur into one of 5 types namely;

1. sinus tachycardia
2. nonspecific ST- segment changes
3. a pericarditis like pattern
4. myocardial infarction
5. arrhythmias.

What is obvious from the medical literature was the need for a clinical study to look prospectively at the role of the electrocardiogram at diagnosing cardiac injuries in patients with a possible occult injury.

(d) Ultrasound

The use of ultrasound for abdominal trauma was first described in 1971 by Kristensen et al[155, 156]. In the 1980's German surgeons pioneered the use of bedside ultrasound for the management of trauma patients but it has only been since the 1990's that this technological application has become widely accepted. It has become standard practice in many Trauma Centers in the United States.[9, 10, 13, 14, 157, 158, 158, 159] The adoption of ultrasound into the Advanced Trauma Life Support Course with an appreciation for the early diagnostic role that it can provide has lead to FAST becoming a catch-phrase in the initial assessment and evaluation of patients.

FAST is the Focused Assessment with Sonography for the Trauma patient and is in essence a rapid assessment in the hemodynamically unstable patient to determine the presence of pericardial or peritoneal fluid in order to identify the cause for the instability and allow for rapid management.[160] In fact FAST is having a dramatic affect as to the way in which the trauma resuscitation is managed and is rapidly evolving into an "extension of the physical exam" with the concept of resuscitation ultrasound.[161]

An international consensus conference defined FAST as an expeditious focused interrogation of the pericardial and peritoneal space looking for free fluid as a marker of injury.[162] It has been shown to be extremely reliable in confirming or excluding the peritoneal cavity as the source of blood loss in the unconscious patient who is hemodynamically unstable after sustaining blunt trauma.[13, 163]

The FAST examination inspects for fluid in 4 areas namely the hepatorenal space, the perisplenic area, the pelvis and the pericardial sac. This 4th component of the FAST has been shown to be of value in penetrating thoracic trauma.[158] The problem that has been encountered though is whether the negative FAST of the pericardial sac is considered to be a true-negative result.[163]

The selection of the probe that is used for the FAST is an often-neglected area of consideration but is of vital importance. The curvilinear probe is the classic probe used in the examination as it allows evaluation of these four areas and is advantageous with respect to time. The problem is that it is a low frequency probe and hence is excellent for the abdominal structures but is not ideal for visualization of the pericardial sac. The phased array probe may well be the solution as the resolution of the heart is excellent and it allows for abdominal evaluation.

Blood in the pericardial sac will be viewed as an echo-lucent dark area and the visceral and parietal layers of the pericardium become distinct echogenic lines. The question has been raised as to whether a hemothorax or pneumothorax will affect the sensitivity of the examination and whether a pneumopericardium affects visibility and hence the accuracy. The epicardial fat pad may also be misdiagnosed as a pericardial effusion. However, the accuracy of US examination has been shown to be dependent on ultrasonographic experience.[164]

Grace Rozycki from Grady Memorial Hospital in Atlanta, USA, has published numerous articles with respect to the surgeon performing ultrasound in the resuscitation room in order to detect a hemopericardium after penetrating chest trauma. She stated that ultrasound was becoming “part of the surgeon’s diagnostic armamentarium” and that in order for ultrasound to be an effective diagnostic modality it must be located in the trauma room and be interpreted by the resuscitating surgeon.[10, 139] The use of ultrasound in the resuscitation room has a number of advantages in that it is non-invasive, portable, rapid and is cost-effective.

The use of surgeon-performed ultrasound in the resuscitation room to detect throaco-abdominal injuries and the need for surgery was assessed in a prospective study by Rozycki et al.[13] The study

included penetrating and blunt trauma and of the 371 patients there were 76 penetrating injuries. Six patients were diagnosed with pericardial tamponade and there was one false positive result. They concluded that one of the best reasons to perform ultrasound in penetrating injuries was for the rapid diagnosis of the traumatic hemopericardium as this allowed for the rapid surgical intervention that was required in these patients.

Ultrasound was used as screening for potential cardiac injuries in a prospective study over a 13-month period on 247 patients presenting with penetrating thoracic wounds but no immediate indication for emergency surgery. Ten patients (4%) were found to have a hemopericardium with cardiac injuries that were confirmed at surgery. The sensitivity, specificity, and accuracy were 100% and there were no false negatives but only the patients with the hemopericardiums detected on ultrasound underwent surgery. The mean examination time was 0.8 minutes. The technique used was use the subcostal view with the patient in the supine position in order to detect a hemopericardium.

Ma et al[7] in 1995 conducted a prospective study on 245 patients who had sustained both blunt and penetrating trauma and reported that the rapid trauma ultrasound was 90% sensitive, 99% specific and 99% accurate for the detection of free fluid in the chest, pericardial sac and abdomen.

Rozycki et al[13] in 1998 performed FAST examinations on 313 patients with penetrating thoracic trauma and reported that ultrasound was most sensitive and specific for the evaluation of patients with precordial or transmediastinal wounds with a sensitivity of 100% and specificity of 99.7%.

In 1999 a multicenter prospective study was published by Grace Rozycki in the Journal of Trauma looking at the role of FAST to detect an acute hemopericardium in patients with possible penetrating cardiac wounds.[14] Pericardial ultrasound was performed in 261 patients and there were 29 cardiac injuries which were identified with no false negatives and 7 false positive examinations resulting in a sensitivity of 100% and a specificity of 96.9%. Patients with a negative ultrasound were followed up for a minimum period of 23 hours. Six of the 7 patients with a false positive examination had an

associated hemothorax and at subxiphoid pericardial window were found to have benign pericardial effusions.

Another prospective study on 32 patients presenting with penetrating chest wall trauma had 8 cardiac injuries documented at FAST for a sensitivity and specificity of 100%.[15]

We have been aware at Groote Schuur Hospital that a false negative FAST of the pericardial sac does occur and that there is a need to look at other criteria as well in determining the need for a SPW. In 2009 Chad Ball from Grace Rozycki's institution published a retrospective series of surgeon-performed US that highlighted the problem of the false negative US.[165] In this series of 228 patients over a 3-year period there were 37 positive US but there were also 5 false negatives. These 5 patients all had associated left sided hemothoraces and had normal repeat ultrasounds performed after drainage of the hemothorax. Two of the 5 patients (40%) with missed cardiac injuries after a negative FAST died. This would suggest that a repeat US after drainage of a hemothorax is not particularly helpful. The mortality associated with a missed injury is also very disturbing. At surgery a pericardial lacerations was found and it was surmised that these patients had drained the pericardial collection into the chest and this was the cause of the negative US. This is certainly a limitation of FAST and raises the point at looking at other criteria in patients with a negative FAST before discharging the patient.

In a retrospective study of 128 penetrating cardiac injuries, Harris et al noted that there were 6 false negatives out of 56 cardiac ultrasounds performed. Three of these patients had large hemothoraces that required surgery for bleeding. There were no false positives in this series.[133] What is apparent when looking at the literature that is concerned with the sensitivity and specificity of ultrasound in detecting pericardial fluid are the small numbers of patients with penetrating cardiac injuries included in the studies. The largest prospective multicentre study had only 42 patients with confirmed cardiac injuries (table 3.1) and the smallest contained 6 patients.

Table 3.1: The largest prospective series in the literature dealing with the detection of pericardial fluid on ultrasound.

Study	*Design*	*Number of patients with penetrating chest injuries*	*Number of cardiac injuries confirmed at surgery*	*Sensitivity (%)*	*Specificity (%)*	*False -*	*False +*
Rozycki et al 1995 [9]	Prospective Single centre	76	6	84	95	0	1
Ma et al 1995[7]	Prospective Single centre	Not stated	6	100	99	0	1
Rozycki et al 1996[10]	Prospective Single center	247	10	100	100	0	0
Rozycki et al 1998 [13]	Prospective Single center	313	22	100	99	0	2
Rozycki et al 1999 [14]	Prospective Multicentre	261	29	100	97	0	7
Bokhari et al 2004[166]	Prospective Single center	49	Not stated	100	50	0	20
Tayal et al 2004 [15]	Prospective Single center	32	8	100	100	0	0

A true positive is defined by Rozycki [13] as the presence of fluid (blood) identified on the ultrasound, and surgery that confirmed the cardiac injury. However no mention is made about the volume of fluid or the measurement of the effusion. One wonders whether these factors need to be considered. Their patients were not in cardiac tamponade and were hemodynamically stable with no indication

for emergency surgery. Some normal patients do have a certain amount of pericardial fluid and this may cause a false positive result. There is no way on ultrasound to distinguish blood from pericardial fluid. Patel in 2003 published a retrospective study on surgeon-performed sonography and he described a true positive as the presence of 5mm of fluid, identified on US either by the parasternal or subxiphoid view, and a cardiac injury identified at surgery.[167] There was no mention where the figure of 5mm was derived from or what the significance was of having less than 5mm of fluid.

Our own experience in Cape Town is that false negative results are seen with US of the pericardial sac and this has led us to include specific clinical criteria as an indication to perform a SPW.

There are certain other questions that need to be addressed with respect to ultrasound. Are there certain factors that may decrease the sensitivity of the test? There were no cases reported of pneumopericardium but can the presence of air decrease the visibility and result in a falsely negative scan. What about the presence of a hemothorax? Can this be a cause of false positive results?

Other issues relate to the safe observation period for a negative scan, and should the scan be repeated at a certain interval. In addition can clinical criteria direct the need for a repeat scan?

The other concern is that US should not replace the clinical examination in the evaluation of the patient. The clinical examination is an essential component in making any form of assessment. There does appear to be a tendency for the US to replace this. Bokhari et al[166] reported the use of ultrasound to screen for chest and abdominal injury in penetrating truncal trauma. In their series of 49 patients there were 20 true positives and 20 false positives but they stated that “the ultrasound examinations were mostly performed before any physical examination or any testing on the patient.”

All of these prospective studies included non-consecutive patients and this would suggest that the expertise even in Trauma Centers in the USA is not always readily available. By 2000 still only 58% of the Trauma Centers in the United States and Canada were performing US in penetrating trauma and only 39% of surgeons were actually undertaking the examination.[168]

There is no doubt that US is an excellent screening tool but at the same time we need to be aware of its limitations, particularly in the case of false negative results that more and more authors are reporting. [169] As Simmons[170] says "the normal ultrasonographic evaluation of the heart and pericardium, is commonly but fallaciously believed to rule out significant risk of injury."

(e) Echocardiography

There have been very few studies that have specifically looked at ECHO in the diagnosis of penetrating cardiac trauma. Meyer et al[8] published a paper in 1995 that compared the sensitivity and specificity of ECHO against the gold standard of the SPW. In this prospective study conducted over a 30-month period, 105 patients who were hemodynamically stable with a penetrating cardiac injury with cardiac proximity were included. Eighty-nine patients had a true negative ECHO result interpreted by the surgeon. There were 9 cardiac injuries identified at surgery and ECHO confirmed 5 of these. They also had 7 false positives and 4 false negatives. The sensitivity of ECHO was only 56% with a specificity of 93% for detecting a cardiac injury. This study highlighted the fact that ECHO has an unacceptably high number of false negative results. It would appear that the presence of a hemothorax tended to have an influence on the ability of ECHO to detect a hemopericardium. This would obviously be a concern in penetrating cardiac trauma because of the frequent associated hemothorax.

Jimenez et al[4] published a prospective study in Surgery in 1990 comparing ECHO versus SPW in the diagnosis of the occult cardiac injury after penetrating chest trauma. Seventy-three patients were included in the study with all having an ECHO and a subsequent SPW. There were only 9 cardiac injuries detected and all these 9 underwent a sternotomy. The sensitivity of ECHO for diagnosing an injury was 90% with a specificity of 97%. There was a single false negative. The mere presence of blood in the pericardial sac may well be too sensitive a marker of an injury as only 30% of the injuries

detected required surgical repair. This is the only study that looked specifically at the amount of fluid in the pericardial sac. They selected a figure greater than 20ml of pericardial fluid as being an abnormal pericardial effusion. Sonography is sufficiently sensitive to be able to detect 20ml of fluid in the pericardial sac.[171] The conclusion they reached was that bedside ECHO was the procedure of choice to diagnose the occult cardiac injury in stable patients.

Grewal reported in 1995 on the evaluation of the SPW in the diagnosis of the occult cardiac injury.[125] In this study there two patients with a negative ECHO who turned out to have cardiac injuries. The one presented with delayed cardiac tamponade following discharge and the second with an episode of hypotension while still in the hospital. There are numerous case reports of where ECHO failed to detect the cardiac injury in an asymptomatic patient.[99] Bolton et al[172] documented 5 cases where ECHO failed to detect a cardiac injury. This may well be an example of where the pericardial blood decompresses through the pericardial laceration into the pleural space.

It would appear that ECHO is as sensitive as US in the detection of the occult cardiac injuries. The worrying concern is the high number of false negative results and the fact that this test cannot be a stand-alone screening test for cardiac injuries. The other point is about the availability of ECHO in the emergency rooms in hospitals and whether there is the available expertise to operative ECHO after-hours.

(f) Pericardiocentesis

Pericardiocentesis was first performed by Riolanus in 1649 and since that date has had a rather stormy course with respect to its role in diagnosing cardiac trauma. Sir Charles Balance was of aware of a number of cases of cardiac injury recorded in Stephen Paget's Surgery of the Heart (1896) and had the following to say of pericardiocentesis in 1919;

"The operation of paracentesis pericardii, or aspiration of the pericardium, should be, I think, banished from surgical practice; just as puncture of the distended abdomen is no longer done in cases of obstruction. It is a leap in the dark, and many cases of wound of the heart or coronary artery have occurred in the course of this operation." [32]

There have been apparently successful results with pericardiocentesis [68, 171, 173, 174] but the majority of reports have suggested that pericardiocentesis is misleading and may have false positive and false negative results in 50% of patients.

Evan et al[112] found in 1979 that pericardiocentesis was not particularly helpful in any of 9 patients who underwent the procedure and that the blood had clotted in the pericardial sac in all patients at exploration.

In general the role of pericardiocentesis in trauma is very limited and it is not recommended in either a diagnostic nor therapeutic role.[6]

CHAPTER 4

SURGICAL MANAGEMENT

"The Surgeon having this job in hand will take it all in the day's work, and just as he plunges his hand into the abdomen into a mass of blood in a case of a ruptured spleen or in a case of a ruptured tubal gestation and seizes the bleeding spot, so he will now plunge his hand into the pericardium and seize the heart, and by digital compression, control the hemorrhage, and proceed to suture the wound."

Sir Charles A. Balance (Consulting Surgeon to St. Thomas's Hospital).

Bradshaw Lecture on Surgery of the Heart.

Delivered before the Royal College of Surgeons of England on the 11th December 1919.

Lancet 1920; January 10; 73-79.

CHAPTER 4

SURGICAL MANAGEMENT

(a) Introduction

The main elements that have contributed towards an improved survival with respect to penetrating cardiac injuries have been the establishment of trauma systems, rapid transportation, immediate resuscitation and early operative intervention. Rapid resuscitation and immediate surgical exploration are considered to be the major reasons for the improvement in the outcome of PCI.[123, 126, 139, 175, 176]

The management of cardiac injuries and penetrating thoracic trauma appeared to be a rather "hit and miss" affair in the 1980's. Various guidelines were published for the management of penetrating thoracic trauma. Thoracotomy was recommended by Goiti et al[177] in 1984 for all patients with penetrating chest injury. Routine thoracotomy was also advocated as the treatment of choice for suspected cardiac injuries in patients with wounds in close proximity to the heart. Penetrating chest injury was classified into 3 groups by Reece et al[126] in 1983 based on the experience of the Glasgow Royal Infirmary and management decisions were based upon this grouping. Patients presenting with thoracic stab wounds were managed with chest drainage and observation if they were hemodynamically stable and any cardiac injury in this group was presumed to have sealed (Table 4.1).

Table 4.1 Reece et al classification of stab wounds to the chest.

Group	*Description*	*Management*
Group 1 (60%)	Stab wound of the chest with little or no hemodynamic instability. A cardiac wound if present is most likely to seal.	Venous access and erect chest x-ray. Chest drainage if required and observation.
Group 2 (30%)	Suspicious chest wound and hypotensive that often responds to transfusion.	Insert central venous pressure and arterial line. Thoracotomy is indicated if the chest drainage is greater than 500ml over 2 hours, or more than 2 l in 6 hours, or if the patient requires ongoing transfusion.
Group 3 (10%)	The unconscious warm patient with no blood pressure and a highly suspicious penetrating chest wound, "apparently dead".	Immediate thoracotomy and relief of tamponade.

A thoracotomy purely because a wound is in proximity to the heart will result in a negative exploration rate of between 40-76%.[143, 178] There is no doubt that the use of US as screening for cardiac injuries in the 1990's marked a major improvement in the management of penetrating cardiac trauma.

In the majority of Trauma Centers, cardiac injuries are managed as follows; patients presenting with cardiac tamponade or massive thoracic bleeding with a systolic blood pressure of less than 90mmHg are taken directly to theatre. If a patient arrives shocked but the blood pressure stabilizes to greater than 90mmHg, then a chest x-ray and mobile cardiac ultrasound are performed.[133]

The majority of surgeons would agree that penetrating cardiac wounds require urgent exploration. Odell et al[179] recommended that if there was doubt about the diagnosis, the patient should be prepared for sternotomy, but a small SPW could be undertaken and the pericardium opened. Only if blood was found was the incision extended into a full sternotomy and the cardiac injury repaired.

When managing cardiac injuries, one does have to ask the question if the surgery is necessary and whether a simple procedure will be adequate as opposed to a more complex one. This is the era of selective conservative management in trauma care, a policy that has been highlighted as having a very strong South African advocacy. The reason for this is often due to the high trauma volume and often less than adequate resources to deal with this influx.[95]

(b) Emergency Room Thoracotomy

Rhee et al[180] published a meta-analysis in 2000 on Emergency room thoracotomy (ERT) and reported a survival of 19.4% for cardiac injuries. The survival rate was best for those patients with penetrating chest injuries. [181]The criteria used for an ERT vary between institutions. An unrecordable blood pressure with normal cardiac auscultation has been used in some centers, while a large review on ERT showed that patients presenting with signs of life, vital signs and a sustainable cardiac rhythm, fared better than patients with only signs of life.[182] Lewis et al recommended that ERT be performed on all cases of collapse or arrest where signs of life have been present in the last 3 minutes.[183] However, Seamon et al[184] have cautioned that survivors do occur when presenting to hospital with undetectable signs of life, no vital signs and abdominal exsanguination. It has also become evident that an ERT is nearly always futile in patients presenting with multiple gunshot wounds to the heart.[185] The majority of centres have abandoned ERT in the case of blunt trauma because of the low number of survivors [186-190] but there may be a place in blunt trauma for witnessed cardiac arrest. [191]

Pre-hospital thoracotomy for penetrating trauma to the chest resulting in a cardiac arrest has resulted in survivors and should be attempted provided there is the necessary expertise. [186]

(c) Surgical Access to the Heart

The ability to carry out prompt emergency surgery in the case of a cardiac injury should be within the capability of every general surgeon who is the person usually first confronted with such an event.[192]

The surgeon needs to be scrubbed and ready to operate before the patient is anesthetized if cardiac tamponade is suspected as the general anesthetic will result in a decrease in the preload and this can cause the patient to decompensate and cause an abrupt cardiac arrest.

The preferred method of exposure is a median sternotomy in the operating theatre[123] and a left anterolateral thoracotomy in the emergency room. It is important that the surgeon has some idea pre-operatively as to which organ is most likely to be injured, and thus a more pragmatic approach can be taken. If the heart is most likely injured there is no doubt that a median sternotomy provides the best surgical access.[111]

A left thoracotomy allows for excellent exposure of the lung, descending aorta and left mediastinum but does not allow for adequate access to the right side of the heart and as a result the incision is often extended across the sternum.[112] Mitchell et al[111] found in their series that 17 of 83 patients (20%) required extension of a left thoracotomy for adequate exposure of a cardiac injury and to manage trauma to the right hemi-thorax.

The median sternotomy provides the best surgical access to cardiac wounds in patients who are sufficiently stable to be taken to the operating room. There is, however, limited access to the thoracic cavities so that it is difficult to manage lung injuries through this exposure.

Median sternotomy also has the advantage of less post-operative pain and a shorter hospital stay than is the case with a thoracotomy.[193, 194]

The argument that a sternotomy takes longer than a thoracotomy is not true. A sternotomy also provides the best exposure to the great vessels as they exit the heart. If the most likely injured viscera is the lung, then a thoracotomy placed on the appropriate side is the best approach. What I have also found is that in the case of an ERT, if the entrance wound is located on the right then it is best to open the right chest with a right anterolateral thoracotomy through the 5th intercostal space.

Several strategies to gain initial control of the bleeding have been described. A Satinsky clamp may be used to seal an atrial wound but should not be used on the thicker walled ventricles as it may cause the ventricles to tear. A Foley catheter may be inserted for temporary hemostasis in the emergency center. A skin stapler may also be used to achieve hemostasis.[33]

(d) Cardiac repair

A number of suture techniques may be used to close cardiac wounds. The favored suture is a mattress suture with Teflon pledgets to prevent the suture from tearing out. The wound should just be approximated. Single sutures may also be used or even a running suture. The surgeon needs to balance the repair with the nature of the injury. A running suture may be more successful where a rapid repair is needed as in a hole in the superior vena cava. A mattress suture is an absolute requirement if an injury is in proximity to a coronary artery.

The cardiac needle needs to be correctly chosen. Generally a polypropylene suture is used and this can be a 2-0, 3-0 or 4-0. The needle is of crucial importance. This must be sufficiently long to allow for a single bite to taken on both sides of the wound thereby alleviating the need to reload.

Pledgets are a very useful adjunct to the repair. While the left ventricular wall will hold sutures extremely well this is not the case with the atria and right ventricle and in these areas pledgets should be used to take the tension off the area of repair.

The posterior surface of the heart needs to be inspected prior to closure to ensure that there is not a through-through injury present.[195] Manual elevation of the heart will cause cardiac output to reduce to zero, so the anesthetist needs to be warned. The heart should not be elevated for more than a few seconds; if there is a posterior cardiac wound, placement of sutures should be alternated with replacing the heart and maintaining the cardiac output.

(e) Coronary artery injuries

The majority of coronary artery injuries can be ligated. Ligation will result in a small infarct in distal vessels that generally does not result in cardiac failure. An intra-aortic balloon pump can be used after ligation if this procedure results in cardiac dysfunction. Cardiopulmonary bypass with acute coronary bypass will be required for a high proximal injury to the left anterior descending coronary artery with evidence of acute cardiac failure. The right coronary artery and the circumflex coronary artery may be ligated but both these injuries are associated with a high mortality.

The overall mortality for coronary artery trauma is 69%.[33]

(f) Intracardiac fistulas and valvular injury

The most appropriate form of management for these injuries is to control any hemorrhage and adopt a damage control philosophy. Intracardiac defects should be dealt with at a later date once the bleeding has been controlled. The patient's chest should be closed and cardiac catheterization performed when the patient has stabilized.[205]

Acute aortic incompetence with intractable cardiac failure will require a valve replacement. Patients with septal defects generally present in the postoperative period with a murmur and the defect is

confirmed on ECHO. These patients should be closely followed as a significant proportion of these will seal spontaneously. Spontaneous closure of the majority of traumatic VSD and ASD usually occurs in 8-12 weeks. Persistence of the shunt implies fistulization or epithelilization and surgery is indicated.[94] The patient needs to be cautioned about the development of an endocarditis when undergoing urological or dental procedures.[196]

(g) The Negative Sternotomy

The negative sternotomy rate (no cardiac injury) is not a frequently reported statistic in the majority of cardiac studies and the reason for this is presumably the fact that most studies are retrospective and include only those patients with documented cardiac injuries and not patients operated on for suspected injuries. Where this is reported it appears to be in the range of 2.8%.[118]

(h) Surgical Management of the Stable Patient

The management of patients arriving at the hospital completely stable and who are identified as having a PCI remains a difficult problem, especially with regard to the timing of surgery. Certain authors feel that the management policy for unstable and stable patients should be the same and that hemodynamic stability may mislead surgeons with respect to the need for urgent therapy.[5, 197] There is also the concern that stable patients with a PCI may suddenly decompensate. Buchman[89] reported on 8 patients presenting in a stable state with a PCI, and two of these patients suddenly deteriorated while being prepared for subxiphoid pericardial window.

Johnson et al[152] reported their 13-year experience with 79 PCI. They performed a SPW in stable patients with a suspected injury, and extended this into a median sternotomy if the window confirmed an intrapericardial injury.

What is apparent is the fact that cardiac injuries are being missed. In a mortuary series from South Africa, 14% of patients with cardiac injuries had died in a hospital without the diagnosis being made.[198]

The Groote Schuur Hospital Trauma Centre sees a large number of patients with penetrating thoracic injuries. There is a small subset of these patients who present completely stable with no evidence of cardiac tamponade or active bleeding. In the past if the ultrasound confirmed the presence of blood in the pericardium, immediate sternotomy was performed and repair of any cardiac defect undertaken. These patients were often very stable, and because limited access to emergency theatre, surgery was sometimes delayed for up to 2 days. It also became apparent that many of these patients did not have a cardiac injury at sternotomy or the cardiac injury appeared to have sealed completely. The implications of a median sternotomy were that an intensive care unit bed was required post-operatively. Furthermore it does have a significant complication rate. Therefore the question as to whether a sternotomy was required in this selected group of patients was raised. At the same time it would be important to have some way of determining whether the cardiac injury had stable clot covering the wound, and the capacity to drain the blood from the pericardial sac so as to prevent the complications of a delayed symptomatic pericardial effusion, a septic pericarditis or a constrictive pericarditis. The subxiphoid window seemed to be the ideal operation to resolve these issues. At the time of performing a SPW the blood in the pericardial sac could be evacuated and the sac could be irrigated to determine if the clot covering any cardiac wound was indeed stable. If there was evidence of active bleeding as a result of a major cardiac injury, a median sternotomy and repair could then be performed. If there was no bleeding, the most appropriate management would be to leave a soft pericardial drain in situ and to observe the patient closely in the high care unit post-operatively.

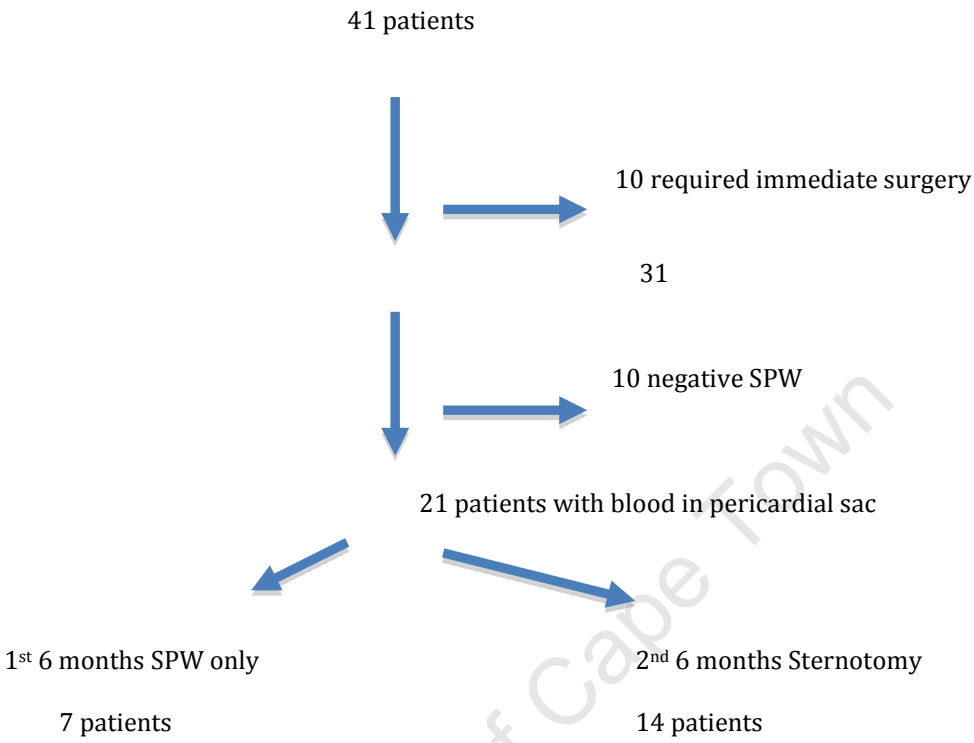
In order to assess this hypothesis it was important to conduct a pilot study in order to determine the number of cardiac wounds that were present in this subset of patients, how many of these wounds had sealed and how many required suturing.[199] We felt sufficiently confident that a SPW was a safe and effective procedure and for the first 6-months of the year we managed all stable patients with a SPW and drainage alone and in the second 6-month period all patients were managed with a

sternotomy. A total of 41 patients were evaluated for a suspected penetrating cardiac injury over this period. Ten patients (24%) arrived with features of cardiac tamponade and underwent immediate surgery. The remaining 31 patients all underwent a SPW. At surgery 10 of these were found to be negative (diagram 4.1) Seven patients underwent SPW and drainage alone and 14 patients underwent sternotomy.

Ten of the 14 (71%) patients that underwent s sternotomy had a non-therapeutic procedure. Only 4 patients had full thickness injuries determined by probing and these were all sealed but were reinforced with sutures. The seven patients that were managed with SPW and drainage were discharged home well. There were no complications related to the procedure and no patients required a delayed sternotomy. At two week follow up there was no clinical evidence of any recurrence of the effusions.

This prospective study certainly supported the hypothesis that this select group of patients can be managed with the simpler surgical procedure of a SPW and drainage of the hemopericardium rather than the need for a median sternotomy. This finding led on to the need for a prospective, randomized trial that was conducted and the findings are published in chapter 8.

Diagram 4.1. Management of the 41 patients with suspected cardiac trauma. (Navsaria, Nicol et al[199])



(i) Site of the Cardiac Injury

With stab wounds the most common injury is to the right ventricle (35%), with the left ventricle being involved in 25% and a multiple chamber injury in the remaining 30%.[86, 112, 174, 200-203] There is a higher incidence of right atrial injury in comparison to left atrial wounds, which is indicative of the anatomical position of the right atrium with respect to a frontal assault.[103] In gunshot wounds it would appear that the left ventricle has an equivalent wounding rate to the right ventricle.[107, 108]

Table 4.2. Incidence of penetrating trauma to the specific cardiac chambers.[33, 107, 175, 204]

Chamber	*Incidence*
Right Ventricle	40-55%
Left Ventricle	25-40%
Right Atrium	4-18%
Left Atrium	3-5%

(j) Cardiac Foreign Bodies

Foreign bodies should ideally be removed as numerous complications have been described such as embolization, endocarditis, coronary artery thrombosis, septic pericarditis, and erosion through the heart.[114, 135] The risk of removal needs to be weighed up carefully against the risks of complications, resulting from leaving the foreign body behind, as a third of these foreign bodies may be difficult to locate at surgery and require fluoroscopy or intra-operative ECHO.[206] There are reports where intracardiac missiles have been well tolerated.[207, 208]

(k) Clinical Outcome

The reported survival rates for penetrating injuries to the heart vary from 15% to 96%.[11, 12, 87, 89-91, 102, 108, 117, 120, 123, 128, 132, 134, 139, 142, 198, 209-215] These outcomes have shown much variability as there appear to be multiple factors involved in determining survival, including the efficiency of the pre-hospital transport which allows more severe cases to arrive at the hospital alive, the proportion of cases that are agonal with a cardiovascular respiratory score of less than 3, and the number of gunshot injuries.

The most important factor affecting survival is the mechanism of injury. The reported mortality varies according to whether the study is population or hospital based. The reported mortality in hospitals for gunshot wounds is 60% to 84% compared to between 22% - 35% for stab wounds.[11, 132, 139] If one considers the population based figures then there is a mortality of 90.3% for gunshots to the heart and 67.4% for stab wounds.[92] Madiba et al[93] in South Africa also reported a higher mortality in gunshot wounds versus stab wounds. This is related to the kinetic injury imparted by a bullet as it passes through tissue creating a zone of damage that is particularly lethal in cardiac wounds. There is a higher proportion of patients with multiple system injuries after gunshot wounds which accounts for the higher mortality.[103, 105, 200, 216, 217]

Table 4.3. Hospital Survival Rates for Penetrating Cardiac Trauma

Author	***Year***	***Country***	***Design***	***Duration (years)***	***Number of Cardiac Injuries***	***SW (%)***	***GSW (%)***	***Survival***
Gao et al[134]	2004	China	Retrospective	16 years	82	90%	10%	96%
Ozyazicioglu et al[209]	2002	Turkey	Retrospective	20 years	38	32%	68%	90%
Tyberski et al[108]	2000	USA	Retrospective	17 years	302	51%	49%	41%
Harris et al[133]	1999	RSA	Retrospective	3 years	128	100%	0%	92%
Asensio et al[11]	1998	USA	Prospective	1 year	60	42%	58%	35%
Wall et al[33]	1997	USA	Retrospective	20 years	711	54%	42%	53%
Johnson et al[152]	1995	USA	Retrospective	13 years	79	75%	25%	94%
Coimbra et al[132]	1995	Brazil	Retrospective	3 years	63	46%	54%	38%
Buckman et al[5]	1993	USA	Prospective	2 years	66	30%	70%	29%
Mitchell et al[111]	1993	USA	Retrospective	15 years	119	41%	59%	58%
Knott-Craig et al[175]	1992	RSA	Retrospective	2 years	129	100%	0%	92%

Whalen et al[218]	1987	RSA	Prospective	2 years	74	100%	0%	70%
Oakland et al[128]	1987	RSA	Retrospective	1 year	38	100%	0%	92%
Feliciano et al[102]	1984	USA	Retrospective	1 year	48	39%	50%	58%
Mattox et al[87]	1975	USA	Retrospective	23 years	337	66%	34%	71%

In a retrospective study from Durban South Africa, which included 70 patients with cardiac trauma seen over a 3-year period, the mortality rate was 50% with all the 4 gunshots demising. The significant factors associated with survival in this study were the presence of cardiac tamponade (p = 0.039), a right ventricle injury, single chamber trauma and rapid operative intervention within 15 minutes. The duration between injury and surgery was felt to be the single most important factor affecting survival.[120]

A retrospective study from the Chris Hani Baragwanath Hospital in South Africa looked at 117 patients with penetrating cardiac injuries over a 2-year period.[142] The risk of death was no different when comparing single or multiple cardiac wounds. Cardiac tamponade also appeared to confer a survival advantage as seen in previous studies.

It has been suggested that patients who present with a cardiac tamponade have a survival advantage. It certainly does make sense that massive hemorrhage would have a higher mortality rate than cardiac tamponade and a number of retrospective studies have supported this view.[97, 108, 141, 142, 171, 180, 203, 205, 210, 219-222] However a prospective study on 66 cases of PCI by Buckman et al[5] failed to show tamponade as an independent predictor of survival. The main problem with this prospective study was that it only included a total of 20 patients with tamponade, nine as a result of stab wounds and 11 resulting from gunshots. This subset is too small for any reliable statistical interpretation. However, a further prospective study undertaken by Asensio et al [11] in 1998 on 60 patients with PCI also found no survival advantage associated with cardiac tamponade. A plausible explanation may

well be that there is a survival advantage in the case of stab wounds to the heart presenting with cardiac tamponade but not in the studies where gunshot wounds to the heart predominate.

There is also a correlation with the AAST cardiac injury scale; Grades 4, 5 and 6 have mortality rates of 56%, 76% and 91% respectively.[202]

The site of the injury is also important with respect to mortality rates. Left sided heart injuries with the higher pressures have been reported to have a lower survival rate than the low pressure right chambers.[12, 120, 223]

Table 4.3. Cardiac chamber mortality rates.[202, 223]

Chamber	***Mortality***
Left Atrial	36-77%
Left Ventricle	12-80%
Right Atrial	25-63%
Right Ventricle	9-49%

However, a prospective study on 60 patients did not show that an injury to a specific cardiac chamber to be a predictor of outcome. Multiple chamber injuries are known to have an increased risk of death in comparison to a single chamber wound.[86, 92, 103, 224]

Other factors that are important in determining survival are the cardiovascular-respiratory score (CVRS) component of the trauma score. The CVRS reflects the physiological status of the patient by assessing the systolic blood pressure, respiratory rate and effort and the capillary refill. A CVRS score equal to 0, comprising no blood pressure, no respiratory effort and absent capillary refill, has a 96% mortality rate.[11] This lack of vital signs on presentation to hospital has also been recognized by other authors as a poor prognostic sign.[103, 106, 203, 220, 225-227] The need for an emergency department

thoracotomy, inability to restore organized rhythm after thoracotomy and aortic cross-clamping have both been show to be predictors of outcome.[11] The presence and severity of associated injuries will also have an influence on survival.[92]

Table 4.4 Factors predictive of mortality in penetrating cardiac trauma.

Accepted prognostic factors	***Disputed prognostic factors***
Physiological status on admission	Presence of cardiac tamponade
Lack of vital signs on admission	Specific chamber involvement
CVRS score	
Mechanism of injury	
Injury Severity Score	
Emergency department thoracotomy	
No cardiac rhythm post thoracotomy	
Great vessel involvement	
Aortic cross clamping	
Multiple chamber involvement	
AAST Organ injury scale	

(l) Post-Operative Follow Up

Residual intracardiac lesions have been reported as in 4 to 56% of patients surviving heart trauma and an immediate post-injury evaluation with ECHO has been advocated. This may identify shunts, valvular abnormalities, and pericardial effusions.[153] Other centers have suggested that ECHO should be done 1 month post-injury as 19% of the cardiac injury survivors will have an abnormality detected.[228-230] A 5-year follow up ECHO assessment showed that survivors of cardiac trauma, without coronary artery or valvular disruption, had normal cardiac function.[231]

(m) Thoracoscopy

Branco was the first to report the role of emergency thoracoscopy in the management of chest trauma in 1946 and a thoracoscopic pericardiotomy for benign and malignant pericardial effusions is a well-recognized procedure.[232-237]

Thoracoscopic pericardial windows was reported by Morales et al [238] to very extremely effective in 97% of cases with minimal complications. [239] Thoracoscopy has been used at our Trauma Center and we published our experience with it in 2006.[240] A thoracoscopic pericardial window (TPW) was performed in 13 patients, who were hemodynamically stable with a suspected occult cardiac injury, and a hemopericardium was found in three patients. In the one patient good visualization of the anterior surface of the heart allowed a cardiac injury to be excluded. In the other two patients, thoracoscopy was followed by a sternotomy and in one patient a myocardial contusion was evident and in the other there was no cardiac injury. Our experience with TPW was that it did not appear to hold any advantage over a SPW. The patients all required a double lumen tube to allow for collapse of the lung and adequate visualization. This requires a certain anaesthetic expertise and added a cost factor to the surgery of an additional 23% with no real benefit to the patient.

(n) Laparoscopy

Grewal et al[125] have used laparoscopy to inspect the pericardial sac and diaphragm in 10 patients with penetrating thoracoabdominal trauma and were able to diagnose two patients with a hemopericardium that was confirmed at SPW. They reported that a hemopericardium did not appear to reflect light from the laparoscope and appeared opaque.

(o) Conservative Management

In the vast majority of centers, which manage penetrating cardiac injuries, the finding of such an injury is an indication for immediate surgery and cardiorrhaphy. Nevertheless there are a handful of cases reported in the medical literature where conservative management (no surgery and no pericardiocentesis) has been used to manage this type of injury in the completely stable patient. Conservative management is certainly more prevalent than is reported, based on personal communication with various trauma surgeons around the world. At the same time it is evident that missed injuries may present with delayed tamponade and death.[241]

Conservative management of PCI has been tried in a number of hospitals in South Africa. One out of a total of 70 penetrating cardiac injuries managed in Durban, South Africa was successfully managed without surgery or aspiration. The authors felt that conservative management was only acceptable in a "select group of patients who remain clinically stable with subtle if any signs of tamponade and in whom a cardiac chamber has not been penetrated." The problem is that the current special investigations are not sufficiently accurate to be able to determine whether the heart has been penetrated or not and the authors do make the point that a conservative approach may be more lethal than the occasional negative surgical exploration.

Harris et al[133] from Tygerberg Hosptial in Cape Town felt that the fact that 48% of lacerations had clotted at the time of surgery in the stable group, could be an indicator that this specific group of patients may be treated conservatively. They managed three out of a series of 128 hemodymanically stable patients with a positive US for pericardial blood conservatively. Two of these patients deteriorated and required delayed surgery, while the third was discharged home. They commented that there was no place for the observation of these patients with suspected PCI.

Campbell found that in a study from Durban, South Africa, that there were 7 missed cardiac injuries discovered at postmortem autopsy in patients that had been admitted to hospital and subsequently discharged.[120]

MIchelow[2] wrote a paper entitled "Penetrating cardiac injuries: selective conservatism- favorable or foolish" in 1987 in the Journal of Trauma. He reported on the conservative management of nine patients and aimed to emphasize that there was a place for conservative management in highly selected cases. These 9 patients all presented with a stab wound to the chest, with normal vital signs, and all patients had a pneumopericardium on chest x-ray. Eight of the patients had a hemopneumothorax on the side of the stab, which was managed with an intercostal drain, and all 9 were discharged after 4 to 14 days. One patient developed a pancarditis on day three and at sternotomy a fistula was present between the right ventricle and the sinus of Valsalva. This was repaired and the patient recovered. They felt that in the small percentage of patients presenting with normal vital signs, an ECG and a chest x-ray should be performed and a chest drain inserted if indicated. The patient should be monitored closely for a period of 48-hours and discharged if they remain stable and if there was no evidence of a cardiac injury.

The complication rate of conservative management of PCI appears to be excessively high. Heller et al[1] reported in a prospective study on the conservative management of 10 patients in whom the diagnosis of cardiac involvement was not certain on admission. Cardiac involvement was later determined by pericarditis like changes on the ECG in all 10 patients. Ultrasounds were not performed. Two myocardial infarcts occurred one with an aneurysm of the left ventricle and coronary artery and late onset hemopericardiums in an additional 4 patients.

There is a single prospective study in the literature by Demetriades et al[242] that deals with the management of the pneumopericardium after penetrating trauma from Baragwanath Hospital in South Africa. It is an important study as it also deals with the non-operative management of hemodynamically stable patients with small pericardial effusions on echocardiography. There were 20

patients included in the study who presented with a pneumopericardium after stab wounds to the chest. Four patients were shocked on admission but were easily resuscitated. Only one patient of the 20 (5%) required a thoracotomy and this was a patient that developed a tension pneumopericardium at 36-hours following admission. The remaining 19 patients made a full recovery. Three of these patients on admission had "small" pericardial effusions on ECHO and were followed up with serial echocardiography and in two the effusion became smaller and in the third stayed the same. The authors believed that a conservative policy was safe and that a pneumopericardium after penetrating trauma was not an absolute indication for surgery, and the decision should be based on clinical grounds. They also suggested that echocardiography and electrocardiography may be helpful in deciding which patients required surgery.

Mayor-Davies[243] stated that there was no place for conservative management, since of the major concerns is the problem of delayed hemorrhage, which may occur up to three weeks post injury and that all PCI should be repaired to prevent delayed hemorrhage.

Von Oppel et al[94] suggested that conservative management may be indicated in a very small select group of patients who were stable with a hemopericardium demonstrated on ECHO provided there was close monitoring available in a high care area for up to 5 days, with follow up for at least 1 month. They did caution, however, that delayed surgical intervention is required in greater than 50% of conservatively managed patients and that there was a significant mortality associated with this approach.

I would not suggest that conservative management of PCI is a viable entity. The mortality rate for missed injuries is reported to be 50% and the complication rate reaches 50%. At the moment there is no way of determining which patients have pericardial injuries alone and which have associated PCI. There also appears to be a considerable complication rate with leaving blood in the pericardial sac.

There is a need to have a procedure that is able to identify those patients with "unstable" clot. This is clot that will undergo lysis which will cause the patient to re-present with bleeding. It does appear

that the SPW may be the answer in that it clears blood from the pericardial sac thereby preventing the later development of a pericarditis and it may help in determining which patients are at risk of bleeding due to unstable clot.

CHAPTER 5

THE SUBXIPHOID PERICARDIAL WINDOW (SPW)

Baron Dominique Jean Larrey described the first pericardiotomy on a trauma patient.[244] A 30-year old man had stabbed himself in the left side of the chest. In 1900 Allingham described what he referred to as the "epigastric operation" for drainage of the pericardium, although the description was very similar to that of Larrey. He made his incision below the 7th costal cartilage and extended this through the costo-xiphoid space to the diaphragm thereby avoiding the pleura and the peritoneum. The sternal end of the 7th costal cartilage was excised in some cases.[32]

While the majority of cardiac injuries arrive at hospital with features of cardiac tamponade or profound hypovolaemic shock, there are a certain number of patient who arrive stable, or who are easily stabilized. It is in these patients that a diagnostic dilemma arises as to the most appropriate method of excluding a potential cardiac injury. This needs to be accomplished fairly rapidly so that the patient is managed appropriately.

The SPW has become established as the gold standard in the diagnosis of the hemopericardium after penetrating trauma. There are, however, numerous antagonists as it is an invasive procedure and there is obviously a desire to replace this with a non-invasive investigation with a similar sensitivity in order to exclude cardiac injuries. Its role in the potential definitive management of a hemopericardium has not been defined. Since the 1990's the SPW has been superseded by use of US in the resuscitation room and its role in trauma has become less pronounced.[28] The current trends in the management of PCI are to perform a pericardial window if the results of the US are equivocal or US is not available.[24]

Surgical Technique of the Subxiphoid Pericardial Window

(i) Anaesthesia

There is no doubt that this procedure needs to be performed in the operating theatre under general anesthesia. However, there have been reports of the SPW being undertaken in the resuscitation room under local anesthesia.

Demetriades in 1986 commented that performing a SPW under local anesthetic on a restless patient is a dangerous procedure and the patient may exsanguinate in less than ideal circumstances.[123]

Duncan et al[143] stated in 1989 that in their experience a SPW could not be satisfactorily done under local anesthesia as the majority of patients are young males who are mostly uncooperative and combative.

(ii) Position

The patients were draped as stated in the Definitive Surgical Trauma Care Course (DSTC©) with exposure from the sternal notch to the pubic symphysis. The patients were placed in the supine position and in a slight reverse Trendelenberg position to allow the pericardial sac to reach its most dependent position relative to the costal margin. This maneuver was particularly useful in patients with narrow costal arches.

(iii) Technique

A 6cm vertical midline incision was made over the xiphoid process. This was continued through the linea alba with care taken not to enter the peritoneal cavity. The xiphisternum was dissected out and excised if it interfered with exposure. A Langenbeck retractor was placed under the sternum and elevated. A sponge on a stick was found to be particularly useful in wiping away the fat pad from the inferior portion of the pericardium. The pleural spaces on both sides of the chest should also be visualized and care was taken not to cause any damage. The pericardial sac was elevated with an Allis clamp and a small incision was made into the pericardium alongside the tented up portion of the pericardium. Hemostasis needs to be perfect prior to the incision so as to determine whether the SPW is positive for blood in the pericardial sac. The pericardium was incised under vision vertically for approximately 4cm. If the pericardial fluid was clear then nothing further is done. If there was blood in the sac, then the clots were evacuated with the suction apparatus and manually removed. The pericardial sac was then irrigated with warm normal saline.

The Role of the Subxiphoid Pericardial Window

The management algorithm which the majority of surgeons use is that penetrating cardiac injuries require immediate exploration. In a large number of cases it is very difficult though to diagnose a cardiac injury and there are a number of clinical scenarios with penetrating chest trauma that simulate a cardiac perforation. An example is the patient that is in shock with a hemothorax and an elevated central venous pressure on the basis of straining or pain but with no cardiac injury.

We would like to propose that a SPW should be the gold standard with respect to the diagnosis of a cardiac injury in these doubtful cases or where a cardiac injury needs to be excluded. This relatively

minor operation with a very low complication rate is much less invasive than a full sternotomy and generally the patient in the case of a negative exploration does not require intensive care monitoring post-operatively.

It would appear that SPW also has a role in the management of patients with penetrating thoraco-abdominal injuries, where the patient presents with an acute abdomen but needs to have a cardiac injury excluded before laparotomy. The SPW is useful in the unstable patient when it is unclear whether the instability is due to a cardiac injury or an associated thoracic injury. The other question, which needs to be answered, is the role of the SPW in excluding a cardiac injury in the hemodynamically stable patient with a penetrating thoracic injury and a possible cardiac injury?

There are only two prospective studies that deal with the issue of the SPW in the diagnosis of occult penetrating cardiac trauma (table 5.1). Meyer et al[8] conducted a prospective study to determine whether echocardiography was equivalent to SPW in the detection of an occult cardiac injury. The study included all patients who were hemodynamically stable with a penetrating chest wound in proximity to the heart. There were 105 patients that met the criteria and all had an echocardiogram performed and also a SPW. There were only 9 significant cardiac injuries, defined as an injury requiring suture repair. SPW was more sensitive than ECHO for detecting cardiac trauma (100% vs 56%) and the specificity was similar (92% vs 93%). This study highlighted the excellent sensitivity and specificity associated with SPW but also the fact that there were 84% true negative SPW which were required to diagnose 9 true positive cardiac injuries. This may indicate that we need to be more selective in our screening of which patients may well have a penetrating occult cardiac injury and to analyze how patients may be optimally screened.

Jimenez[4] also compared the sensitivity and specificity of the SPW versus ECHO in the diagnosis of the occult injury. There were 73 patients prospectively analyzed with each patient undergoing an ECHO and a SPW following admission with juxta-cardiac penetrating trauma. Nine of the 73 patients had cardiac injuries and all these were detected by the SPW but two were pericardial lacerations. Once

again, when SPW was used as the screening tool up to 80% of patients underwent an unnecessary surgical procedure.

In a retrospective study performed by Duncan et al[143] and published in 1989, the SPW was used to diagnose occult cardiac injuries. Fifty-one patients were evaluated with a SPW after sustaining juxta-cardiac penetrating trauma. There were 12 patients with a positive SPW and at sternotomy a cardiac injury was confirmed in all 12. The SPW did not result in any deaths or complications.

Arom et al[148] managed 50 patients with clinically suspected cardiac tamponade and the SPW was positive in 46 patients and there were no false positives. The negative SPW rate was only 8% in this study but this was due to the fact that the patients were hemodynamically unstable; in fact only 15 out of the 50 patients had a systolic blood pressure of greater than 80mmHg.

Grewel[125] in a retrospective review of the use of the SPW in managing hemodynamically stable patients with a suspected cardiac injury, found that the incidence of the occult cardiac injury in these patients was 20%. This implies that 80% of patients would undergo a SPW unnecessarily.

Andrade- Alegre et al[144], in a retrospective study, used the SPW as a diagnostic tool to rule out PCI in 76 patients without an obvious cardiac wound. In 16 patients (21%) the SPW identified a hemopericardium and in all 16 there was a cardiac injury at surgery. Where the SPW was performed solely on the basis of the proximity of the wound to the heart and not on clinical features the percentage with a positive SPW was only 6%.

False negative SPW has been reported, but is relatively uncommon. Attar et al[139] had two false negative SPW out of a total of 10 in their retrospective series on 109 penetrating cardiac injuries.

The morbidity associated with SPW is extremely low with reported rates of around 0 - 1.3%.

The evidence would seem to suggest that SPW is a very sensitive means of determining the presence of a hemopericardium. However, SPW does not indicate the severity of the cardiac trauma and it is invasive. It is unlikely that SPW can be used on its own as a screening modality since around 75-80% of the SPW are negative. Rather there needs to be a closer examination of other non-invasive tests that may enable the clinician to then determine which patients are in need of a SPW in order to reduce the number of negative SPW.

Table 5.1. Studies on the SPW in the diagnosis of cardiac injury.

Study	***Design***	***Number of patients with suspected cardiac injury***	***Positive SXW for blood***	***Number of cardiac injuries***	***False positives***	***Sensitivity***	***Percentage of negative SPW performed***
Meyer et al 1995 [8]	Prospective	105	16	16	1	100%	84%
Jimenez et al 1990 [4]	Prospective	73	9	9	0	100%	80%
Duncan et al 1989 [143]	Retrospective	51	12	12	0	100%	76%
Arom et al 1977 [148]	Retrospective	50	46	46	0	100%	8%
Grewel et al 1995 [125]	Retrospective	122	26	26	0	100%	80%
Brewster et al 1988 [145]	Retrospective	108	30	28	2		72%
Miller et al 1987 [245]	Retrospective	104	19	19	1 (and 1 false negative)		
Andrade-Alegre et al 1994 [144]	Retrospective	76	16	16	0	100%	

CHAPTER 6

PNEUMOPERICARDIUM

A pneumopericardium after penetrating trauma is a rare event. It is most commonly encountered in ventilated neonates and following blunt trauma. There is no consensus in the literature on the management of a patient presenting with a pneumopericardium and consists of a series of case reports with the last patient series on this topic being published nearly 21- years ago. The suggested management of a pneumopericardium after penetrating trauma ranges from mandatory exploratory surgery to rule out a cardiac injury [246] to conservative management in carefully selected patients.[247]

(a) Definition

A pneumopericardium was first described by Bricheteau in 1844 and was defined as the collection of air or gas in the pericardial sac.[248]

(b) Etiology

A pneumopericardium is most commonly encountered in neonates on positive pressure ventilation and in patients after blunt chest trauma. In a review of the literature, Cummings found that trauma and positive pressure ventilation were responsible for 62% of the cases of pneumopericardium.[248] Other causes include chest wall fractures, trachea and bronchial injuries, lung contusion, esophageal perforation and sepsis in the pericardial sac. A list of causes of a pneumopericardium is outlined in table 6.1.

Table 6.1 Causes of a pneumopericardium.

Trauma - blunt (closed chest trauma with increased intrathoracic pressure) • Positive pressure ventilation • Severe asthma • Difficult labor • Blunt compressive force Trauma - penetrating
Fistula formation from adjacent organs ((ulcer/ infection/ carcinoma) • Lung • Stomach • Esophagus • Liver
Infectious pericarditis
Iatrogenic • tracheostomy • bone marrow biopsy
Valsalva maneuver
Transternal surgery

(c) Incidence after Penetrating Trauma

A pneumopericardium associated with penetrating chest trauma is a rare event. Cummings et al[248] reviewed 252 cases of pneumopericardium in 1984 and reported that only 17 of these cases were as a result of penetrating chest trauma.

Demetriades et al[247] found a 15% incidence of a pneumopericardium in their series of proven cardiac injuries after penetrating trauma.

(d) Pathogenesis

A pneumopericardium will result after penetrating trauma if there is a communication between the pericardial sac and the airway or a pneumothorax. Air may also enter from an exterior wound.[249, 250]

(e) Clinical Symptoms and Signs

The classic clinical sign of a pneumopericardium is the mill-wheel murmur or bruit de Moulin that was originally described by Bricheteau in 1844 in a patient with a pyopericardium. The spectrum of presentation is the same as that for a penetrating cardiac injury. These patients may also present with a tension pneumopericardium and this will present clinically as a cardiac tamponade.

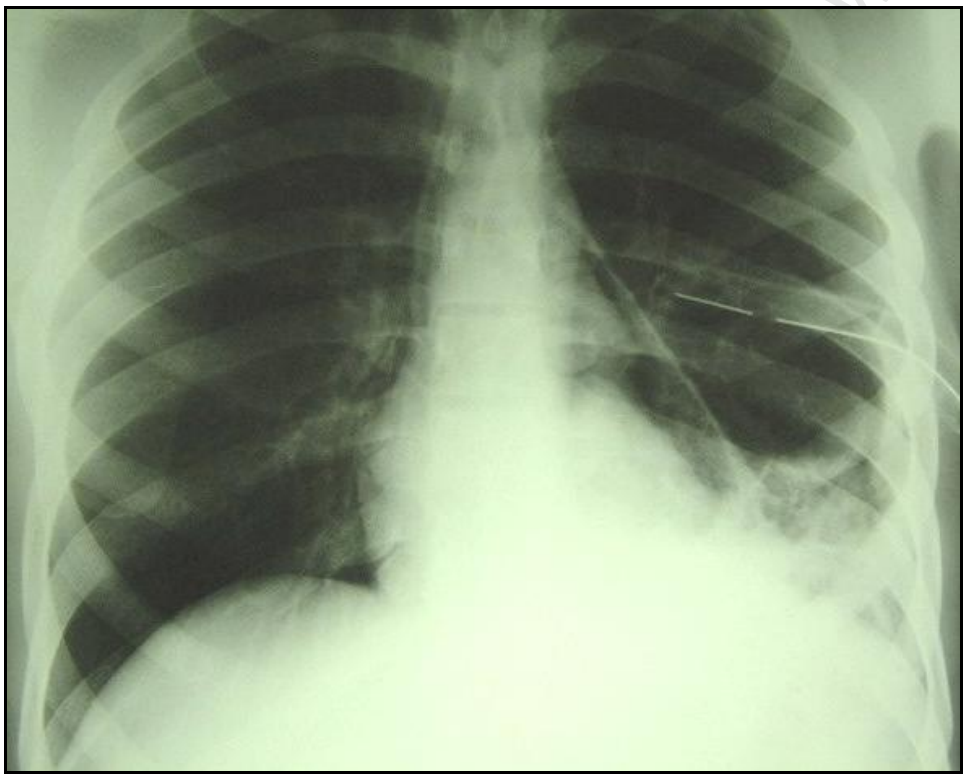
(f) Diagnosis

Wenkebach in 1910 first identified a pneumopericardium on a chest X-ray and the diagnostic features of a pneumopericardium were elaborated on by Cimmino in 1967.[251] A chest x-ray will show the heart partially or completely surrounded by air with the pericardium sharply outlined (figure 6.1). There may also be an air-fluid level in the pericardial sac. The diagnosis of a pneumopericardium can be made on a chest X-ray, ultrasound of the pericardial sac or on CT scan of the chest. It is always important to consider the differential diagnosis of a medial pneumothorax and a pneumomediastinum when one considers the possibility of a pneumopericardium after penetrating chest trauma on a chest x-ray. The easiest distinguishing factor is to look at whether the air extends above the pericardial reflection on the aortic arch. In the latter two differentials, air will extend above the pericardial attachment on the aortic arch but will not in the case of a pneumopericardium. Another useful radiological feature of a pneumopericardium is the “transverse band of air sign”, which signifies the presence of air in the transverse sinus of the pericardium, located behind the origin of the great vessels and in front of the atria, which is never present with a medial

pneumothorax or a pneumomediastinum.[252] Another distinguishing feature between a pneumopericardium and a pneumomediastinum is that if the patient is in the decubitus position, air in the pericardium will shift whereas air in the mediastinum will not in the short period between the radiographs.[251, 253]

The “small heart sign”, which is a sudden decrease in the cardiothoracic ratio or cardiac size on chest radiography, has been described as a feature that should alert the surgeon to the presence of a tension pneumopericardium and impending tamponade.[254]

Figure 6.1 Pneumopericardium after a stab wound to the chest.



(g) Complications

There is evidence in the literature to suggest that a pneumopericardium from blunt trauma and ventilation can result in a tension pneumopericardium in a significantly high proportion of cases. Cummings et al[248] reported that cardiac tamponade developed in 37% of patients and occurred most frequently in patients after trauma and in neonates requiring positive pressure ventilation. The mortality rate of the patients who developed cardiac tamponade was 56%. Obviously this series comprised patients with blunt trauma and neonates with underlying disease processes but it is important to note. There were only 17 cases of pneumopericardium caused by penetrating trauma out of a total number of 249 patients. Two of these 17 patients (12%) later developed a tension pneumopericardium.

Spotnitz et al[246] described the first reported case of a tension pneumopericardium following penetrating trauma in 1987. He reported a 28-year old male who had sustained a penetrating wound to the paraxiphoid area. He was managed with a left anterior thoracotomy and the pneumopericardium was released. There was no direct myocardial injury.

One of the major problems is that a tension pneumopericardium can develop very rapidly. Sun et al[255] described a case report of a 24-year old male who presented initially with stable vital signs following a stabbed chest with a pneumopericardium on chest X-ray. The patient suddenly deteriorated with the clinical signs of cardiac tamponade and required an emergency sternotomy to release the tension pneumopericardium. There was no underlying cardiac injury in this case.

Cummings[248] reported on a 20-year old male with a gunshot wound to the right chest with the bullet lodged between the 4th and 5th thoracic vertebrae. The patient was hemodynamically stable on presentation but had a sudden cardiac arrest and required intubation followed by a right anterior thoracotomy in the radiology suite. The patient had a tension pneumopericardium that was released and taken to theatre where a hole in the superior vena cava and trachea was repaired. The hole in the

trachea was communicating with the pericardial sac. The patient died from cerebral hypoxia 7 days later.

(h) Incidence of a tension pneumopericardium

Levin found that a third of patients with a pneumopericardium will develop hemodynamic compromise.[256] Capizzi[257] reported on 12 of 32 patients (37%) of patients with a pneumopericardium after blunt trauma developed a tension pneumopericardium. This was the same incidence to that described by Cummings et al. Haan described the single case report of a patient that developed a tension pneumopericardium after a motor-vehicle accident.[258]

Demetriades states that an isolated pneumopericardium following penetrating trauma is very rarely symptomatic and in their review of the literature in 1990 there were only two such cases.[247]

(i) Management of Penetrating Pneumopericardium

There is a single prospective study in the literature from Baragwanath Hospital in South Africa which deals with the management of the pneumopericardium after penetrating trauma (table 6.2).[242] It is an important study as it is to date is the largest study on the pneumopericardium occurring after penetrating trauma.

There were 20 patients included in the study who presented with a pneumopericardium after stab wounds to the chest. Four patients were shocked on admission but were easily resuscitated. Only one of the 20 (5%) patients required a thoracotomy and this was a patient who developed a tension pneumopericardium at 36-hours following admission. The remaining 19 patients all made a full recovery. Three of these patients on admission had “small” pericardial effusions on echocardiography

and were followed up with serial echocardiography. In two patients the effusion became smaller and in the third stayed the same. The authors believe that a conservative policy is safe and that a pneumopericardium after penetrating trauma is not an absolute indication for surgery, but the decision should be based on clinical grounds. They also suggested that echocardiography and electrocardiography might be helpful in deciding which patients require surgery.

Table 6.2. Articles on a pneumopericardium after penetrating trauma.

Study	***Year***	***Design***	***Number of patients***	***Tension***	***Surgery***	***Mortality***
Demetriades et al[247]	1990	Case report	1	1	Thoracotomy	0%
Demetriades et al[242]	1990	Prospective	20	1(5%)	Thoracotomy in 1/20	0%
Spotnitz et al[246]	1987	Case report	1	1	Thoracotomy	0%
Sun et al[255]	2010	Case report	1	1	Sternotomy	0%
Cummings et al[248]	1984	Case report	1	1	Thoracotomy	100%

CHAPTER 7

THE MISSED CARDIAC INJURY

The frequency of missed cardiac injuries is rarely reported in the literature. It has been stated that the true incidence of PCI will not be known as patients may demise after discharge from hospital or they may be completely asymptomatic.[243] It is, however, important for us as clinicians to be aware of the potential danger of missing a cardiac injury and what the consequences are. The purpose of this chapter is to look at missed cardiac injuries so that we as clinicians can learn from our mistakes and are better equipped to identify PCI in the future.

The numbers of patients presenting with delayed pericardial effusions appears to be decreasing. There have been 8 reported cases in the literature from 1950 to 1989 compared to 22 cases diagnosed before 1950. This is no doubt related to aggressive screening for potential occult cardiac injuries with US and ECHO.[241] These patients presented between 4 to 73 days after injury.[170]

The diagnosis of a cardiac injury can be challenging particularly in the stable patient. A paper entitled "Pitfalls in the management of penetrating chest trauma" comments on the fact that three out of 14 PCI (21%) were not diagnosed preoperatively in their series and that the diagnosis of a cardiac injury is not straightforward especially where the classic features of cardiac tamponade are not present.[3] Up to 20% of patients with PCI will not show any symptoms or signs of a cardiac injury after a penetrating thoracic wound.[94]

The late sequelae of penetrating cardiac injuries have been documented and consist of ventricular false aneurysms, atrial or ventricular septal defects, valvular abnormalities, aortopulmonary or aortocardiac fistula, coronary artery to chamber or vein communication, electrocardiographic abnormalities and pericarditis.[229, 259-263]

A post-traumatic pericarditis occurs in approximately 22% of PCI (the management is symptomatic as in the postcardiotomy syndrome) unless a purulent or constrictive pericarditis develop.[264] The presence of blood in the pericardial sac initiates an autoimmune reaction with the production of antibodies to the myocardium and pericardium.[265]

Mayor- Davies presented 4 case reports of missed cardiac injuries in 1992.[243] Two of the cases represented 12 and 19 days after initial injury with features of cardiac tamponade and both were successfully managed with SPW and the other with a sternotomy and repair of the right ventricle. The other two cases showed the dangers of relying purely on US in the screening of patients with PCI. The first had a normal US of the heart on admission but died on day 4 due to a missed hole in the intrapericardial part of the aorta. The second patient presented shocked with multiple stab wounds but the ECHO showed no effusion. This patient developed cardiac tamponade 3 days post admission and died from a perforation of the left ventricle and transection of the left anterior descending artery. The major concern of these cases that are presented is the fact that a missed injury can present up to 19 days post initial injury, the fact that the initial US may be normal and that the mortality rate for these injuries is as high as 50%.

SECTION C CLINICAL STUDIES

"It is a fact that there is no unequivocal sign of injury to the heart. When a man or woman is seen with a knife sticking in the cardiac region of the chest and the victim is living, the handle of the knife moves synchronously with the beating of the heart."

John Bland-Sutton[18]

CHAPTER 8

Randomised Clinical Trial comparing Sternotomy versus Subxiphoid Pericardial Drainage alone in the management of the Stable patient with a Hemopericardium after Penetrating Thoracic Trauma

(a) Introduction

Penetrating cardiac trauma is associated with significant mortality with most patients dying before reaching hospital. However, a subset of patients will present hemodynamically stable to a Trauma Center after penetrating thoracic trauma with a suspected cardiac injury and are fully conscious with no signs of cardiac tamponade or active bleeding. How these patients with a normal physical examination and the ultrasound finding of blood in the pericardial sac should be managed remains controversial.

The current management algorithm recommends that a penetrating cardiac injury in a hemodynamically stable patient should undergo a sternotomy and exploration.[266] The experience at Groote Schuur Hospital in Cape Town with performing a mandatory sternotomy in this group of patients was that the cardiac injury if present had sealed. We conducted a pilot study in 2001 and found that 71% (10 out of 14) of patients had a non-therapeutic sternotomy for a tangential or partial injury and the cardiac wound had sealed in the 4 patients with a full-thickness injury[199]. Seven patients with a confirmed hemopericardium were successfully managed with a subxiphoid pericardial window (SPW) and drainage of the blood in the pericardial sac. There were no complications and no patients required a delayed sternotomy.

Delayed rupture of cardiac injuries has been well documented, and it is obviously imperative that a major cardiac injury that has not completely sealed is identified. We have found that by performing a subxiphoid pericardial window, these major injuries start to bleed on table if the pericardial sac is irrigated. If bleeding is encountered then median sternotomy and repair of the cardiac defect is required. If there is no active bleeding, patients can be safely managed with simple drainage of the pericardial sac and no sternotomy. Thus these stable patients can be managed with a minor surgical procedure and not require an intensive care unit postoperatively. In addition the morbidity associated with a sternotomy can be avoided. In order to test this hypothesis we undertook a prospective randomized trial to compare SPW plus pericardial drainage alone versus SPW plus median sternotomy. This is the first prospective, randomized clinical trial ever performed on penetrating cardiac injuries in the world literature.

Method

This was a single centre parallel-group study with equal randomization conducted at Groote Schuur Hospital/ University of Cape Town between November 2001 till February 2009.

All adult patients aged 18- years or older, who had sustained penetrating chest trauma, who were hemodynamically stable with a hemopericardium confirmed at subxiphoid pericardial window, and who had no signs of active bleeding at SPW were included in the study.

The exclusion criteria included hemodynamic instability, evidence of cardiac tamponade, intubated patients, respiratory failure, presence of traumatic septal or valvular defects, a delayed presentation of longer than a week, and an impaired level of consciousness.

This study was approved by the Faculty of Health Sciences Research Ethics Committee of the University of Cape Town.

(i) Management Protocol

Groote Schuur Hospital Trauma Centre is a level-1 Trauma Centre serving a population of around 2 million in the greater Cape Town area. Patients with penetrating chest trauma in proximity to the heart as a result of stab wounds or low-velocity gunshot wounds were admitted to the resuscitation area. Patients who have sustained a hypovolaemic cardiac arrest with signs of life in the preceding 10 minutes and those with a systolic blood pressure less than 70mmHg, which was not responding to resuscitation, were intubated and an emergency department thoracotomy performed through the 5th intercostal space on the side of the injury. If there was massive hemorrhage from the pleural cavity or the intercostal drain had greater than 1.5l of blood, then the patient underwent emergency surgery. If there were features of cardiac tamponade, then emergency surgery was performed. If the patient was expected to survive for at least 10 minutes, then this emergency surgery was performed in the operating room. If the patient was not expected to survive 10 minutes, an emergency department thoracotomy was undertaken. All transmediastinal gunshot wounds were assumed to have a cardiac injury unless this had been excluded. Unstable patients with a transmediastinal thoraco-abdominal gunshot wound with an acute abdomen were subjected to a subxiphoid pericardial window prior to the laparotomy. If this was positive, a median sternotomy in addition to a laparotomy was performed. If the patient was hemodynamically stable, a CT angiogram of the chest was done to determine the trajectory of the bullet and the presence of any blood in the pericardial sac.

Patients with penetrating chest trauma who were hemodynamically stable on arrival or who required less than 2l of fluids in total for resuscitation, and who were otherwise conscious and well, were considered for the study. A chest x-ray, an electrocardiogram and an ultrasound of the pericardial sac were performed. The presence of any fluid in the pericardial sac was considered as positive. Patients with a suspected haemopericardium were admitted to a high care unit for continuous monitoring for a period of at least 24 hours. If the patients became unstable during this period of time, then the patient was taken for emergency surgery.

Patients with a hemopericardium diagnosed on ultrasound, or where there was a clinical suspicion of an underlying cardiac injury due to the presence of a pneumopericardium, or where the ultrasound findings were equivocal, underwent a subxiphoid pericardial window. This was performed after at least 24-hours of observation.

(ii) Technique of subxiphoid pericardial window

The SPW was performed under general anesthetic and involved a small 5 cm incision below the sternum. The pericardial sac was opened and the presence of any blood noted either in the form of clots or in blood staining of the pericardial fluid. The pericardial sac was irrigated vigorously with 500ml of warm saline. The heart was examined for any active bleeding. If there was active bleeding then a median sternotomy was performed to repair the hole in the heart. If there was no active bleeding then the patients were randomized to either median sternotomy or drainage of the pericardial sac with a soft pericardial drain.

(iii) Randomization process

A computerized random number generator was used for the allocation of patients. At the start of the operation, the intervention (either median sternotomy or simple drainage of the pericardial sac) was handed to the anaesthetist in an opaque, sealed envelope. After the SPW had been performed, and the presence of blood in the pericardial sac and the absence of active bleeding confirmed, the envelope was opened by the anaesthetist and the surgeon informed of the intervention required.

(iv) Endpoints of the study

The primary endpoint of the trial was survival to discharge from hospital. The secondary endpoints were the requirement for the intensive care unit, the total hospital length of stay and any complications which were encountered.

Participants in the study were requested to attend a follow-up clinic at two weeks after discharge. A research assistant followed up the patients who underwent pericardial drainage alone.

(v) Definition of terms

Hemodynamically stable implied that the patient had a systolic blood pressure reading equal to or greater than 100mmHg.

A hemopericardium was defined as the finding of any blood in the pericardial sac on US or the presence of blood in the pericardial fluid during the SPW.

A negative SPW was the complete absence of any blood in the pericardial sac at the time of the SPW.

(vi) Statistical analysis

The number of patients needed to treat was calculated at 110 (55 in each group) with a power of 100% and an alpha value of 0.05 with success (1.0 vs 0.2). Continuous variables were compared with the use of the t-test or Wilcoxon rank-sum test. Skewed variables were summarized as medians. Chi-square analysis and Fisher's exact test were used for the analysis of categorical variables where appropriate. Levene's test for the homogeneity of variances was used to determine the comparability of the two groups. Confidence intervals were based on the normal approximation to the binomial distribution. P values of less than 0.05 were considered to be significant.

(c) Results

During the study period between October 2001 and February 2009, a total of 348 patients underwent surgery for an obvious or suspected cardiac injury. One hundred and fifty-seven patients required either an emergency department thoracotomy or emergency surgery. The remaining 191 of the 348 patients with penetrating chest trauma were hemodynamically stable on presentation or required less than 2l of resuscitation fluid, and were assessed for eligibility into the study. Thirty-three patients

were excluded from the study for the reasons indicated in table 8.1. Eleven patients were less than 18 years of age, and ten patients were referred with delayed presentations from surrounding hospitals, six of who had features of septic pericarditis. Three patients had traumatic septal defects, three patients refused consent for the study, and three patients presented in acute respiratory failure requiring emergency intubation. There were two patients with traumatic valvular injuries and one patient had sustained an associated blunt head injury with a decreased level of consciousness.

Table 8.1 Reason for patient exclusion from the study

Reason	***Number of patients***
Less than 18 years of age	11
Septic pericarditis	6
Delayed haemopericardium	4
Respiratory failure	3
Traumatic septal defect	3
Traumatic valvular defect	2
No consent	3
Blunt head injury	1
TOTAL	33

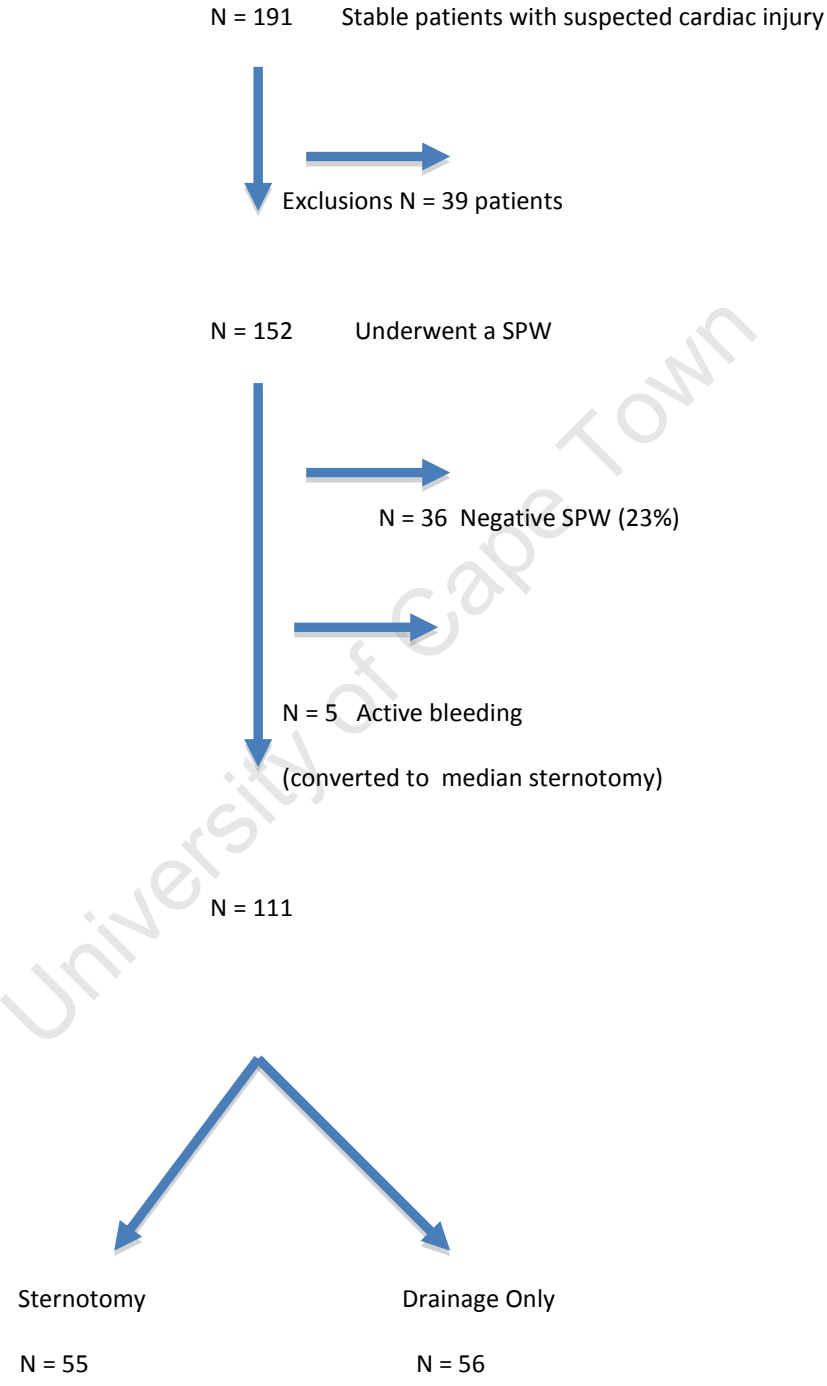
A further 6 patients were excluded from the study as they became haemodynamically unstable during their period of 24-48 hours of observation in the high care unit and were taken for emergency surgery. One of these 6 patients died from delayed cardiac tamponade which occurred on day 3-post admission. Surgery had been delayed because of a lack of an intensive care unit bed. This 32-year old male had a sudden delayed cardiac tamponade with a cardiac arrest in the high care unit (the details of this patient are discussed in the next chapter). He was found to have a 1cm hole in the right atrium

which was sutured, but he died from an ischemic encephalopathy and multiple organ failure two days later.

One hundred and fifty-two patients were taken to the operating room after 48-hours of observation for a SPW. At surgery 36 patients had a negative SPW. Five patients started actively bleeding at the time of performing the SPW and were converted to a median sternotomy. At sternotomy one patient had a 3cm laceration of the superior vena cava, two patients had holes in the right ventricle, and two had holes in the left ventricle. These perforating cardiac wounds were all sutured.

One hundred and eleven patients were confirmed at SPW to have a hemopericardium without any evidence of active bleeding. Fifty-five of these patients were randomized to sternotomy and fifty-six to pericardial drainage only. There were no protocol deviations and no exclusions after randomization. (Figure 8.1)

Figure 8.1. Flow diagram of pericardial drainage alone compared with sternotomy for the management of the stable patient with a haemopericardium.



Patient characteristics

The 111 patients selected for the study were stable on arrival or easily stabilized. The revised trauma score was 7.841 in 95% of the patients (range 6.376-7.841). One-hundred and seven patients (96%) were males and there were 4 females. The mean age of the sternotomy group patients was 29 ± 9.0 years compared to 27 ± 7.8 years in the drainage only group (p =0.09). There were 54 stab wounds and 1 gunshot wound in the sternotomy group and 55 stab wounds and a single GSW in the drainage group.

Table 8.2. Characteristics of the patients at entry.

Variable	***Sternotomy N = 55 (SD)***	***Drainage only N = 56 (SD)***	***P Value***
Age (years)	29.4 (9.04)	26.7 (7.80)	0.09
Revised Trauma Score	7.813 (0.16)	7.791(0.22)	0.56
Hb	11.4 (1.57)	11.2 (2.04)	0.54
CVP cmH_20	13.5 (6.22)	13.7 (4.94)	0.88
Size of effusion of US in mm	8.3 (5.88)	8.9 (5.91)	0.57
Mechanism of Trauma	SW 54 GSW 1	SW 55 GSW 1	1.00

SW = stab wound GSW = gunshot wound S.D = standard deviation

The baseline characteristics of the two groups were comparable with respect to age, revised trauma score, hemoglobin on presentation, initial CVP measurement, the size of the pericardial effusion on US and the mechanism of trauma (table 8.2).

(i) Sternotomy Group N = 55 Patients

Thirteen (24%) of the 55 patients who were assigned to sternotomy were found to have no cardiac injury. Another 38 patients (69%) had tangential wounds. The remaining four patients (7%) had what appeared to be full-thickness cardiac injuries (table 8.3).

Table 8.3. Grade of the cardiac injury found at sternotomy.

AAST Grade	*Number of patients (%)*	*Description*
1	13 (24%)	No cardiac injury but pericardial laceration.
2	38 (69%)	Tangential cardiac wound
3	0	Tangential cardiac wound with tamponade
4	3 (5%)	Penetrating wound to RV/RA/LA
5	1 (2%)	Penetrating wound to LV

RV = right ventricle RA = right atrium LA = left atrium LV = left ventricle

51 of the 55 patients (93%) who were randomized to sternotomy had either no cardiac injury or a tangential injury. There were only 4 patients with penetrating wounds to the endocardium and in all of these the wounds had completely sealed.

(ii) Pericardial drainage group N = 56

A total of 56 patients were randomized to pericardial drainage alone with no sternotomy. Obviously the grade of the cardiac injury could not be determined in this group. The blood was drained from pericardial sac and a soft drain placed.

(iii) Morbidity and mortality

There was one death post-operatively in the 111 patients (0.9%) and this was a patient that had been assigned to sternotomy. An iatrogenic injury to the left internal mammary artery occurred during the sternotomy. After surgery the patient returned to the intensive care unit, became hypotensive, and despite returning to theatre for hemostasis sustained an ischemic encephalopathy and demised.

The complications recorded in the two groups are presented in table 8.4. There was a single patient who developed sternal sepsis following a sternotomy, and this required extensive surgery in the form of a sternal debridement and pectoral flaps. He made a full recovery. There was also a patient in the sternotomy group who had a spontaneous asystolic cardiac arrest when the heart was being inspected for a cardiac wound. This patient responded to internal cardiac massage, adrenaline intravenously and subsequent defibrillation and cardiac rhythm was restored without any consequences. There were an equal number of patients with pneumonia that required medical management (n=11).

Table 8.4. Morbidity and Mortality

Complication	***Sternotomy N = 55***	***Drainage N = 56***
Atelectasis	6	1
Pneumonia	11	11
Pulmonary edema	1	2
Reaccumulation of hemothorax	2	4
Sternal sepsis	1	0
Wound sepsis	2	2
Cardiac arrest	1	0
Death	1	0

Fischer's Exact test was used to compare the morbidity and mortality profile between the two treatment options. There was no significant difference (p= 0.412)

(iv) Intensive care unit and hospital stay

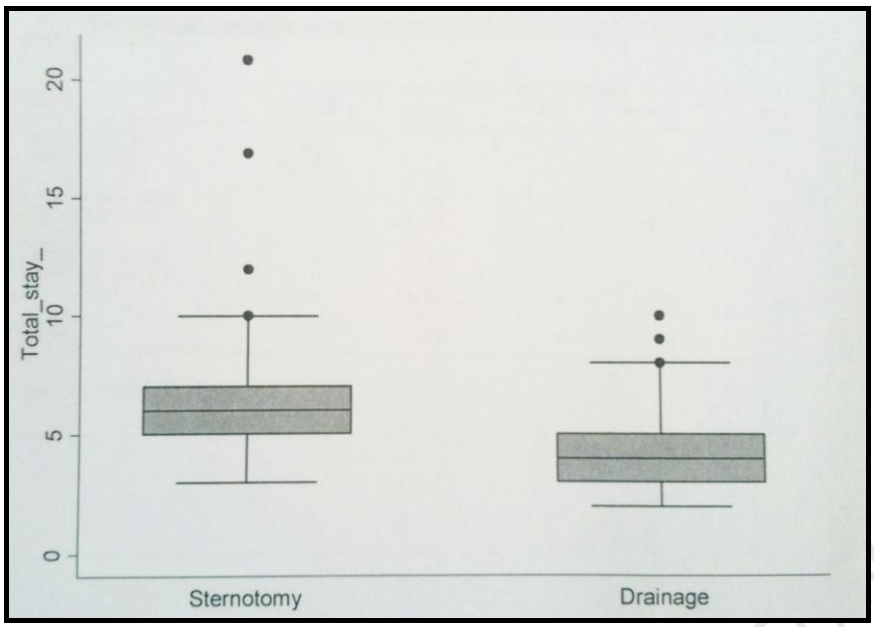
Thirty-nine patients who underwent a sternotomy required the intensive care unit (ICU) post-operatively. The remaining 11 patients were extubated after surgery and were monitored in a high care unit. Nine patients in the drainage group required ICU management. The mean ICU stay for the sternotomy group was 2.04 days (range 0-25 days) compared to 0.25 days (range 0-2) for the drainage only (table 8.5) (p = 0.0003). The estimated mean difference highlighted a stay of 1.8 days shorter in the ICU for the drainage group with 95% CI (0.8 to 2.7 days). With respect to the drainage group, 84% left the ICU within one day compared to only 20% in the sternotomy group.

Table 8.5 Length of intensive care unit

	Sternotomy N=55	**Drainage N = 56**	**P value**
ICU stay (days)	2.04 (range 0-25)	0.25 (range 0-2)	<0.001
Total Hospital Stay	6.5 (4-25)	4.1 (2-10)	< 0.001

The mean total hospital stay for the sternotomy group was significantly longer than the drainage group (6.5 days versus 4.1 days, p < 0.001 95% CI: 1.4 to 3.3 days). This is demonstrated in Figure 8.6.

Figure 8.6.Boxplot of total hospital stay



In the group comprising drainage only, all the patients were discharged home well. No patient required delayed surgery for a delayed cardiac tamponade or a symptomatic pericardial effusion.

(v) Follow up

The 56 patients who underwent the pericardial drainage were followed up as follows. Forty-four patients were alive and well with a mean follow up of 23 months (range 2 weeks to 5 1/2 years). There have been 3 documented deaths in the drainage only group after discharge. Two patients were stabbed again and died in this second assault. The first patient was 16-months post surgery and the other was 8 months. The third patient, according to his mother, died in his sleep after complaining that he was not feeling well. This patient was 10-months post surgery and it has not been possible to locate any autopsy report of his death. The remaining 9 patients were not contactable and have been lost to follow up.

Discussion

The group of patients who were selected for this trial was a highly selected group of patients representing 111 out of 348 patients (32%) who underwent cardiac surgery. It was thought to be important to only use patients who had the gold standard of a subxiphoid pericardial window to confirm or refute the presence of a hemopericardium. Ultrasound in our institution has proven to be excellent in the screening for cardiac injuries but only has a sensitivity of 86% and false negatives do occur in the presence of a hemothorax. This accounts for the fact that there were a total of 36 negative SPW (24%) as we do still rely on clinical criteria as well to determine the need for a SPW.

The performance of a subxiphoid window allows for the identification of the major penetrating cardiac injuries, which require repair, by the demonstration of active bleeding from the pericardial sac during the procedure. The process of irrigation of the pericardial sac does appear to facilitate bleeding and helps in the identification of patients with “unstable” clot which requires suture repair. Five major cardiac injuries were identified in this manner and all underwent a median sternotomy and suture repair.

Thirteen patients had no cardiac injury and 38 patients had tangential cardiac wounds at sternotomy. A total of 93% of patients at sternotomy had either no cardiac injury or were tangential. The remaining 4 patient's injuries had sealed. It was noticed that although a grading system does exist for cardiac trauma it is very difficult to accurately grade the injuries as tangential or full-thickness without probing the cardiac wounds and this may result in bleeding.

The fact that a large proportion of cardiac wounds in patients presenting stable have sealed has been previously documented. Harris et al found that clotted lacerations of the heart were present at sternotomy in 21 out of the 43 patients (48%) who were stable on presentation.[133]

There appeared to be a similar number of complications between the two groups but the added complications of cardiac arrest on table and sternal sepsis would appear to imply that the complications of the sternotomy group were more severe. The numbers of complications were too small for any meaningful statistical comparison. There was an unexpected single death in the sternotomy group, which resulted from a surgical error. This does highlight the fact that a sternotomy is not a benign operation and that deaths related to the procedure will occur even in young trauma patients. The death of the patient, which occurred before randomization (stable on presentation but then developed cardiac tamponade in hospital), reinforces the concept that one has to be vigilant in observing these patients. The fact that a patient had to wait 3 days for surgery is unacceptable but does reflect the huge emergency workload which is performed at our hospital and that there is a desperate need for more intensive care unit beds in our environment.

The intensive care unit stay and the total hospital stay were significantly shorter in the drainage versus the sternotomy group. Thus the adoption of this surgical policy will reduce the demand on the intensive care unit. The fact that 9 patients were lost to follow-up in the drainage group may add an element of concern to this management practice of simple drainage alone, but this has now become our standard management since the study was completed, and there has not been a single death known to us.

It is not possible to compare this study with any others in the literature as all the studies recommend immediate surgery and cardiorrhaphy.[123, 126, 139, 175, 176, 267] This management strategy of identifying stable patients with suspected cardiac injuries, performing a SPW and only opening the chest if there is evidence of active bleeding, is the result of being exposed to a large volume of cardiac trauma.

It would appear that draining the pericardial sac does decrease the complications of a delayed pericardial effusion and constrictive pericarditis as none of these were documented in the follow-up of our patients.

In summary, pericardial drainage alone appears effective and safe in the management of the haemopericardium in the stable patient after penetrating chest trauma with no increase in mortality and a shorter ICU and hospital stay.

CHAPTER 9

The Straight Left Heart Border:

A new radiological sign for detection of a hemopericardium after penetrating chest trauma.

(a) Introduction

The detection of a cardiac injury in a patient who is hemodynamically stable after a penetrating chest injury with no clinical features of Beck's triad can be extremely difficult. It has been stated that if there is a penetrating injury overlying the cardiac silhouette then there is a 60% chance of an underlying cardiac injury.[174] Ultrasound has been particularly useful in diagnosing the hemopericardium but there is the concern over a possible false negative ultrasound and it is apparent that there is a need to look at the clinical signs of the patient in order to improve the pick-up rate for cardiac injuries. The chest x-ray is not considered generally to be of much use in the diagnosis of a hemopericardium since at least 200ml of fluid is required before the cardiac silhouette is affected.[136] It has, however, been noticed at the Groote Schuur Hospital Trauma Centre that a filling in of the aorto-pulmonary window, called the straight left heart border sign is almost always associated with the diagnosis of a hemopericardium at surgery. The aim of this study was to determine if this was a reliable and reproducible sign of a hemopericardium.

(b) Methods

All patients with a penetrating chest injury who were admitted to Groote Schuur Hospital Trauma Centre between 1st October 2001 till the 28th February 2009, who had an erect chest x-ray performed

on admission, who were easily resuscitatable and had no indication for immediate emergency surgery, and were taken to theatre for the performance of a subxiphoid pericardial window (SPW) were entered into the study.

A single trauma surgeon (the author) reviewed all the chest x-rays. A straight left heart border (SLHB) was diagnosed if the aorto-pulmonary window was filled in giving a straight appearance to the left heart border. The trauma surgeon was blinded to the presence or absence of a hemopericardium. An example of a normal chest x-ray and an x-ray with a SLHB are demonstrated in figures 9.1 and 9.2respectively.

Figure 9.1 Normal chest x-ray

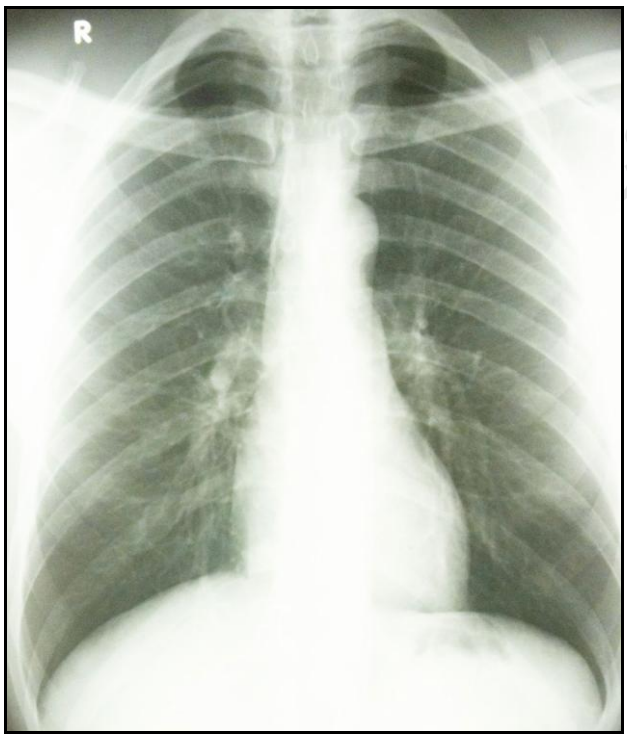
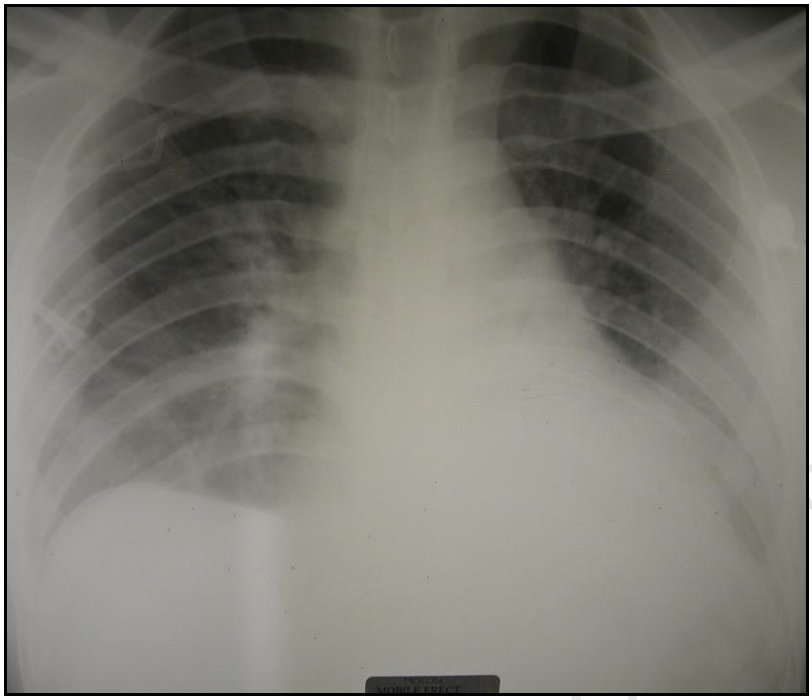


Figure 9.2. Straight Left Heart Border demonstrated.



A true positive was the presence of a SLHB on the chest x-ray and a hemopericardium found at SPW. A false positive was defined as the presence of the SLHB sign on chest x-ray but the SPW was negative for blood.

Statistical analysis was conducted using the chi-square test for categorical variables. A p value of less than 0.05 was considered to be significant.

(c) Results

During the study time period, there were 162 patients with possible cardiac injuries after penetrating chest trauma who had had an erect chest x-ray on admission to the Trauma Centre. The mean age of the patients was 27.7 years (range 13-62).

Fifty-five of the 162 patients (34%) were noted to have a straight left heart border. Forty-nine patients with a SLHB on chest x-ray were found to have a hemopericardium at SPW (true positives) and there were six patients with a SLHB that were negative for blood at the time of performing a SPW (false positive). Seventy-five patients had a hemopericardium at surgery but did not have the feature of a SLHB (see figure 9.3). The sensitivity of this radiological sign was 40% with a specificity of 84%. The straight left heart border was highly significant in predicting the presence of a hemopericardium (p = 0.005 Odds ratio = 3.48 Lower =1.41 Upper =8.62)

Figure 9.3 Results of the SLHB in predicting the presence of a hemopericardium.

	SPW +ve	***SPW –ve***	***Row totals***
SLHB + ve	49	6	55
SLHB – ve	75	32	107
	124	38	162

Chi- squared p = 0.00460

Odds ratio = 3.48 Lower 1.41 Upper 8.62.

(d) Discussion

There are widely divergent opinions on the sensitivity of a chest x-ray to diagnose a penetrating cardiac wound. A chest x-ray is not considered by some authorities to be particularly useful and is felt to be seldom diagnostic of a penetrating cardiac injury.[150] It is even considered to be misleading as the cardiac size may not be enlarged in cardiac tamponade and this may result in a misdiagnosis.[28]

The characteristic findings on a chest x-ray that may suggest the presence of a hemopericardium after penetrating chest trauma are an enlarged heart shadow, a pneumopericardium and widening of the

upper mediastinum. These features may be present in up to 50% of patients presenting with a hemopericardium.[119] The enlargement of the cardiopericardial contour has been regarded in the literature as being non-specific.[249, 268, 269]

The left heart border on the normal chest roentgenogram is formed in the upper portion by the aorta, in the middle section by the pulmonary artery and left atrial appendage, and in the lower section by the left ventricle.[270]

A straight left heart border has been described in association with a number of medical conditions including mitral stenosis and mitral regurgitation, where the left atrial enlargement causes the left heart border to "straighten".[271, 272] A persistent left superior vena cava, constrictive pericarditis, and congenital absence of the pericardium also lead to flattening of the left ventricular border.[273, 274] The congenital absence is due to left common cardiac vein atrophy with ischemia of the pericardium resulting in its agenesis.[275] A corrected transposition of the great vessels also creates a SLHB that represents the contour of the transposed ascending aorta.[276, 277] A SLHB may also indicate a previous left lower lobectomy.[278, 278] Pectus excavatum is also a cause of a straight left heart border, caused by a shift in the heart to the left, and a further feature on the chest x-ray is an indistinct right heart border.[279, 280]

The straight left heart border is a newly described radiological sign associated with penetrating thoracic trauma that is indicative of the presence of blood in the pericardial sac and this causes a straightening out and filling in of the aorto-pulmonary window. Although it is not a very sensitive sign (49%) for the presence of a hemopericardium, and the absence of a SLHB does not exclude a cardiac injury, it is highly specific (84%) and when it is present should alert the surgeon to the presence of a hemopericardium.

CHAPTER 10

THE J-WAVE

Electrocardiographic evidence of an occult cardiac injury

(a) Introduction

While some centers have considered the electrocardiogram (ECG) to be of little value in diagnosing a cardiac injury, this has not been the author's experience. In fact the 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.

There is a definitive need for a simple diagnostic aid that can guide, what is often a junior medical officer dealing with a penetrating thoracic wound, in the necessity to refer a patient for further investigation into a possible cardiac injury. Changes in the ECG may be such a diagnostic aid.

Non-specific ST changes have been documented to be present in between 30-60% of patients with penetrating cardiac injury. Most studies have included small numbers and have failed to state specifically what comprises a non-specific ST segment change. The other issue is that in patients presenting with cardiac tamponade or hemorrhagic shock, the diagnosis is often obvious, and surgery, not an ECG, is required.

What has also become evident through dealing with a large number of cardiac injuries each year is the presence of a J-wave on the ECG in patients with occult cardiac injuries (diagram 5.1) Traditionally a prominent J-wave on ECG in the human is considered to be pathognomonic of hypothermia.[281-286] The aim of this study was to identify the ECG changes that were present in patients with possible cardiac injuries who were easily resuscitatable, presenting to a level 1 Trauma Center and to outline what the features on an ECG should be a warning sign of possible cardiac trauma.

(b) Method

This was a prospective study conducted on all patients admitted to the Groote Schuur Hospital Trauma Center following penetrating chest trauma who did not have an indication for emergency surgery and that underwent an ECG and later a subxiphoid pericardial window for a potential cardiac injury.

All the patients were easily resuscitatable with less than 2 liters of crystalloid. A standard 12-channel ECG was performed shortly after admission. All the ECG tracings were reviewed by a single trauma surgeon (the author).

A J-wave was defined as the small notch on the S wave as demonstrated in figure 10.1. ST-segment elevation was defined as an elevation from the baseline of more than 2mm in more than 2 of the leads as seen in figure 10.2.

Diagram 10.1. A J wave on the ECG (J-wave inside the black circle).

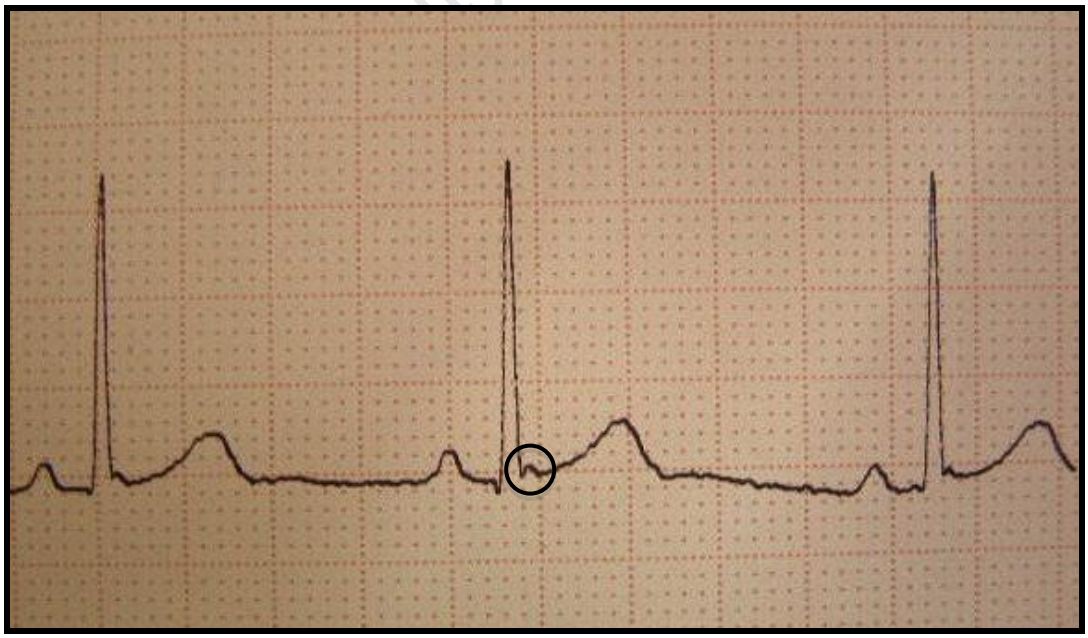
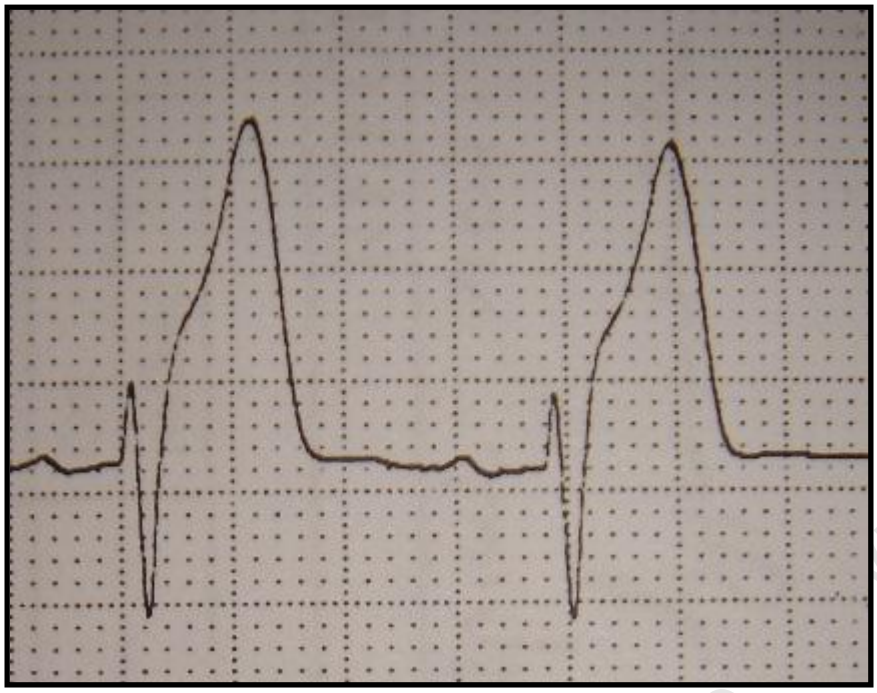


Figure 10.2. ST-segment elevation on the ECG.



All patients had a subxiphoid pericardial window undertaken and this either confirmed or negated the presence of a hemopericardium. The presence of blood in the pericardial sac was considered to be positive. The indications for the SPW were the presence of fluid in the pericardial sac on ultrasound (FAST), an equivocal ultrasound result related to poor visualization, the presence of a pneumopericardium, and continued clinical suspicion of a cardiac injury despite a negative ultrasound.

A true positive result was where the ECG change (either ST segment elevation or a J-wave) documented correlated with the finding of blood in the pericardial sac.

A true negative result was the absence of any ECG change and no blood in the pericardial sac.

A false positive result was where the ECG finding was present but there was no hemopericardium.

A false negative result was where there was no ECG change but blood was present in the pericardial sac.

(c) Results

There were 174 patients with penetrating chest injuries where an ECG had been performed and the patients had subsequently undergone a SPW for a possible cardiac injury. The mean age of the patients was 28 years (range 11-65) and there were 7 females. The mechanism of injury was stab wounds in 167 patients and 7 low velocity gunshot wounds.

The indication for the subxiphoid pericardial window is outlined in table 10.1. The main indication for surgery was a positive ultrasound in 158 of the patients (91%).

Table 10.1. The indication for performing a subxiphoid pericardial window.

Indication	***Number of patients***
Positive ultrasound for fluid	158
Equivocal ultrasound (poor visualization)	2
Pneumopericardium	7
Continued clinical suspicion	7
Total	174

The SPW was positive for blood in 135 of the 174 patients (77%). Of the seven patients where there was continued clinical suspicion despite a normal cardiac ultrasound, four had ST segment changes, the presence of J-waves and straightening of the left heart border on erect chest x-ray. Two patients were shocked in the pre-hospital phase and had ECG changes, and one patient had a straight left heart border and elevated ST segments.

ST segment elevation was present in 108 of the 174 patients (62%) who underwent a SPW. In 90 of these patients this was a true positive and in 21 patients a true negative result. There were 18 false positive results and 45 false negatives. The sensitivity of the ST segment elevation for predicating the

presence of a hemopericardium was 66.7% and the specificity was 53.8% (p =0.02 Odds ratio 2.33 Lower = 1.14 Upper = 4.77). These results are demonstrated in table 10.2. The positive predictive value of ST segment elevation was 83.3% and the negative predictive value 31.8%

Table 10.2 Two-way summary table with the observed frequencies of ST segment elevation.

Subxiphoid pericardial window finding	***ST Segment elevation present***	***ST segment elevation absent***	***Row totals***
Positive	90	45	135
Negative	18	21	39
	108	66	174

Chi-square p = 0.02 Odds ratio 2.33 Lower = 1.14 Upper = 4.77

A J-wave was present on the ECG in 65 (37%) of the 174 patients with a possible cardiac injury. There were 59 true positives and 6 false positives. The results are documented in table 10.3. The sensitivity of a J wave to detect a hemopericardium was 43.7% and the specificity was 84.6% (p < 0.001 Odds ratio 4.27 Lower = 1.76 Upper = 10.55). The positive predictive value was 90.7% and the negative predictive value 30.3%.

Table 10.3. Observed frequencies of a J-wave on ECG related to the surgical findings.

Subxiphoid pericardial window finding (SPW)	***J-wave present***	***J-wave absent***	***Row totals***
SPW +ve	59	76	135
SPW –ve	6	33	39
	65	109	174

Chi-square p = 0.0007 Odds ratio 4.27 Lower = 1.76 Upper = 10.33

Table 10.4 depicts an overview of the results of the ECG changes in predicting the presence of a hemopericardium.

Table 10.4: The results of the ECG changes in predicting the presence of a hemopericardium.

ECG change	***Result***	***ECG change***	***Hemopericardium***	***Number of Patients***
ST segment elevation	True positive	√	√	90
	True negative	χ	χ	21
	False positive	√	χ	18
	False negative	χ	√	45
J-wave	True positive	√	√	59
	True negative	χ	χ	33
	False positive	√	χ	6
	False negative	χ	√	76

√ = present χ= absent

(d) Discussion

The J-wave, also known as the Osborn wave, is a deflection on the ECG that occurs following the QRS complex. This wave form was originally described in 1938 by Tomaszewski.[287, 288] Dr John Osborn described it as an injury current that resulted in ventricular fibrillation during experimentally induced hypothermia. The amplitude of the J wave is directly proportional to the degree of hypothermia.[289]The J-wave has been described in association with a number of other conditions including hypercalcaemia [290, 291], head injury[292], subarachnoid hemorrhage[293], cardiorespiratory arrest from

over sedation[294], cardiac ischaemia, vasospastic angina, [295] the Brugada syndrome [296, 297], and idiopathic ventricular fibrillation.[298-300295, 301] Only rarely is a distinct J-wave observed in clinical practice under normal conditions but it has been observed in the ECG of humans and animals for more than 40-years.[286, 302]

The basis for the J-wave was proposed in 1995 by Yan and Antzelevitch to be a prominent action potential notch in the epicardium but not the endocardium during repolarization phases 1 and 2. It is thought that the epicardium denotes an action potential with a prominent transient outward K^+ current (I^{to}) mediated notch while the endocardial action potential has a much smaller I^{to} current and this difference results in a transmural voltage gradient during ventricular repolarization. [286, 301, 303]The J-wave has not been described in the medical literature in association with penetrating cardiac injuries. The presence in association with a haemopericardium may be due to the myocardial injury resulting in an accentuation of the spike and dome morphology of the epicardial action potential. This study clearly demonstrates that its presence signifies a significant risk of a hemopericardium after penetrating thoracic trauma. The sensitivity is low at 43.7% but with a specificity of 84.6% it should be a major warning sign to clinicians that the risk of a hemopericardium is extremely high and such patients should be referred to a Trauma Center for further investigation and management.

CHAPTER 11

The Role of Ultrasound in detecting Occult Cardiac Injuries

(a) Introduction

The diagnosis of a cardiac injury in the patient who arrives in the resuscitation room and does not have an acute indication for emergency surgery can be difficult. It has been recognized that certain patients with potentially life-threatening chest wounds may present relatively asymptomatically.[106, 142] The clinical examination may be unremarkable and many surgeons have come to rely on ultrasound of the pericardial sac in order to guide their management in hemodynamically stable patients. Ultrasound has been shown in prospective studies to have a sensitivity of between 83.8 – 100% and a specificity of 94.7 – 100% for the detection of occult cardiac injuries and has become the investigation of choice world-wide to diagnose these injuries.[7, 9, 10, 13-15, 166] Unfortunately most of the studies conducted on the role of ultrasound included a large number of patients with penetrating chest trauma but very small numbers with actual cardiac injuries. The number of cases has varied from 10 to 29 patients. If ultrasound is to be the investigation of choice then it is essential that surgeons understand the advantages and the limitations of the study so that an appropriate decision is made regarding patient management.

The aim of this study was to determine the sensitivity and positive predictive value of emergency room ultrasound in the diagnosis of cardiac injuries.

(b) Methods

All patients presenting with a penetrating chest wound and a possible cardiac injury to the Groote Schuur Hospital Trauma Centre between October 2001 and February 2009 were prospectively evaluated. All patients were fully conscious and either stable or required less than 2l of crystalloid to achieve hemodynamic stability, and had no indication for emergency surgery.

Patients were excluded if they required emergency surgery for hemodynamic instability, an exsanguinating thoracic bleed, and evidence of cardiac tamponade or if they underwent a laparotomy for an associated thoracoabdominal or abdominal injury.

All patients were clinically evaluated, a central venous pressure line was inserted and the pressure monitored. Each patient had an erect chest x-ray and an electrocardiogram. An ultrasound of the pericardial sac was performed by a radiology registrar in the resuscitation room looking for the presence of fluid in the pericardial sac. If present the amount of fluid was measured in millimeters (mm). The ultrasound was considered to be positive for a hemopericardium if there was any fluid in the pericardium. If the visualization was poor, the ultrasound was considered to be equivocal and the reason noted. The presence or absence of a hemothorax was also documented. The revised trauma score was calculated for each patient.

All patients who had an acute hemopericardium confirmed at ultrasound or where there was an equivocal ultrasound report, underwent a subxiphoid pericardial window (SPW). If the ultrasound was negative but there remained a clinical suspicion of an occult cardiac injury, then the ultrasound was repeated at 24-hours. A clinical suspicion of a cardiac injury was considered if there was the presence of shock in the pre-hospital phase, if the electrocardiogram showed features of ST-segment elevation, if the cardiothoracic ratio on chest x-ray was greater than 50%, or if there was enlargement of the cardiac size on a repeat chest x-ray.

The SPW was done in theatre under general anesthetic and was positive if there was any blood or blood clots noted within the pericardial sac.

(i) Definitions

A true positive result was defined as where both the ultrasound and the SPW confirmed the presence of blood in the pericardial sac.

A true negative was where the ultrasound did not reveal any pericardial fluid and the SPW was negative for blood.

A false positive arose where the ultrasound demonstrated pericardial fluid but the SPW was negative.

A false negative was defined as a normal ultrasound but at the SPW blood was located within the pericardium.

The presence of pre-hospital shock was where the patient was noted to have a blood pressure of less than 100mmHg at any stage during the pre-hospital phase.

The size of the pericardial effusion was taken at the maximum width of the fluid in the pericardial sac and was measured in mm.

Continuous variables were compared with the use of the t-test or Wilcoxon rank-sum test. Chi-square analysis and Fisher's exact test were used for the analysis of categorical variables where appropriate

(c) Results

There were a total of 172 patients who underwent a subxiphoid pericardial window for a possible cardiac injury between October 2001 and February 2009 and who had been investigated pre-operatively with an US of the pericardial sac. The median age of the patients was 26 years (range 11 to 65 years) and 168 (96%) were males. The mechanism of the penetrating chest injury was stab

wounds in 166 (96%) and low velocity gunshot wounds in 6. Fifty-nine of the 172 patients (34%) were in shock in the pre-hospital phase. The median hemoglobin on presentation was 11.0g% (range 4.7 to 17.0).

The ultrasound was positive for fluid in 152 of the 172 patient with a mean measurement of blood in the pericardial sac of 8.1mm (range 0 to 30mm). There were 117 true positives confirmed at SPW, thirty-five false positives, 18 false negatives and 2 true negatives. These results are illustrated in table 11.1

Table 11.1 US as a screen for potential cardiac injuries.

	Ultrasound Positive	***Ultrasound Negative***	
SPW + ve	117	18	135
SPW – ve	35	2	37
	152	20	172

The sensitivity of the US to detect a hemopericardium was 86.7% with a positive predictive value of 77%. It is obviously essential to examine the 18 patients with a false negative US results very closely. Six of the 18 false negative US had a pneumopericardium detected in the pericardial sac but no fluid. Eleven of the remaining 12 patients had a hemothorax that was managed with an intercostal drain. Seven of the 18 patients with a false negative result had a repeat US performed 24-hours post admission and in 6 the repeat US now demonstrated the presence of pericardial fluid and the patients were operated upon (table 11.2). There was one patient with two negative US examinations that was discharged home only to return with a delayed symptomatic pericardial effusion.

Table 11.2: Six false negative ultrasounds

Patient number	***Ultrasound examination on presentation***	***Indication for repeat ultrasound examination***	***Repeat Ultrasound result***
1	Pneumomediastinum	Suboptimal visualization	13mm hemopericardium
2	Pneumopericardium	Suboptimal visualization	5mm hemopericardium
3	Normal	Increasing heart size on chest x-ray	15mm hemopericardium
4	Normal	Straight left heart border	15 mm hemopericardium
5	Normal	Straight left heart border	8mm hemopericardium
6	Normal	Central venous pressure of 23cm H20 on admission	6mm hemopericardium

(d) Discussion

All tests have their shortcomings and it is important for surgeons to be aware of the sensitivity of the tests that they order as they guide the management process. The sensitivity of US at our institution is 86.7% with a positive predictive value of 77%. This is very good for a screening test but it also indicates that the US cannot be relied upon as the sole screening modality. It is essential to diagnose a cardiac injury and the fact that there were 18 false negatives from US screening is not acceptable.

There would appear to be two main factors, which limit the screening sensitivity of US. The first is the presence of air in the pericardial sac, and secondly a hemothorax. Six of the 18 false negatives had a

pneumopericardium and eleven of the remaining 12 patients had a hemothorax. There is no doubt that both air and blood may interfere with the ability to visualize fluid in the pericardial sac.

A repeat US after 24-hours allowed a further 6 patients with a hemopericardium to be identified and this should be considered in cases where a clinical suspicion exists.

There have been a number of case reports in the literature which also highlighted the issue of false negative results which resulted in a delayed diagnosis of a PCI. A 23-year old man from Turkey was admitted 6-months after the initial injury with a traumatic aorto to left atrial fistula and features of cardiac tamponade. The initial clinical evaluation and ECHO on admission to hospital were negative.[205]

From Korea there was the case report of a 22-year-old female who presented with a stab wound to the chest with a left-sided hemothorax. The initial ECHO showed a small amount of fluid in the pericardial sac without any shunt or injury to the myocardium. It was only on follow up ECHO performed the next day following the clinical deterioration of the patient that a VSD was demonstrated, which was repaired surgically.[304]

A case report from Spain documented a normal ECHO study on presentation in a 32-year old man with a precordial stab wound. This patient had a cardiac arrest from a delayed cardiac tamponade 4 days later. Emergency surgery was performed and there was a laceration to mid-segment of the left anterior descending coronary artery that required suturing.[305]

There were two case reports from the United States of delayed cardiac tamponade presenting 4 and 14 days after stab wounds to the chest with an initial normal evaluation on admission comprising US, ECHO and CT scan of the chest.[170]

These cases are important to note because it is still being stated in numerous journals that "transthoracic ECHO is the most effective tool that can rapidly and accurately evaluate the status of cardiac injury and provides an anatomic and hemodynamic information at the patient's bedside." [304,

[306-308] It would appear that these generic statements are made but remain unsubstantiated. There can be no doubt that SPW is the most accurate tool that is currently able to evaluate the presence of a hemopericardium.

In summary, an US of the pericardial sac is an extremely useful screening test but it must be used in conjunction with other clinical parameters so that a hemopericardium may be detected.

CHAPTER 12

A New Screening Regimen for Occult Cardiac Injuries

(a) Introduction

The importance of diagnosing a PCI in the stable patient is to prevent secondary hemorrhage that may occur from 48-hours up to 3-weeks post injury. These delayed bleeds have been reported to occur from the right ventricle, the right atrium and the intrapericardial portion of the aorta.

There is no doubt that the SPW remains the gold standard with respect to the diagnosis of potential cardiac injuries after penetrating chest trauma. The problem with SPW being adopted as the sole screening method is that it is invasive and requires a general anesthetic. When used in isolation there are also a large number of negative explorations that range in the medical literature from between 75-80%. [143, 145, 245]

The emergence of ultrasound evaluation of the pericardial sac since the 1990's has relegated the role of the SPW to the second line of evaluation.[309] The initial evaluation of US was that it was highly sensitive and specific.[9, 10, 13, 14] There are, however, more recent reports of false negative results from FAST of the pericardial sac appearing in the literature and there is concern over the fact that in the presence of a pericardial laceration, a hemopericardium may decompress into the pleural cavity resulting in a false negative result. In our own institution at Groote Schuur Hospital, ultrasound evaluation of the pericardial sac has a sensitivity of 86.7 and a positive predictive value of 77%. What has become apparent is that the clinical, radiological and electrocardiographic criteria that have often been lambasted in making the diagnosis of a cardiac injury are in fact very important and need to be relied upon more frequently to allow accurate screening for cardiac injuries.

The aim of this study was to look at the role of additional clinical, radiological and electrocardiographic signs of a potential cardiac injury in patients presenting with penetrating chest trauma to see if these could improve the accuracy of the detection of a hemopericardium. A high index of clinical suspicion of a cardiac injury should be considered in the presence of a penetrating wound in the vicinity of the heart, in the presence of shock in the pre-hospital phase, if the central venous pressure is greater than 12cm H_2O, in the presence of elevated ST-segments on the ECG, an associated hemothorax, in the presence of a straight left heart border (SLHB), and in the presence of a cardiothoracic ratio (CTR) of greater than 50% on the erect chest x-ray.

The current use of a SPW to exclude high-risk cardiac injuries results in a negative SPW rate in the region of 75% if this is used as the primary screening test. The current study has demonstrated that the presence of a J wave on the ECG has a sensitivity of 44% and a specificity of 85% in diagnosing a hemopericardium. The SLHB on the erect chest x-ray has a sensitivity of 40% and a specificity of 84% in detecting a hemopericardium. Combining these two clinical parameters into the risk assessment was considered to have the potential to decrease the number of negative SPW and to increase the pickup rate for a hemopericardium in the face of a false negative US.

(b) Methods

This was a prospective study conducted from October 2001 till February 2009 on all patients that presented to Groote Schuur Hospital with a suspicious penetrating chest wound who were hemodynamically stable or easily stabilized with less than 2l of crystalloid. All patients were evaluated with a chest x-ray and an electrocardiogram. A central venous line was placed at the discretion of the attending surgeon. All patients underwent an immediate US examination of the pericardial sac. The presence of any fluid in the sac was considered to be a positive US. If there was poor visualization or the presence of air in the sac this was considered to be equivocal. A repeat US was conducted 24-hours later if the initial scan was negative but clinical concern remained in the light of unexplained pre-hospital shock, elevated CVP, increased CTR or elevated ST segments or J waves on the ECG. The

presence of a SLHB on the chest x-ray was an indication for a SPW as was the detection of any fluid on the US. All patients included in this study underwent a SPW.

(i) Definitions

Pre-hospital shock is a documented blood pressure of less than 100mmHg at any point during the pre-hospital phase.

Hemodynamically stable refers to patients with a systolic blood pressure of greater than 100mmHg.

A suspicious penetrating wound is a wound in the region extending from the right mid-axillary line across to the vertebral column on the posterior left chest wall with the superior boundary being the supraclavicular triangles and the sternal notch and the inferior boundary consisting of the costal margins but including the epigastric area.

A *positive SPW* is the finding of any blood in the pericardial sac both clot and blood staining of the pericardial fluid.

A *negative SPW* is the absence of any blood in the pericardial sac at surgery.

(c) Results

One-hundred and seventy-five patients presented to the Trauma Center with penetrating chest trauma who were easily resuscitated comprising 168 males and seven females with a median age of 26.0 years (range 13-62). The mechanism of trauma was a stab wound in 168 cases (96%) and a single gunshot wound in 7 (4%).

All 175 patients had a SPW performed under general anaesthetic. The SPW was positive for a hemopericardium in 135 of the 175 patients (77%) with negative SPW in 40 patients (23%). Fifty-nine patients (34%) were shocked in the pre-hospital phase and 48 of these patients were found to have a hemopericardium. The overall sensitivity of pre-hospital shock in determining the presence of a hemopericardium was 35.6%, a specificity of 71.8% and a positive predictive value of 81.4% (see table 12.1) The presence of shock was not found to be statistically significant with a p value of 0.39.

A CVP line was placed in 140 of the 175 patients. The mean CVP reading was 13.6 cm H_2O (range 1 – 31). A CVP measurement of ≥ 12cm H_2O was present in 86 patients and 78 of these were confirmed at SPW to have a hemopericardium. The sensitivity of the CVP reading of ≥ 12 cm H_2O was 68.4%, specificity 69.2%, and a positive predictive value of 90.7%. A CVP reading of ≥ 12cm H_2O was found to be highly significant in its ability to detect a hemopericardium ($p < 0.001$).

The mean and median CTR was 56% and 57% respectively (range 37-74). The CTR was ≥ 50% on erect chest x-ray in 130 patients and in 103 of these patients a hemopericardium was present. The sensitivity and specificity for the CTR was 88% and 27% respectively. A CTR of ≥ 50 was only mildly significant ($p =0.03$) however, in a comparison of CTR in the group of patients with a hemopericardium versus patients without, the CTR was highly significant ($p = 0.0003$).

A hemothorax was present on chest x-ray in 132 patients (76%). The sensitivity and specificity of the presence of hemothorax in the detection of a hemopericardium was 76.9% and 25.6% respectively. A hemothorax was not statistically significant in its presence indicating a positive SPW ($p= 0.75$ Odds ratio 1.15 lower =0.50 upper =2.61)

Table 12.1 Sensitivity and specificity of the screening tests for a hemopericardium.

Screening Test	***Sensitivity***	***Specificity***	***Positive Predictive Value***	***Negative Predictive Value***	***P value***
Shock in pre-hospital phase	35.6%	71.8%	81.4%	24.3%	0.39
CVP ≥ 12cmH_2O	68.4%	69.2%	90.7%	33.3%	0.0004
CTR > 50%	88.0%	27.0%	79.2%	41.7%	0.38
Hemothorax on CXR	76.9%	25.6%	78.0%	24.4%	0.74

There were 18 patients, with an initial normal pericardial US, where a hemopericardium was detected at SPW. These patients are represented in table 12.2. The various methods of screening are depicted with their positive or negative results in this table. A close inspection of the available data shows that if one used a the following clinical parameters all the patients would have been detected with a hemopericardium; a CVP of ≥ 12cm H_2O, the presence of J waves, a CTR of ≥ 50%, a SLHB and the presence of a pneumopericardium on chest x-ray or US.

Table 12.2. The presence or absence of risk factors for an occult cardiac injury in the 18 patients with a negative initial pericardial ultrasound but a confirmed hemopericardium at SPW.

Case No.	*Shock*	*CVP >12*	*ST changes*	*J waves*	*CTR >50*	*SLHB*	*HT*	*PP*	*1st US*	*Repeat US*
1.	X	X	√	X	√	X	√	√	Pneumomediastinum.	13mm effusion (24h)
2.	X	√	√	√	√	√	√	X	Negative	
3.	X	X	√	√	X	√	√	X	Negative	
4.	X	√	√	√	X	X	√	√	Pericardial air. No fluid.	5mm effusion (24h)
5.	√	√	√	X	X	X	√	X	Negative	
6.	X	NR	√	X	√	√	X	√	Pericardial air. No fluid.	
7.	X	X	√	X	√	√	√	X	Negative.	15mm effusion.(48h)
8.	X	NR	√	X	√	√	√	X	Negative.	15mm effusion.(24h)
9.	X	X	√	√	√	√	√	X	Negative. Repeat US at 24h showed 8mm effusion.	8mm effusion.(24h)
10.	X	X	√	X	√	√	√	X	Negative	
11.	X	X	X	X	√	X	√	√	Pericardial air. No fluid.	
12.	√	X	√	√	√	√	√	X	Negative	
13.	X	X	√	X	√	X	√	√	Pericardial air. No fluid.	
14.	√	NR	X	√	X	X	√	X	Negative	
15.	X	X	√	X	√	√	X	X	Negative	
16.	X	X	X	X	√	X	X	√	Pericardial air. No fluid	
17.	X	NR	√	√	X	X	√	X	Negative.	Negative.(48h)
18.	X	√	X	X	√	X	√	X	Negative.	6mm effusion.(48h)

Present √

Absent X

CVP = central venous pressure > 12 cm H20

CTR > 50 = cardiothoracic ratio of greater than 50%.

SLHB = straight left heart border on erect chest x-ray.

HT = hemothorax.

PP = pneumopericardium on chest x-ray.

US = ultrasound.

NR = not recorded

(d) Discussion

There is little doubt that US and ECHO are the current best available non-invasive modalities in the screening for a penetrating cardiac injury. However, both modalities may be negative particularly in the patient with an associated hemothorax. There have been numerous reports of the initial US or ECHO being negative with the patient later presenting with a symptomatic cardiac injury.[305] It is essential to recognize the shortcomings of the diagnostic tests that are currently available to detect a hemopericardium. An ECHO has been shown to unable to detect a pericardial effusion where the total blood amounts are less than 50cm[149, 310]

The US also appears to be inaccurate if a pneumopericardium is present. Two of the patients who presented with a pneumopericardium and no fluid detected on the initial scan developed pericardial fluid at a repeat scan 24-hours later.

A CVP reading of ≥ 12cm H_2O ($p < 0.001$) was very sensitive in the ability to detect a hemopericardium. The CTR ≥ 50% had a sensitivity of 88% but a specificity of only 27% and was only mildly significant ($p=0.03$) in its ability to diagnose blood in the pericardial sac. What would appear to be more reliable is an increasing CTR on sequential chest –x-rays.

If one had applied the presence of any one of these screening modalities as an indicator for an emergency SPW, then all the patients with a false negative US on admission would have been

detected; a CVP ≥ 12cm H_2O, a J wave, a SLHB or the presence of pericardial air. A positive result for any of these screening tools should prompt the surgeon to perform a subxiphoid pericardial window.

CHAPTER 13

Delayed in-hospital Cardiac Tamponade

(a) Introduction

The incidence of delayed cardiac tamponade, where patients with penetrating chest trauma initially present to hospital in a stable condition, has not been documented. It has been our policy to investigate patients for "occult" cardiac injuries by obtaining chest X-rays, electrocardiograms and pericardial ultrasounds on all patients where an occult cardiac injury may be suspected. If the ultrasound confirms the presence of a hemopericardium, the patient is admitted to the high care unit for a period of observation, provided the patient remains stable, prior to a subxiphoid pericardial window (SPW) being undertaken 24 to 48 hours later. This time period would allow for any cardiac injury to seal and would decrease the number of non-therapeutic sternotomies.

The aim of this study was to determine the incidence of delayed cardiac tamponade in patients who were admitted to the high care unit after penetrating chest trauma with the diagnosis of a stable haemopericardium and who developed features of cardiac tamponade while under observation and required emergency surgery.

(b) Method

All patients with penetrating chest trauma and a hemopericardium present on ultrasound who developed cardiac tamponade after initial admission to a high care unit in a stable condition between October 2001 till February 2009, were included in the study.

(c) Results

One hundred and fifty-eight patients with penetrating chest injury and suspicion of an occult cardiac injury were admitted to the high care unit during the study period. Six of these patients (4%) became unstable during the period of observation in the high care unit and required emergency surgery. They were all male patients with a mean age of 26 years (range 19 to 34) and all had sustained stab wounds to the chest. The clinical features of the 6 patients are highlighted in table 13.1.

The 6 patients were all clinically stable on admission with a mean revised trauma score of 7.973 (range 7.550 – 7.841). None of the patients had clinically distended neck veins and the mean central venous pressure on admission was 17cm H2O (range 12 – 23). The ultrasound confirmed the presence of a hemopericardium in all the patients. The time from injury to the development of delayed cardiac tamponade was within 24 hours in 5 of these patients. Five of these patients developed the classic clinical signs of tamponade with distended neck veins and hypotension. The 6th patient dropped his blood pressure and sustained a cardiac arrest on day 3 post admission. At surgery all the patients had evidence of tamponade with blood clot in the pericardial sac. They all had underlying cardiac injuries. Five of the six had holes in the heart with two involving the right ventricle, two in the left ventricle and one in the right atrium. The other patient had a graze of the left atrium.

One of the 6 patients died. This patient was a 32-year-old male who had been referred by a nearby hospital following a stab wound to the left parasternal area 4th intercostal space. On admission he had a systolic blood pressure of 106mmHg and a pulse rate of 78 beats per minute. He was fully conscious and not distressed with a central venous pressure measurement of 18cm H_20 and a hemoglobin value of 13g%. He had evidence of ST segment elevation on his electrocardiogram and his chest X-ray showed a left sided hemothorax for which an intercostal drain had been placed. He was placed in the high-care unit and was due to be operated on after 24-hours but an ICU bed was not available. His surgery was delayed till the next day but he became unstable that night with features of cardiac tamponade and had a cardiac arrest in the ward. He was rushed to theatre and was found to have a

wound of the right atrium that was repaired. Post-operative, he remained unconscious with evidence of an ischemic brain injury. He developed multiple organ failure and died two days later.

Table 13.1 A summary of the haemodynamically stable patients with a hemopericardium that developed in-hospital cardiac tamponade.

No.	*Mechanism*	*RTS*	*PI*	*CVP (cm)*	*Heart size*	*US (mm)*	*Time from injury (hrs)*	*Cardiac injury*	*AAST grade*	*PCTI*	*Total Hospital Stay (days)*	*Complications*
1	SW	7.841	5	15	N	7mm	<24	1cm hole LV	5	20	8	Pneumonia
2	SW	7.841	5	23	Increased	12mm	<24	1cm hole RV	4	10	8	Nil
3	SW	7.841	5	15	N	7mm	<24	1cm hole RV	4	10	7	Pneumonia
4	SW	7.841	5	12	Increased	10mm	<24	0.5cm hole LV	5	20	6	Nil
5	SW	7.841	5	20	Increased	11mm	<24	Graze LA	3	5	6	Nil
6	SW	7.841	5	18	Increased	8mm	72	1cm hole RA	4	10	2	Ischemic encephalopathy and died on day 2 post-operatively

(d) Discussion

There was a significant mortality of 17% in this study of delayed in-hospital cardiac tamponade with one of the 6 patients dying from an ischemic encephalopathy. It is obviously unacceptable that a

patient with a suspected cardiac injury has to wait 3 days for surgery. Unfortunately the demands on the emergency theatres and intensive care units are excessive and the system is overburdened with trauma patients.

Patients with cardiac injuries may be incredibly stable on admission and in centers, where the trauma demand on the theatres outstrips the available resources, triaging of patients is required. This does mean that patients may have to wait for a theatre to become available.

The results of this study clearly indicate that conservative management of the patient with a hemopericardium is not a viable option. These 6 patients were all stable with small effusions detected on US screening. There were no features to distinguish these 6 patients (4%) from the other 152 patients that remained hemodynamically stable awaiting SPW.

With respect to the randomized, controlled study (RCT), it is evident that patients who undergo the surgical protocol as suggested must have the SPW done at 24-hours as suggested. There was this single mortality in this series and there was a patient that demised in the RCT from an iatrogenic injury to an internal mammary artery. I do not think that this lessens the findings of the RCT but it does make one acutely aware that these patients do have to be watched very closely in a high care environment until the SPW is performed.

CHAPTER 14

The role of the Subxiphoid Pericardial Window in

The Role of the Subxyphoid Pericardial Window in excluding Occult Cardiac Injury after Penetrating Thoraco-abdominal Trauma.

(a) Introduction

The incidence of combined thoracic and abdominal injuries following penetrating chest trauma has been reported to be between 6 and 42%.[93, 118, 311, 312] This wide variation in the incidence most likely reflects the proportion of gunshot wounds included in a particular series. One would expect a higher incidence of combined thoracic and abdominal injuries with gunshot wounds as reported by Evans et al.[112]

Patients with penetrating thoracoabdominal injuries are at risk for a potential cardiac injury. The incidence of an occult cardiac injury in a hemodynamically stable patient where the tract overlies the cardiac silhouette has been stated to be in the region of 20-30%.[125, 143] When an indication exists to perform a laparotomy there is also a need to establish whether the heart has also been injured. There is very little medical literature on how to exclude an associated cardiac injury in a patient with an acute abdomen after penetrating thoracoabdominal trauma where the wound is in the vicinity of the heart.[153]

There is a need in patients with thoracoabdominal injuries for the hemopericardium to be diagnosed, and for the diagnostic method to have a high sensitivity. Furthermore, it is essential that the diagnosis of the hemopericardium be made as rapidly as possible so that the hemodynamic instability of the patient can be quickly corrected. Ultrasound of the pericardial sac has certainly aided the management of this group of patients, but the sensitivity and specificity of the test is variable and there is a concern about the number of false negative reports, particularly in association with a

hemothorax. A SPW could be the most practical solution in this particular group of patients, where the patient is already receiving a general anesthetic.

The aim of this study was to investigate the incidence of an occult hemopericardium in patients with thoracoabdominal injuries, and to determine the incidence of adverse effects following SPW. There is precious little data in the literature with respect to the management of combined thoracoabdominal trauma[153] and it for this reason that we conducted a study to look into the role of how to screen for a cardiac injury in a patient with a penetrating wound in close proximity to the heart who requires a laparotomy for an associated acute abdomen.

(b) Methods

All patients presenting between October 2001 and February 2009 to the Groote Schuur Hospital Trauma Centre with a penetrating thoracoabdominal injury in close proximity to the heart, and an indication for an emergency laparotomy, but no immediate indication for a thoracotomy were included in the study. A thoracoabdominal injury was defined as an injury to both the thoracic and abdominal cavities, with or without a concomitant diaphragm injury, confirmed either clinically, radiologically or in theatre.

All patients were resuscitated according to the Advanced Trauma Life Support (ATLS®) guidelines.{{}} The Revised Trauma Score (RTS) was calculated for each patient.

The indications for an emergency laparotomy after penetrating thoraco-abdominal trauma were as follows; the presence of an acute abdomen, a complete spinal cord injury with a penetrating abdominal wound, an unconscious patient with a penetrating thoraco-abdominal wound, bowel evisceration, and the presence of blood per rectum. Free air under the diaphragm without abdominal

signs was not considered to be an indication for exploration in the conscious patient in the absence of abdominal signs.

Exclusion criteria were patients presenting with the suspicion of cardiac injury but no need for an exploratory laparotomy, obvious cardiac injuries presenting with hypovolaemic shock and cardiac tamponade, emergency department thoracotomies and any patient with an indication for an urgent thoracotomy. The indications used for an urgent thoracotomy are drainage of greater than 1,5 liters of blood from an intercostal drain or ongoing bleeding of more than 200ml per hour.

SPW was performed when there was concern about the possibility of a cardiac injury. This was defined as; the presence of a hemopericardium on ultrasound, a bullet tract in close proximity to the heart, and clinical suspicion because of an elevated central venous pressure greater than 12cm H_20 , electrocardiographic changes or an enlarged heart on chest x-ray or unexplained hemodynamic instability.

The abdominal injuries were graded using the Penetrating Abdominal Trauma Index (PATI) and the cardiac injuries were graded according the Cardiac Injury Scale in accordance with the American Association for Surgery Trauma (AAST) as outlined in table 14.1.

Table 14.1: The Cardiac Injury Scale

Grade	***Injury Description Cardiac Injury Organ Scale.***
1	Penetrating pericardial wound without cardiac injury, cardiac tamponade or cardiac herniation
2	Penetrating tangential cardiac wound up to but not extending through endocardium, without tamponade
3	Penetrating cardiac injury with septal rupture, pulmonary or tricuspid incompetence, papillary muscle dysfunction or distal coronary artery occlusion without cardiac failure

	Penetrating tangential myocardial wound up to but not through endocardium, with tamponade
4	Penetrating cardiac injury with septal rupture, pulmonary or tricuspid incompetence, papillary muscle dysfunction or distal coronary artery occlusion producing cardiac failure
	Penetrating cardiac injury with aortic or mitral incompetence
	Penetrating cardiac injury of the right ventricle, right or left atrium
5	Penetrating cardiac injury with proximal coronary artery occlusion
	Penetrating left ventricular perforation
6	Penetrating would producing >50% tissue loss of a chamber

The length of intensive care unit and total hospital stay were measured as well as any complications and deaths which occurred. The cardiac-related complications were defined as any missed cardiac injury, any cardiac tamponade, and any septic complications involving the heart and pericardial sac.

(c) Results

During the study period from October 2001 to February 2009, a total of 50 patients, with an indication for emergency laparotomy, underwent a SPW to exclude a possible cardiac injury. There were 47 men and 3 women, with a mean age of 25.6 years (range: 15-44). Forty-one (82%) patients sustained gunshot wounds (GSW) and 9 (18%) had stab wounds in the thoraco-abdominal region. The mean RTS was 7,597 (range 2.930-7.481)

Twenty-one patients were shocked on presentation, 4 had distended neck veins, 11 had a CVP of greater than 12cm of H20, five patients had an enlarged heart on chest x-ray, and non-specific ST-

segment electrocardiographic changes were present in 13. A pericardial US (FAST) was performed in 9 patients and in 6 there was the appearance of blood in the pericardial sac.

The indication for the emergency exploratory laparotomy was an acute abdomen in 48 patients, bowel evisceration in 1 and a penetrating abdominal injury in an unconscious patient in 1 patient.

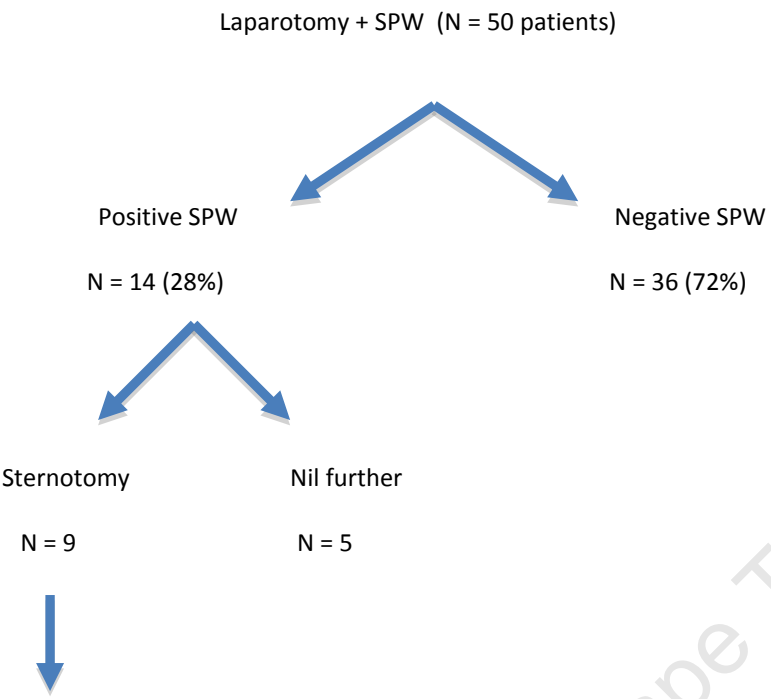
The indication for the SPW in each patient is tabulated in table 14.2.

Table 14.2: The indications for the performance of a subxiphoid pericardial window.

Indication	***Number of patients***
Bullet tract in proximity to the heart	22
US showing a hemopericardium	6
Clinical suspicion based on ECG, CVP or chest X-ray	20
Unexplained hemodynamic instability	2
TOTAL	50

The SPW was positive for blood in the pericardial sac in 14 of the 50 patients (28%). Nine of these 14 patients had their SPW incision extended into a median sternotomy (see table 14.3). In these 9 patients there were 3 tangential injuries to the right and two tangential injuries to the left ventricle (Grade 2), three perforating injuries to the right ventricle (Grade 4) and one hole in the left ventricle (Grade 5). In 5 of the 14 patients (36%) the surgeon felt comfortable that a major cardiac injury was not present and merely drained the pericardial sac. In all 5 cases, after initial drainage of between 100-200ml of blood there was no further evidence of active bleeding. The SPW was able to prevent a chest exploration from being carried out in 36% of the patients with a confirmed hemopericardium and thereby prevent the morbidity of further major surgery.

Table 14.3: Surgical management of the 50 patients.



Cardiac Injuries identified:

Grade 2 n =5 (3 tangential injuries to right ventricle and 2 to left ventricle)

Grade 4 n = 3 (3 perforations of the right ventricles)

Grade 5 n = 1 (1 perforating left ventricle injury)

During laparotomy 110 intra-abdominal injuries were diagnosed. The liver (n=25) was the most frequently injured organ, then the colon (n=16) and the stomach (n=15). The mean penetrating abdominal trauma index (PATI) was 14,7 range [0 – 37]. Associated thoracic injuries were found in 37 patients (71%) and consisted of 33 hemothoraces (66%) and 11 pneumothoraces (22%). The associated injuries are listed in table 14.4.

Table 14.4: Associated Injuries

Region	***Injury***	***Number of Patients***
Chest	Hemothorax	13
	Pneumothorax	11
Abdomen	Solid organ	32
	Bowel	29
	Diaphragm	19
	Vascular	4
Other	Maxillofacial	4
	Neurologic	2

The mean hospital stay for patients with a positive SPW was 9 days (range 4-23) and a mean ICU stay of 1,8 days (range 0-20). Thirty-six patients who underwent a negative SPW had a mean hospital stay of 7 days, eleven patients (31%) required a mean ICU stay of 4.2 days (range 1-9).

One patient (2%), who underwent a SPW, suffered from a cardiac-related complication. This consisted of a tension pneumopericardium resulting post-operatively after a negative SPW procedure. This necessitated a second SPW to relieve the cardiac tamponade effect. The associated injuries in this case were a pneumohemothorax and a laceration of the stomach. This patient was discharged well after 6 days without the need for surgical intensive care. There were no other complications related to the SPW itself. Specifically there were no infections involving the pericardial sac despite the fact that 43% (6/14) of the patients had bowel perforations and contamination.

The overall mortality in this series was 8% (4 patients). All of the patients died as a result of massive blood loss within 24-hours after admission following a damage control strategy to deal with the major

intra-abdominal injuries. Three of these patients had no associated cardiac injuries and one patient had a hole in the right ventricle. This patient had severe associated abdominal injuries with an extensive parenchymal liver injury (grade 5), and stomach, colon and small bowel perforations. This low mortality is indicative of the fact that this is a selected group of patients where the initial major concern was the abdominal cavity in a patient with a thoracoabdominal injury.

There were no cardiac complications encountered in the 5 patients who merely had drainage of the pericardial sac after a positive SPW. Their mean hospital stay was 5.6 days with a range of 4-7 days. One of these patients acquired a pneumonia that responded to treatment and another patient developed an ileus that settled on conservative management. The complication rate associated with the performance of a SPW was 3%. There was no increase in mortality by performing a SPW in addition to an exploratory laparotomy for penetrating thoraco-abdominal trauma.

(d) Discussion

There have been very few studies which have looked specifically at the role of the SPW in diagnosing occult cardiac trauma in patients who require a laparotomy for an acute abdomen after penetrating thoraco-abdominal trauma.

The diagnosis of a cardiac injury can be very difficult especially in the cohort of patients with an associated intra-abdominal injury. The signs of cardiac tamponade may not be present as a result of the hypotension from abdominal hemorrhage or the clinical signs of the acute abdomen may also divert attention away from the cardiac injury.[135] The CVP may be falsely elevated as result of shivering, overtransfusion, kinking of the line or malposition, or may be low in the face of abdominal hemorrhage. The classic sign of muffled heart sounds is an extremely difficult sign to pick up and is rarely present.

The use of ultrasound of the pericardial sac as part of the FAST (focused assessment sonography for trauma) is emerging as a safe, precise and quick diagnostic instrument. However, the results of cardiac ultrasound depend on the experience of the investigator, machine resolution and presence of chest wall injuries, surgical emphysema, obesity and pneumothorax and hemothorax.[313] We have been concerned about the number of false negative ultrasounds which occur in this setting and currently the sensitivity of ultrasound in diagnosing a hemopericardium is 87%

Ultrasound (US) to detect pericardial effusion was only performed in 9 of the 50 patients (18%) and was found to be positive in 6 patients, with five patients having a positive SPW. There was one single false positive ultrasound. This patient sustained a gunshot wound to the left thoraco-abdominal region. He was hemodynamically stable with a soft abdomen on clinical examination. A chest x-ray showed a left sided hemothorax and a bullet in-situ in the anterior mediastinum but away from the heart. The hemothorax was managed with an intercostal drain and the patient underwent serial abdominal evaluations. On day 2 post admission he developed an acute abdomen and an ECG showed ST-segment elevation. A repeat US now showed a 10mm pericardial effusion. He was taken to theatre for a SPW which was negative, and a laparotomy which revealed a laceration of the left hemidiaphragm that was repaired. The three negative US for pericardial effusion was confirmed at SPW to be true negatives. The reason why only 18% of patients had an ultrasound was related to a lack of expertise in this entity in the emergency room staff, since the radiologists perform the ultrasound in our institution. Asensio et al [313] published a series of thoracoabdominal trauma and only 16% of their patients had an ultrasound performed prior to surgery. This low figure may also represent concern over whether a negative US is in fact a true negative particularly in this series where 71% of patients had associated hemopneumothoraces.

According to the medical literature the sensitivity and negative predictive value for SPW is close to 100 %. The current study demonstrates a sensitivity of 100% and a negative predictive value of 100% for SPW excluding cardiac injuries. In five patients, although the SPW was positive, there were no signs of active bleeding and the surgeon was convinced that there was not a major cardiac injury

requiring intervention. The SPW in these cases prevented these 5 patients from having a combined sternotomy and laparotomy.

The complication rate following a SPW has been described as neglible.[125, 143, 145, 245] In this series there was a 3% cardiac-related morbidity after performing a SPW. There were no negative chest explorations. The mortality rate in this series was only 8% despite the fact that 82% of patients sustained gunshot wounds. Other studies have reported mortality rates as high as 59% where there have been combined procedures, although this also obviously relates to the severity of the injury and the physiological status of the patient. Although it is not possible to conclude from the data presented, the low mortality rate of 8% may be related to the screening ability of the SPW to exclude a cardiac injury and prevent the chest from being unnecessarily opened. There is a concern over the fact that 72% of the SPW were negative but at the same time it is essential to exclude a cardiac injury.

It remains unresolved whether to have a two-team approach, with one managing the chest and the other the abdomen. Furthermore, in the case of a single surgeon, which cavity should be managed in the first instance is unclear. Saadia et al have suggested that intra-abdominal hemorrhage should take precedence over cardiac tamponade.[314] Certainly if there is intra-abdominal bleeding this should take precedence, but if this is not encountered then a cardiac reason for the shock should be considered with a proximity wound and a subxiphoid pericardial window done. This is a very quick maneuver and we favour the classic approach as opposed to the transdiaphragmatic operation. The reason for this is that we feel that it may prevent contamination of the pericardial sac from peritoneal soiling to keep the two incisions separate.

Some authors would suggest that a full thoracotomy is required if a hemopericardium is encountered. In this series this was not done in 5 patients and the pericardial sac was merely drained with a soft drain. A combined chest and abdominal exploration is a major undertaking, particularly in the unstable patient, and if there is a chance of decreasing the number of combined explorations then our approach with the SPW is justified. At the same time it is important for the surgeon to be aware that the heart needs to be carefully inspected at SPW if there is a hemopericardium and no obvious

injury to the heart. The exposure through a SPW is limited and in these cases where it is not obvious, the chest should be opened through a median sternotomy.

The incidence of cardiac injury in patients with penetrating thoracoabdominal trauma in this series was 30 %. The complication rate associated with the performance of a SPW was 3%. There was no increase in mortality by performing a SPW in addition to an exploratory laparotomy for penetrating thoracoabdominal trauma. Nine occult cardiac injuries were detected which required a sternotomy. The SPW is a safe and reliable surgical intervention to exclude a cardiac injury in patients suffering penetrating thoracoabdominal trauma. A “quick thoracotomy” instead of a SPW should be avoided as it is time consuming and can push the patient to the edge of the physiological envelope.

CHAPTER 15

The Management of a Pneumopericardium

(a) Introduction

A pneumopericardium on chest X-ray after penetrating trauma is a rare event and the literature is divided on the most appropriate form of management. The surgical management of a pneumopericardium varies from mandatory exploratory surgery, irrespective of the clinical status of the patient in order to exclude an underlying cardiac injury [246], to conservative management in a carefully selected group of patients.[242] The aim of this study was to outline the clinical presentation of a pneumopericardium after penetrating chest trauma and to suggest a management protocol.

(b) Methods

This was a prospective study conducted over a period of 7-years (October 2001 till February 2009) on all patients presenting to Groote Schuur Hospital Trauma Centre with the radiological appearance of a pneumopericardium on chest x-ray following penetrating chest trauma. All chest x-rays with the appearance of a pneumopericardium were reviewed by a single trauma surgeon. A pneumopericardium was differentiated from a medial pneumothorax and a pneumomediastinum by the fact that the air did not extend above the level of pericardial reflection on to the aorta arch and the presence of the "transverse band of air sign", which signifies the presence of air in the transverse sinus of the pericardium.[252, 315]The clinical presentation of the patient was noted together with the revised trauma score and the indication for surgery in the patients who required immediate surgical exploration. Patients were resuscitated according to basic Advanced Trauma Life Support (ATLS®) guidelines.[149] The stable patients and those presenting with shock but who were easily resuscitable with less than 2 liters of crystalloid, were investigated with an ultrasound of the heart or a CT scan,

and were observed in a high care unit until a subxiphoid pericardial window (SPW) was performed at 24- hours post admission. If the patient became unstable during this period of observation, they were taken immediately to surgery for a SPW. A median sternotomy was only performed in addition to the SPW if there was evidence of active bleeding from the heart at the time of the SPW. The outcome and complications of the patients was noted and the duration of their hospital stays.

(c) Results

Twenty-seven patients who presented with a pneumopericardium following penetrating chest trauma were included in the study. All were males with a mean age of 25 years (range 12-36). The mechanism of injury was a stab wound in 26 patients and a multiple low velocity gunshot wounds to the chest and left shoulder in one patient. Three patients arrived intubated. The mean revised trauma score for these 27 patients was 7.566 (range 4.094-7.841).

Six of the 27 (22%) were unstable and required immediate surgical intervention (table 15.1). Included in this group of unstable patients was a patient who presented with a tension pneumopericardium. This was a 23-year old male who had presented to a nearby hospital with multiple stab wounds to the chest and abdomen, and had an acute abdomen. He was hemodynamically stable and was taken to theatre for his abdominal signs at the peripheral hospital and was found to have a wound of the transverse mesocolon. Post-operatively he became hemodynamically unstable and was referred through to our Trauma Centre. On presentation, he was shocked with the clinical features of cardiac tamponade and on chest X-ray he was noted to have a massive pneumopericardium. He was taken to theatre where a SPW released a large amount of air and a relook laparotomy was performed. At laparotomy he was found to have a missed injury to the left hemidiaphragm which communicated with the pericardial sac. He made a full recovery. Two other patients presented with features of cardiac tamponade and at median sternotomy were found to have bleeding from the left atrium, which was repaired. The second patient was bleeding from a hole in the right ventricle. Two other

unstable patients with a pneumopericardium also had an acute abdomen. The one patient had a thoracoabdominal stab wound with a negative SPW and at laparotomy an injury to the right lobe of the liver was identified. One patient had multiple gunshot wounds to left shoulder and chest and underwent a negative SPW and a negative laparotomy. The final patient presented in hypovolaemic shock and bleeding from the left-sided chest drain. At sternotomy he had a bleeding internal mammary artery which was ligated and a hole in the pericardial sac but no cardiac injury. There were no deaths in this group of patients and the mean hospital stay was 6.5 days (range 4 – 11 days).

Table 15.1 Indications for surgery in unstable patients with a pneumopericardium.

Patient Number	***Indication for surgery***	***Surgery performed***	***Underlying Cardiac Injury***
1.	Tension pneumopericardium	SPW + Laparotomy	No
2.	Cardiac Tamponade	Sternotomy	Yes (left atrium)
3.	Cardiac Tamponade	Sternotomy	Yes (right ventricle)
4.	Exsanguinating thoracic bleed	Sternotomy	No
5.	Multiple gunshot wounds and acute abdomen	SPW + Laparotomy	No
6.	Acute Abdomen	SPW + Laparotomy	No

Twenty-one patients arrived hemodynamically stable or were easily resuscitatable. Two patients had a widened mediastinum on chest X-ray and were sent for CT angiography of the chest, which confirmed the presence of the pneumopericardium. The remaining 19 patients all underwent an ultrasound of the pericardial sac. The results of the ultrasound are displayed in table 15.2. Ten were positive for blood in the pericardial sac. In 4 cases pericardial air could be seen on the ultrasound of the heart, and five were considered to be normal.

Table 15.2. Ultrasound findings in the 21 stable patients with a pneumopericardium.

Finding at Ultrasound	***Number of Patients***
Normal	5
Pericardial air only	4
Blood	10
Total	19 (2 patients had pericardial confirmed on CT scan for a total of 21 patients)

Two of the 21 (9.5%) patients who had arrived initially stable developed a tension pneumopericardium within 24-hours of arrival and required emergency surgery. They were taken to theatre and a subxiphoid pericardial window (SPW) was performed, at which there was a gush of air in both cases and the hemodynamic improved dramatically. No sternotomy was performed. These two patients were both discharged three days post-operatively.

The remaining 19 of the 21 patients underwent a SPW after 24-hours of observation. In 10 patients (53%) the SPW was positive for blood and in 4 of these 10, a median sternotomy was undertaken. At sternotomy 2 patients had no cardiac injury (50%), one patient had a sealed injury to the left ventricle, and the other a sealed injury to the right ventricle. The mean hospital stay for these 4 patients was 4.5 days (range 3 – 6 days). In the remaining 6 patients the blood in the pericardial sac was drained and the pericardial sac irrigated. No further surgery was performed. All these 6 patients were discharged home with a mean hospital stay of 3 days (range 2-7). Nine patients were found to have no blood present in the pericardial sac at SPW.

Figure 15.1. Tension pneumopericardium in patient 1.

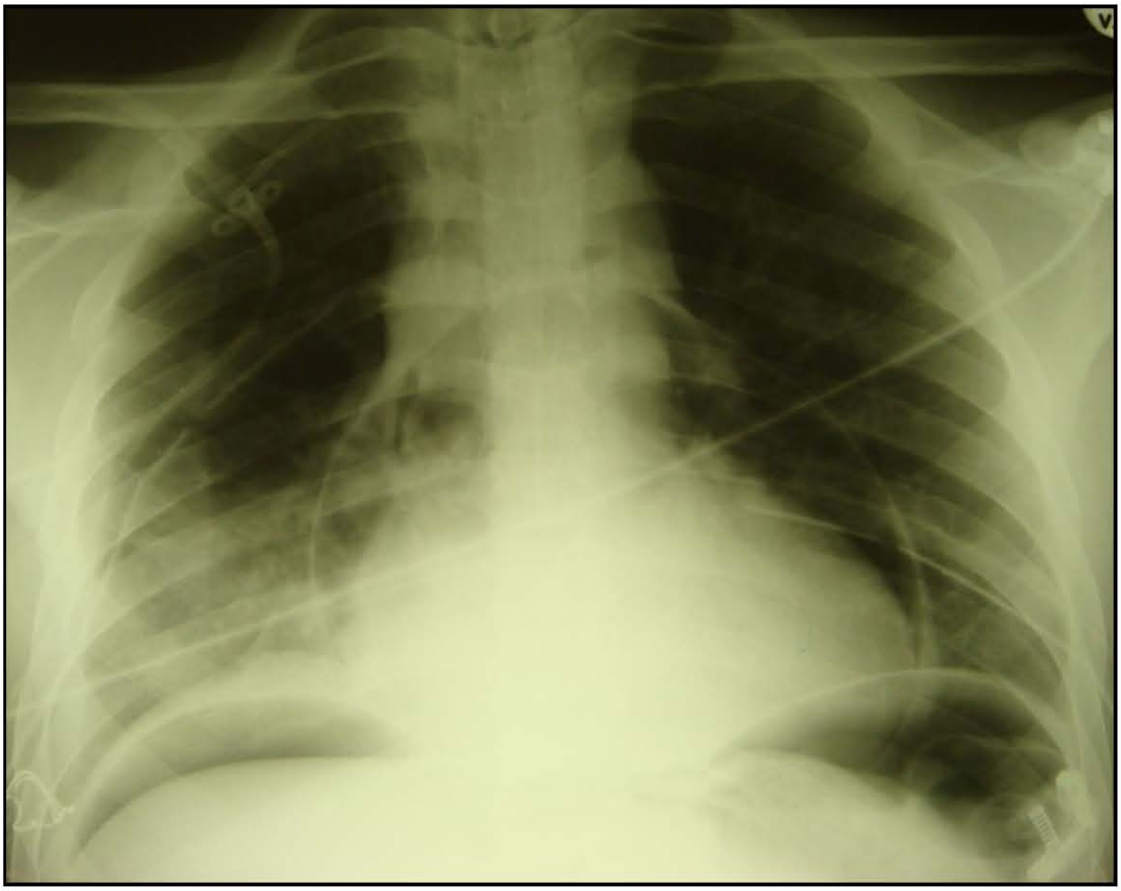
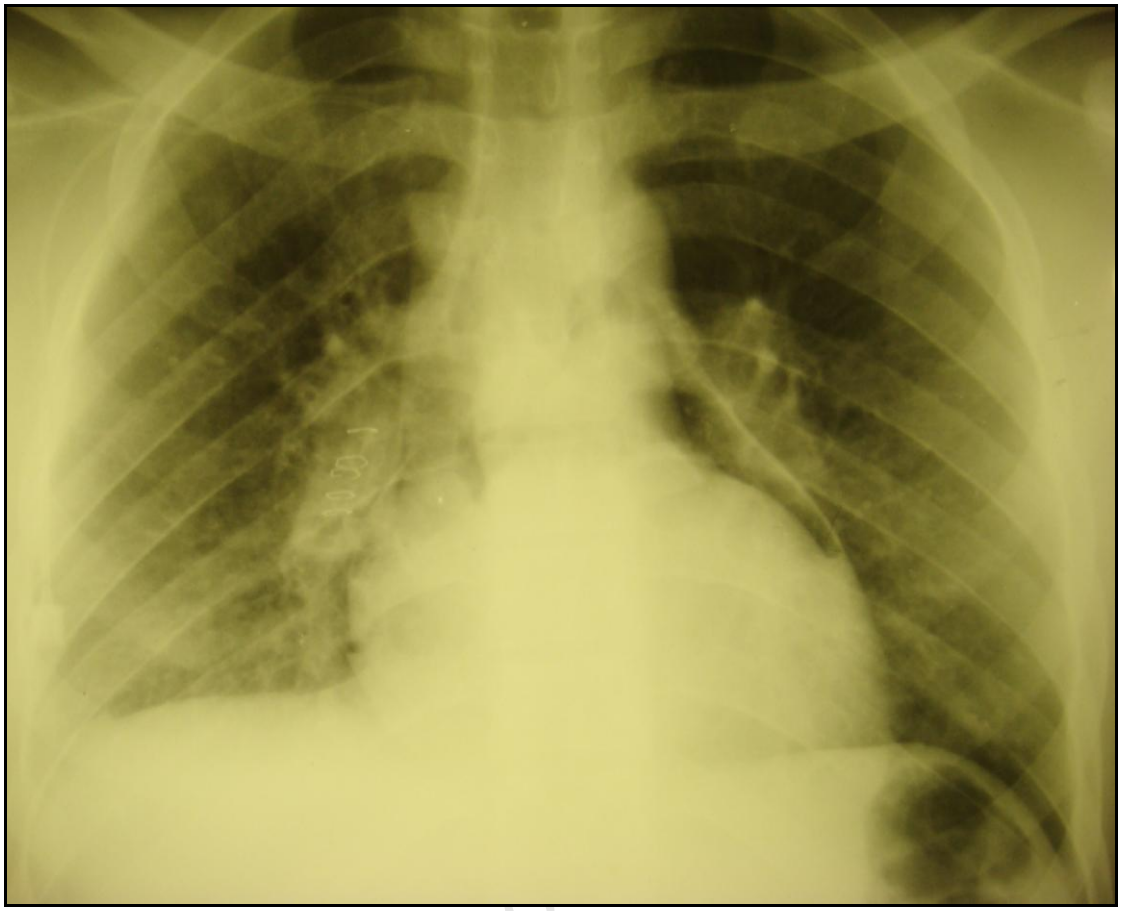


Figure 15.2. Tension pneumopericardium in patient 2.



There were 5 complications noted in these 21 patients. There were three cases of pneumonia which responded to antibiotics, a single case of a urinary tract infection and a patient that developed a post-cardiotomy syndrome which was managed with non-steroidal anti-inflammatories.

(d) Discussion

Six of the 27 patients with a pneumopericardium were unstable on admission and required emergency surgery. One of the six patients had a tension pneumopericardium. The performance of a SPW in these acute cases obviated the need for a median sternotomy in two cases (33%).

Two cases (9.5%) of tension pneumopericardium developed in the 21 patients who were initially stable. These two patients required emergency surgery. This was a sudden development and could not have been predicted. This is a major concern and is the reason why conservative management should not be practiced in the case of a pneumopericardium after penetrating thoracic trauma. Michelow et al[2] managed 9 patients with stable vital signs and a pneumopericardium conservatively and this was successful in eight patients. Demetriades et al[242] in their series of 20 patients successfully managed 19 patients with conservative management but one patient developed a tension pneumopericardium and required emergency surgery at 36-hours post admission.

A median sternotomy is not required as half of patients have no underlying cardiac injury and in the other half the cardiac wound had sealed.

Patients with a penetrating chest injury with a pneumopericardium who are unstable require emergency surgery. A delayed tension pneumopericardium developed in 9.5% of patients who were initially stable and it is our recommendation that all stable patients with a pneumopericardium after penetrating chest trauma should undergo a SPW. A sternotomy is not required in stable patients with no evidence of active bleeding, as the underlying cardiac injuries if present has sealed.

CHAPTER 16

Missed Penetrating Cardiac Injuries

(a) Introduction

There is a real concern in all clinician's that deal with penetrating chest injuries that they may be missing a cardiac injury. The difficulty in making the diagnosis in patients presenting hemodynamically stable to emergency units has been stressed. There are no prospective series that deal with the issue of missed cardiac injuries.

Delayed cardiac tamponade requiring surgery has been reported to occur up to 43 days after the initial injury.[94]

The aim was to study all missed cardiac injuries that have been referred to Groote Schuur Hospital Trauma Center or that have been missed in our own center with respect to their presentation and surgical management in order to ensure that these injuries are correctly identified and managed.

(b) Method

All cardiac injuries which were not initially identified and were admitted between November 2001 till February 2009 were included in this study. The delay to diagnosis, site of injury, mechanism, revised trauma score, clinical presentation, special investigations, surgical management, hospital stay and outcome were documented in each patient.

(i) Definitions

The precordium was defined as the anatomical region bounded laterally by the nipple lines, superiorly by the sternal notch and inferior by the xiphoid process.

A septic pericarditis was defined as a symptomatic patient with a temperature, elevated white cell count and with US confirmation of a pericardial effusion.

(d) Results

There were 11 patients who presented with a missed cardiac injury over the 7 years of the study. Ten patients were male and a single female with a mean age of 27 years (range 16 – 42). The mechanism of injury was stab wounds in ten and a gunshot precordium in one patient. All the stab wounds and the single gunshot wound were within the anatomical region defined as the precordium. Two patients with cardiac injuries were missed at our own institution and the remaining 9 had been initially treated and discharged from smaller surrounding hospitals. The time delay from the injury to presentation was a mean of 12 days (3 to 19 days).

The commonest presentation was that of a symptomatic pericardial effusion in 7 patients, a septic pericarditis in 4 with two of these patients demonstrating features of cardiac tamponade. The commonest symptom was chest pain which was present in 8 of the 11 patients (73%) and shortness of breath (55%). Seven patients had distended neck veins, four were pyrexial, and the heart sounds were described as muffled in the two patients with the obvious diagnosis of cardiac tamponade (Table 16.1). None of the eleven patients developed a pulsus paradoxus. On chest x-ray the heart was enlarged in 6 and there was a concomitant pleural effusion in 4 patients. On electrocardiogram 10 of the 11 patients had a pattern of ST-segment elevation consistent with a pericarditis.

Table 16.1. Presenting symptoms and signs of missed cardiac injuries

Symptom/ Sign	***Number of patients***
Chest pain	8
Dyspnoea	6
Fever	4
Distended neck veins	7
Elevated ST-segments	10
Pleural effusion	4
Cardiomegaly	6
Heart Sounds – muffled	2
- pansystolic murmur	1

An US confirmed the clinical diagnosis by detecting a pericardial effusion in all 11 patients with two of the patients having evidence on ultrasound of cardiac tamponade. The mean measurement of the effusion on US was 19.4mm (range 7mm – 40mm).

A pre-operative CT scan was performed in three patients due to the presence of a large area of opacification on the chest x-ray which made it difficult to determine if there was consolidation or a pleural collection. The CT scan confirmed a large pleural collection in three patients.

The surgical management is summarized in table 16.2. Seven patients were managed with a SPW and drainage, two with a SPW followed immediately by a sternotomy and two patients had a thoracotomy with evacuation of large pleural collections and a pericardiotomy.

Table 16.2. Surgical Management.

Patient Number	*Clinical Presentation*	*Size of effusion on US (mm)*	*Surgery*	*Pericardial sac drainage*	*Complications*
1	PE	12.4mm	SPW + Sternotomy	300ml blood	Nil
2	PE	13mm	SPW	500ml blood	Nil
3	Septic CT	15mm	SPW + Sternotomy	300ml pus	Empyema
4	Septic CT	20mm	Thoracotomy	Pus and fibrin +++	Nil
5	PE	7mm	SPW	270ml blood	Nil
6	PE	14mm	SPW	500ml blood	Nil
7	Septic PE	18mm	SPW	300ml blood	Constrictive pericarditis Septic shock
8	Septic PE	18mm	SPW	200ml blood	Nil
9	PE	40mm	SPW	700ml blood	Empyema
10	PE	16mm	SPW	300ml blood	Reaccumulation
11	PE	40mm	Thoracotomy	300ml blood	Nil

A thoracotomy and pericardiotomy was undertaken in the two patients who had a large pleural collection identified on CT scan. This allowed for the pleural cavity to be adequately cleared. In one case 1000ml of seropurulent fluid was evacuated and in the second 300ml of clotted blood.

In the patients who had a SPW followed by a sternotomy, the sternotomy was done for a specific reason in each patient. The surgeon was concerned in both cases that the cardiac injury may still be actively bleeding. In the first a delayed hemothorax had developed and the chest drain inserted had drained 1000ml of blood and in the second, the surgeon felt that at SPW there was active bleeding from the pericardial sac. In both instances any cardiac injury could not be identified at sternotomy. A pleural collection was also cleared out via the sternotomy in the one patient. The mean volume of fluid removed from the pericardial sac was 395ml (range 200ml – 700ml).

Seven patients recovered rapidly post- surgery without any complications. Two patients developed an empyema, the one was successfully treated with an intercostal drain and antibiotics and the second required a posterolateral thoracotomy which was done 3 weeks later. He made a full recovery post-surgery. One patient, who presented with a pericardial effusion, required a repeat SPW 4 days after the initial SPW as he had an ongoing pyrexia and increasing heart size. At repeat SPW 200ml of pus was drained and he subsequently recovered. Another patient, who presented with a septic pericarditis, was in septic shock on inotropes in the intensive care unit. He remained septic after the initial SPW and drainage and a repeat SPW was done 11 days later. He remained septic despite this and on day 17 post admission, a sternotomy and pericardectomy was performed for a constrictive pericarditis. This patient also made a full recovery.

Although pus swabs were taken routinely from the pericardial sac with each case, in only 3 patients was an organism identified. The patient who developed a constrictive pericarditis had an Acinetobacter baumanii identified and the two other patients had a mix of organism comprising staphylococcus aureus, streptococcus pyogenes, proteus mirabilis, and enterococcus faecalis.

Five of the eleven patients required intensive care management post-operatively with a mean stay of 12 days (range 2 – 41 days). The mean total hospital stay was 11 days (range 2-43 days). There were no deaths in this series.

Nine of the eleven patients presented to a peripheral hospital following a precordial chest wound and in none of these patients was an US performed. Eight of these patients had been managed with an intercostal chest drain for an associated hemothorax. They were all discharged home.

The two cardiac injuries that presented to our hospital and were missed are discussed here in more detail. The first case was a 21-year-old male presenting with a gunshot entrance wound to the right of the sternum in the 3rd intercostal space. There was no exit wound but x-rays located a retained bullet in the spinal canal at the level of the 7th thoracic vertebra. He was shocked in the pre-hospital phase and was admitted to our hospital fully conscious, a systolic blood pressure of 91mmHg and a

respiratory rate of 25. The neck veins were not distended, there was no pulsus paradoxus, but his heart sounds were muffled. His hemoglobin level was 10g% and his blood pressure improved after a single liter of crystalloid. On clinical examination he had a complete spinal cord injury at the 5th thoracic level. A chest x-ray showed a right hemothorax which was managed with an intercostal drain. He had ST-segment elevation and J waves on his ECG. Since he was hemodynamically stable a CT scan of the chest was done and this confirmed the presence of a bullet in the spinal canal but the heart was normal with no pericardial effusion. He was discharged from the Trauma Center to the Acute Spinal Cord Injury unit where his chest drain was removed after 4 days. On day 9 post admission he became short of breath with precordial chest pain but was apyrexial. A chest x-ray showed that a large right-sided hemothorax had redeveloped. A chest drain was inserted that drained 1 liter of blood. An US of the pericardial sac showed a 12.4mm pericardial effusion and a large right residual pleural collection. He underwent a SPW at which 300ml of blood was drained and a sternotomy was performed. It was not possible to identify a cardiac injury but a pericardial rent was evident. The right pleural cavity was opened and 200ml of liquefied hematoma was drained and the chest washed out. He returned to the Acute Spinal Unit and his further course was uncomplicated. He was discharged home after 40 days of rehabilitation.

The second missed cardiac injury was a 42-year old male who had been stabbed in the 6th intercostal space in the mid-clavicular line. He was not shocked in the pre-hospital phase and presented hemodynamically stable with a systolic blood pressure of 120mmHg. He had a left sided hemothorax diagnosed on chest x-ray and a left intercostal drain was inserted. An ECG showed ST segment elevation and the presence of J waves. An US performed on admission was negative for the presence of a hemopericardium and he was admitted to the ward for care of his intercostal drain. An US was repeated 24-hours later because of the abnormal ECG and this repeat US was also negative. The intercostal drain was removed and he was discharged home after 2 days. He represented with chest pain and dyspnoea with ST segment elevation and a third US now showed a 7mm pericardial effusion. He was taken to surgery and at a SPW he drained 270ml of blood. The pericardial sac was irrigated and drained. He had an uncomplicated post-operative course and was discharged home 5 days later.

(d) Discussion

A delayed hemopericardium occurring after penetrating chest trauma has been rarely reported in the medical literature. In 2003 there were only 36 documented cases which had occurred since 1950 with 24 of these cases reported from Tygerberg Hospital in South Africa with their experience in the management of cardiac injuries over an 8-year period.[241, 316-320] They managed 16 of the 24 patients by SPW and drainage, sternotomy in 5 and a thoracotomy in 3. Caceres et al[321] reported a single case report of a patient with a delayed presentation of a pericardial effusion after a stab wound that was successfully managed by a thoracoscopic pericardiotomy.

The two missed injuries in the current review illustrate a couple of important concepts in the screening of potential cardiac injuries. A CT scan of the chest may miss an underlying pericardial injury as demonstrated in the first case. It is difficult to determine if there was a cardiac injury in this case or whether the pericardial effusion developed from blood entering the pericardial sac from the hemothorax. The second patient had two negative US done, the first on admission and the second 24-hours later and both were falsely negative. This patient did have J waves and it would be appropriate in light of the high sensitivity of J waves in detecting a hemopericardium that a SPW as a diagnostic measure is performed in these cases. A hemothorax was present and any pericardial fluid may have exited into the pleural cavity but this case does highlight the issue that a false negative US may occur in the patient with an associated hemothorax.

All penetrating chest wounds must be evaluated with an US of the pericardial sac. If this investigation is not available at a peripheral hospital then the patient must be referred to an appropriate hospital. US of the heart may also miss an occasional cardiac injury. If the patient develops symptoms, particularly chest pain, or reaccumulates a hemothorax, a second ultrasound of the pericardium must

be performed. There have been numerous reports in the literature documenting that the initial ECHO report may miss a cardiac injury in the stable patient with an associated hemothorax.[8, 170, 305]

The operation of choice for these patients with a delayed pericardial effusion is a SPW. If there is an associated pleural collection then the procedure of choice is a thoracotomy and pericardiotomy. A CT scan is particularly useful in distinguishing between a pneumonic process and a pleural collection and should be done prior to surgery so that a thoracotomy and pleural clearout is undertaken if a collection is present. This is a better approach than a sternotomy is these cases particularly if the patient is showing signs of sepsis. A sternotomy and inspection of the heart is not required as it is not necessary as any cardiac injury is no longer visible. This experience is similar to that of Harris et al who reported the 24 patients presenting with delayed traumatic pericardial effusions and found no actively bleeding cardiac injuries.[316]

Although there was no mortality in this series, an initial missed diagnosis is associated with a significant mortality. At Baragwanath Hospital in Johannesburg, South Africa, an autopsy study over a 2-year period in the late 1970's identified 5 patients who had been discharged from hospital and subsequently demised from their missed PCI.[142]

It was suggested in 1932 that there was a relationship between a hemopericardium and the later development of a constrictive pericarditis.[322] There have been a few reports in the literature of patients developing a constrictive pericarditis after aspiration treatment of a traumatic hemopericardium.[323, 324] The reason why only a handful of cases of a hemopericardium will develop this complication is not known but infection in the pericardial sac is not required.

Until 1958 there have been 10 reported cases where a hemopericardium lead to the development of a constrictive pericarditis which required a pericardectomy. It was suggested that this process would take weeks to months to develop.[73, 323] Strauss reported a case in 1944 of a constriction syndrome which developed 7 years after a broken needle was left in the pericardial sac against the right atrium.[325]

The recommended treatment of a purulent pericarditis is pericardiocentesis and an appropriate antimicrobial agent for a period of least 4 weeks.[326, 327] In the setting of a purulent pericarditis after penetrating trauma the treatment should be surgical drainage via a SPW and broad spectrum antibiotics. If the effusion reaccumulates then the SPW should be repeated and if there is no improvement then a total pericardectomy needs to be performed. One would expect that aspiration of the pericardial sac would be inadequate as in the 80% of the pericardial effusions presented had clot present in the pericardial sac. A similar view has been expressed by other authors.[241, 316, 328]

SECTION D

CONCLUSION

"The essential component of successful management is the trauma surgeon who can best determine which patient qualifies for nonoperative or selective management and which patient needs operative interventions."

LD Britt

The distinguished Dr William Matory Lecture.

Nonoperative trauma management: Has the pendulum swung too far?

J Natl Med Ass 2003; 95: 964-968.

CHAPTER 17

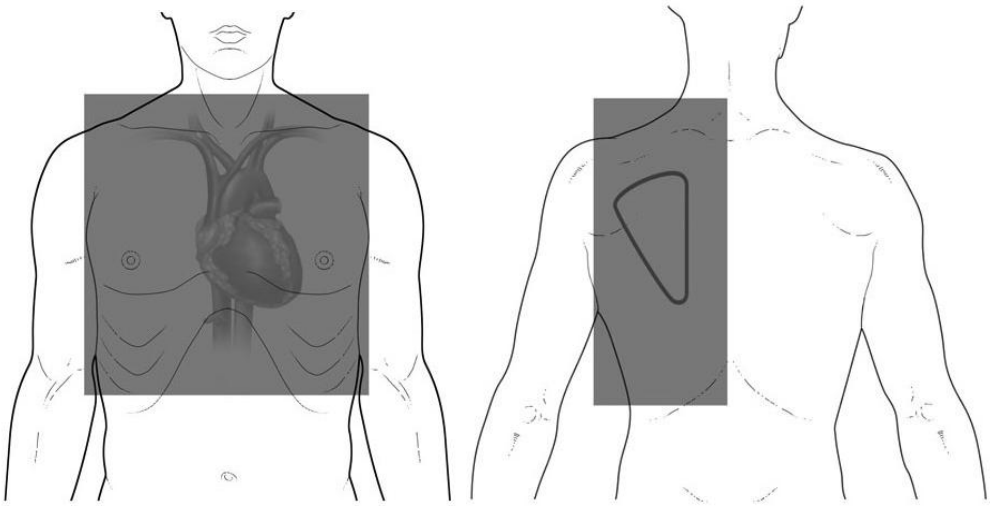
RECOMMENDED SCREENING AND SURGICAL MANAGEMENT OF PENETRATING CARDIAC INJURIES

The management of a penetrating cardiac injury has slowly advanced through the ages from a sense of mysticism, to helplessness, to conservative management, to the introduction of surgical repair, to pericardiocentesis and finally in the 1970's a dramatic move to immediate surgical intervention for all suspected injuries regardless of clinical presentation.

The questions which have arisen from the studies conducted on PCI have been concerned with the most appropriate form of screening for the stable patient and the treatment which should be offered to a hemodynamically stable patient with a hemopericardium after penetrating thoracic trauma.

A number of areas have been described in the literature as to when a clinician needs to consider a PCI. These include the cardiac silhouette, the cardiac box and a cardiac proximity wound. The problem has been that PCI from wounds located outside these areas have a higher mortality than those within. This is most likely due to the fact that the clinician is not considering a PCI for wounds located outside these described areas. A new area, that encompasses all reports of injuries in the literature and that also considers the 348 cardiac operations that have been performed for suspected cardiac trauma at our centre, is proposed to solve the problem. A cardiac injury should always be considered a possibility if the patient presents to the emergency department with a penetrating external wound placed within the cardiac zone. This extends from the right axillary line across to include the neck, epigastrium and the area of the back and shoulder as illustrated (diagram 17.1). Gunshot wounds entering in the neck, chest and pelvis may result in a PCI.

Diagram 17.1. The Cardiac Zone – the high risk area for a penetrating cardiac injury.



If there is a stab wound in the cardiac zone or a gunshot wound in the areas mentioned, then the patient must be screened for a PCI. In the past the chest x-ray, CVP and the ECG have not been found to be particularly effective in the diagnosis of a PCI. This has been because they were not being used correctly. A straight left heart border on the erect chest x-ray is a new radiological sign of a hemopericardium and is described in detail in chapter 9. Although the sensitivity was only 40%, it was highly specific when present (84%) in its ability to detect a hemopericardium (p=0.005). The J wave on the ECG has been documented in the trauma literature to be associated with hypothermia, but is also a marker of a PCI with a sensitivity of 44% and a specificity of 85% ($p < 0.001$). The CVP has been considered in some studies to be useful in diagnosing a PCI. In the current study a CVP reading of ≥ 12cm H_2O was found to be extremely useful to diagnose a hemopericardium in the stable patient with a sensitivity of 68.4%, specificity of 69.2% and a positive predictive value of 90.7% ($p < 0.001$). Cardiomegaly has been mentioned as a sign of a cardiac injury. A cardiothoracic ratio (CTR) of greater than 50% was found to have a sensitivity of 88% but was not particularly specific for a hemopericardium (27%). What may be of more importance when monitoring patients is an increase in the CTR on sequential chest x-rays.

Ultrasound of the pericardial sac is an excellent screening tool since it is mobile, rapid and non-invasive. US is associated with a false negative rate of 10.4% and this is most often due to the presence of a hemothorax and air in the pericardial sac obscuring vision. A hemopericardium may also decompress into the pleural cavity through the pericardial tear and this may also result in a negative US in association with a hemothorax. In the current study the sensitivity of US was 87%. It is therefore imperative that the clinical assessment of patients is combined with the chest x-ray, CVP and ECG as described in order to improve our diagnostic acumen.

If a patient arrives lifeless or has a hypovolaemic cardiac arrest, the patient requires an emergency department thoracotomy. If there are the obvious features of a cardiac injury and the patient is unstable, then the patient requires immediate surgery. If the patient is easily resuscitatable and remains hemodynamically stable, then screening can be performed. Screening for a cardiac injury should consist of a clinical examination followed by the insertion of a CVP line, erect chest x-ray, an ultrasound of the pericardial sac, and an electrocardiogram. The chest x-ray should be performed after the CVP line is inserted so as to ensure that there is no hemopneumothorax and to check the position of the line in the superior vena cava. The pericardial US (FAST) may be undertaken at an earlier stage as part of the adjunct to the primary survey.

The clinician must be aware of the sensitivity and specificity of the available screening modalities as determined from the clinical studies in this thesis and are presented in table 17.1.

Table 17.1. Sensitivity and specificity of the screening tests

Test	*Sensitivity*	*Specificity*	*Positive Predictive Value*	*P value*
Pre-hospital Shock	36%	72%	81%	0.39
CVP ≥ 12 cm H20	69%	68%	91%	<0.001
CTR ≥ 50%	88%	27%	79%	0.04
SLHB	40%	84%	89%	0.005
ST segment	66%	54%	83%	0.23
J wave	44%	85%	91%	<0.001
Ultrasound	87%	Not calculated	77%	0.15

The presence of any one of the following; CVP ≥ 12cm H_2O, a straight left heart border on chest x-ray, a J wave on ECG, a pneumopericardium (table 17.2), and a negative pericardial ultrasound after penetrating thoracic trauma should have a subxiphoid pericardial window (SPW) in order to completely exclude a cardiac injury. All patients with a positive US for blood in the pericardial sac should undergo a SPW. The SPW remains the gold standard for the detection of a hemopericardium. The use of a combination of clinical, radiological and electrocardiographic signs reduces the problem of the incidence of unnecessary SPW from the quoted figure in the literature of around 70-80% down to 23% (figure 8.1) in this series.

Table 17.2. Screening tests that if present require a mandatory SPW

CVP ≥ 12 cm H_2O
J wave on ECG
Straight left heart border
Pericardial air either on the chest x-ray of on US

When a hemopericardium is suspected or diagnosed, the patient should be placed under close observation in a high care unit for 24-hours. If there is any evidence of hemodynamic instability, the patient must have emergency surgery. If the patient remains stable, a SPW is performed with irrigation of the pericardial sac after 24-hours thereby allowing any cardiac injury to seal. If there is any sign of active bleeding at SPW, a median sternotomy is done and the cardiac defect repaired. This enables the patients with major cardiac injuries and unstable clot to be identified that would be at risk of delayed cardiac tamponade. If there is no active bleeding, the pericardial sac is drained and the patient is returned to the high care unit for a further 24-hours. The drain may be removed when there is no further drainage and the patient can be discharged home.

This is a safe and effective way of managing the patient who is stable with a hemopericardium and the washing out of the pericardial sac will help to prevent any late complications of a delayed pericardial effusion, septic or constrictive pericarditis. There is a significant reduction in ICU requirement ($p < 0.001$) and in total hospital stay ($p < 0.001$).

The incidence of an underlying cardiac injury in thoracoabdominal penetrating trauma where the patient presents with an acute abdomen and a wound in the cardiac zone is 28%. The SPW is an excellent way to exclude an injury to the heart and can be performed without any increase in morbidity. It can also prevent the need for a median sternotomy in 36% of patients.

There is no place for the conservative management of PCI. Around 4% of patients who present hemodynamically stable will develop cardiac tamponade in hospital and will require emergency surgery.

A pneumopericardium in the stable patient should be managed with a SPW in order to prevent the development of a tension pneumopericardium, which will occur in 10% of cases, and this may have devastating consequences.

A CT scan of the pericardial sac may miss a cardiac injury and the sensitivity and specificity of the investigation has not been confirmed. If a blood is detected in the pericardial sac on CT, then the patient should have a SPW performed.

Missed cardiac injuries may present between 4-73 days after the initial trauma. It is vital that all chest stab wounds in the region of the cardiac zone should be screened with a cardiac US. In patients who present with a delayed injury, a SPW is the best form of management. There is no need for a median sternotomy as the cardiac wound will have sealed. If there is an associated pleural collection, then the patient should have a thoracotomy and pericardiotomy.

It is vital to detect a penetrating cardiac injury and effective cardiac screening with a combination of the clinical examination, special investigations and ultrasound will allow us as clinicians to be in a position to diagnose these injuries with a greater degree of certainty.

SECTION E ABSTRACTS OF THE CLINICAL STUDIES

"The operator may diagnose a wound of the heart, but subsequently a wound only of the pericardium, possibly associated with a superficial wound of the surface of the heart, may be found, or a wound of the coronary artery or of one of the great vessels may be present. In each of these cases blood will occupy the cavity of the pericardium. It must not be forgotten that the haemopericardium may be due to hemorrhage from a vessel of the pericardium, and there may be no other source of bleeding."

Sir Charles Balance (Consulting Surgeon to St. Thomas's Hospital).

Bradshaw Lecture on Surgery of the Heart.

Delivered before the Royal College of Surgeons of England on the 11th December 1919.

Lancet 1920; January 10; 73-79.

Randomised Clinical Trial comparing Sternotomy versus Subxiphoid Pericardial Drainage alone in the management of the Stable patient with a Hemopericardium after Penetrating Thoracic Trauma.

Introduction:

The current international practice is that a penetrating cardiac injury in a hemodynamically stable patient, without evidence of bleeding or tamponade, should undergo a sternotomy and exploration. The experience at Groote Schuur Hospital in Cape Town with performing a mandatory sternotomy in this group of patients was that sternotomy was unnecessary and the cardiac injury if present had sealed completely.

Methods:

This was a single centre parallel-group study with equal randomization conducted at Groote Schuur Hospital/ University of Cape Town between November 2001 till February 2009. All adult patients aged 18- years or older, who had sustained penetrating chest trauma, who were hemodynamically stable with a hemopericardium confirmed at subxiphoid pericardial window (SPW), and who had no signs of active bleeding at SPW were included in the study. This study was approved by the Faculty of Health Sciences Research Ethics Committee of the University of Cape Town.

Results:

One hundred and eleven patients were confirmed at SPW to have a hemopericardium without any evidence of active bleeding. Fifty-five of these patients were randomized to sternotomy and fifty-six to pericardial drainage only. Fifty-one of the 55 patients (93%) who were randomized to sternotomy had either no cardiac injury or a tangential injury. There were only 4 patients with penetrating wounds to the endocardium and in all of these the wounds had completely sealed. There was one death post-operatively in the 111 patients (0.9%) and this was a patient that had been assigned to sternotomy. The mean ICU stay for the sternotomy group was 2.04 days (range 0-25 days) compared to 0.25 days (range 0-2) for the drainage only ($p < 0.001$).

Conclusion:

Pericardial drainage alone appears effective and safe in the management of the haemopericardium in the stable patient after penetrating chest trauma with no increase in mortality and a shorter ICU and hospital stay.

A Straight Left Heart Border- A new radiological sign of a hemopericardium.

Introduction:

The detection of a cardiac injury in a patient who is hemodynamically stable after a penetrating chest injury can be extremely difficult. A filling in of the aorto-pulmonary window, called the straight left heart border (SLHB), is a radiological sign that we have found to be commonly associated with the presence of a hemopericardium at surgery. The aim of this study was to determine if this was a reliable and reproducible sign of a hemopericardium.

Methods:

All patients with a penetrating chest injury who were admitted to Groote Schuur Hospital Trauma centre between 1st October 2001 till 28th February 2009, who had an erect chest X-ray performed on admission, who were easily resuscitable and had no indication for immediate surgery, and were taken to theatre for the performance of a subxiphoid pericardial window (SPW) were entered into the study. Statistical analysis was conducted using chi-square test for categorical variables. A p value of less than 0.05 was considered to be significant.

Results:

There were 162 patients with possible cardiac injury after penetrating chest trauma who had an x-ray on admission to the trauma centre. The mean age of the patients was 27.7 years (range 13-62). 55 of the 162 patients (34%) were noted to have a hemopericardium at SPW (true positives) and there were 6 patients with a SLHB that were negative for blood at the time of performing a SPW (false positive). 75 patients had a hemopericardium at surgery but did not have the feature of a SLHB. The sensitivity of this radiological sign was 40% with a specificity of 84%. The straight left heart border was highly significant in predicting the presence of a hemopericardium (p= 0.005)

Conclusion:

The straight left heart border is a newly described radiological sign associated with penetrating thoracic trauma that is indicative of the presence of blood in the pericardial sac resulting in a straightening out and filling in of the aorto-pulmonary window. Although it is not very sensitive sign (40%) it is highly specific (84%) and when it is present should alert the surgeon to the presence of a hemopericardium.

The J- wave: a New Electrocardiographic Sign of an Occult Cardiac Injury.

Introduction:

There is a definitive need for a simple diagnostic aid that can guide, what is often a junior medical officer dealing with a penetrating chest injury, in the necessity to refer a patient for further investigation into a possible cardiac injury. Changes in the ECG may be such a diagnostic aid. The aim of this study was to identify the ECG changes that were present in patients with possible cardiac injuries who were easily resuscitatable, presenting to a level 1 Trauma Centre and to outline what the features on an ECG should a warning sign of possible cardiac trauma.

Methods:

This was a prospective study conducted on all patients admitted to the Groote Schuur Hospital Trauma centre following penetrating chest trauma during the period of 1st October 2001 and 28th February 2009, who did not have an indication for emergency surgery and that underwent an ECG and later a subxiphoid pericardial window (SPW) for a potential cardiac injury. All the patients were easily resuscitatable with less than two litres of crystalloid. A standard 12- lead ECG was performed shortly after admission. A J wave was defined as the small wave on the R-ST junction.

Results:

There were 174 patients where an ECG was performed and the patient subsequently underwent SPW for a possible cardiac injury. The mean age of the patients was 28 years (range 11-65). The mechanism of injury was stab wounds in 167 patients and 7 low velocity gunshot wounds. A J –wave was present on the ECG in 65 (37%) of the 174 patients with a possible cardiac injury. The sensitivity of a J wave to detect a hemopericardium was 44% and the specificity was 85% ($p < 0.001$).

Conclusion:

This study demonstrates that presence of 'J' waves on ECG signifies a significant risk of a hemopericardium after penetrating thoracic trauma. Though the sensitivity is low at 44% but with a specificity of 85% it should be a major warning sign to clinicians that the risk of a hemopericardium is extremely high and such patients should be referred to a trauma centre for further investigation and management.

The Role of Ultrasound in detecting Occult Cardiac Injuries

Introduction

Ultrasound has been shown in prospective studies to have a sensitivity of between 83.8 – 100% for the detection of cardiac injuries and has become the investigation of choice world-wide. If ultrasound is to be the investigation of choice then it is essential that surgeons understand the limitations of the study so that an appropriate decision is made regarding patient management. The aim of this study was to determine the sensitivity and positive predictive value of emergency room ultrasound in the diagnosis of occult cardiac injuries.

Methods

All patients presenting with a penetrating chest wound and a possible cardiac injury to the Groote Schuur Hospital Trauma Centre between October 2001 and February 2009 were prospectively evaluated. All patients were fully conscious and either stable or required less than 2l of crystalloid to achieve hemodynamic stability, and had no indication for emergency surgery.

Results

There were a total of 172 patients who underwent a subxiphoid pericardial window for a possible cardiac injury between October 2001 and February 2009 and who had been investigated pre-operatively with an US of the pericardial sac. The median age of the patients was 26 years (range 11 to 65 years) and 168 (96%) were males. The mechanism of the penetrating chest injury was stab wounds in 166 (96%) and low velocity gunshot wounds in 6. The sensitivity of the US to detect a hemopericardium was 86.7% with a positive predictive value of 77%. There were 18 false negatives. Eleven of these patients had an associated hemothorax; six had a pneumopericardium detected, and one patient with two negative US examinations that was discharged home only to return with a delayed symptomatic pericardial effusion.

Conclusion

There would appear to be two main factors, which limit the screening sensitivity of US. The first is the presence of air in the pericardial sac, and secondly a hemothorax. The presence of a hemothorax would warrant a repeat US at 24-hours and other clinical parameters suggestive of a cardiac injury need to be identified so that an occult cardiac injury may be detected.

A New Screening Regimen for Occult Cardiac Injuries

Introduction

Ultrasound has become firmly established as the screening modality of choice worldwide. There are, however, recent reports of false negative results from the ultrasound of the pericardial sac appearing in the literature. The aim of this study was to look at the role of additional clinical, radiological and electrocardiographic signs of a potential cardiac injury in patients presenting with penetrating chest trauma to see if these could improve the accuracy of the detection of a hemopericardium.

Methods

A prospective study conducted from October 2001 till February 2009 on all patients that presented to Groote Schuur Hospital with a suspicious penetrating chest wound, who were hemodynamically stable, or easily stabilized with less than 2l of crystalloid. Patients were evaluated with a chest x-ray, an ECG, central venous line and an immediate US of the pericardial sac. The presence of any fluid in the sac was considered to be a positive US. A repeat US was conducted 24-hours later if the initial scan was negative but clinical concern remained in the light of unexplained pre-hospital shock, elevated CVP, increased CTR or elevated ST segments or J waves on the ECG. The presence of a SLHB on the chest x-ray was an indication for a SPW as was the detection of any fluid on the US. All patients included in this study underwent a SPW.

Results

One-hundred and seventy-five patients presented to the Trauma Center with penetrating chest trauma. The mechanism of trauma was a stab wound in 168 cases (96%) and a single GSW in 7 (4%). All 175 patients had a SPW performed under general anaesthetic. A CVP ≥12 cm H2O had a sensitivity of 68.4% and a specificity of 69.2% ($P < 0.001$) in the diagnosis of a hemopericardium. The presence of shock in the pre-hospital phase ($P = 0.39$), and a cardiothoracic ratio of greater than 50% ($P = 0.38$) were not reliable indicators.

Discussion

The presence of an effusion on pericardial US is an indication for surgery. In addition, the presence of; a CVP ≥ 12cm H_2O, a J wave, a SLHB or pericardial air should prompt the surgeon to perform a subxiphoid pericardial window.

Delayed in-hospital Cardiac Tamponade

Introduction

The aim of this study was to determine the incidence of delayed cardiac tamponade in patients who were admitted to the high care unit after penetrating chest trauma with the diagnosis of a stable haemopericardium and who developed features of cardiac tamponade while under observation and required emergency surgery.

Methods

All patients with penetrating chest trauma and a hemopericardium present on ultrasound, who developed cardiac tamponade after initial admission to a high care unit in a stable condition between October 2001 till February 2009, were included in the study.

Results

One hundred and fifty-eight patients with penetrating chest injury and suspicion of an occult cardiac injury were admitted to the high care unit during the study period. Six of these patients (4%) became unstable during the period of observation in the high care unit and required emergency surgery. They were all male patients with a mean age of 26 years (range 19 to 34) with stab wounds to the chest. The 6 patients were all clinically stable on admission with a mean revised trauma score of 7.973 (range 7.550 – 7.841). The ultrasound confirmed the presence of a hemopericardium in all the patients. The time from injury to the development of delayed cardiac tamponade was within 24-hours in 5 of these patients. Five of these patients developed the classic clinical signs of tamponade with distended neck veins and hypotension. The 6th patient dropped his blood pressure and sustained a cardiac arrest on day 3 post admission. At surgery all the patients had underlying cardiac injuries. One of the 6 patients died.

Conclusion

The results of this study clearly indicate that conservative management of the patient with a hemopericardium is not a viable option. These 6 patients were all stable with small effusions detected on US screening. There were no features to distinguish these 6 patients (4%) from the other 152 patients that remained hemodynamically stable awaiting SPW. A SPW should be performed on these patients at 24-hours post injury.

The Role of the Subxyphoid Pericardial Window in excluding Occult Cardiac Injury after Penetrating Thoraco-abdominal Trauma.

Introduction

Penetrating thoraco-abdominal injuries, where the tract is in close proximity to the heart, are at risk for a cardiac injury. The aim of this study was to determine the incidence of an occult cardiac injury in the group of patients presenting with an acute abdomen after penetrating thoraco-abdominal injury and to determine the morbidity and mortality associated with a diagnostic subxiphoid pericardial window in this setting.

Methods

This study was conducted over 8-years on all patients with a penetrating thoraco-abdominal injury with an acute abdomen where there was concern about a potential cardiac injury from the tract of the injury.

Results

Fifty patients with an indication for emergency laparotomy underwent a SXW to diagnose a possible cardiac injury. The incidence of an occult cardiac injury in this group was 28% (14 patients out of 50). Nine cardiac injuries were identified at sternotomy and in 5 patients (36%) a sternotomy was avoided by performing the SPW. The overall mortality rate for this group of patients was 8%.

Conclusion

The incidence of a cardiac injury in patients with penetrating thoraco-abdominal trauma in this series was 28%. The complication rate associated with the performance of the SPW was 3%. The SPW identifies cardiac injuries and also prevents an unnecessary sternotomy in 36% of confirmed hemopericardiums.

The Management of a Pneumopericardium following Penetrating Chest Trauma: a prospective analysis.

Introduction

A pneumopericardium presenting after penetrating chest trauma is a rare event. The surgical management of this clinical problem has not been well documented in the past. The aim of this study was to document the mode of presentation and to suggest a protocol for the management of a pneumopericardium after penetrating chest trauma.

Method

A prospective audit of patients presenting to Groote Schuur Hospital Trauma Centre between October 2001 and February 2009 with a pneumopericardium on chest X-ray after penetrating trauma with respect to their presentation and surgical management.

Results

There were 27 patients in total who presented with a pneumopericardium. The mean age was 25 years (range 17-36). The mechanism of injury was a stab wound to the chest in 26 patients and a single patient had sustained multiple low velocity gunshot wounds. The mean revised trauma score was 7.566 (range 4.094-7.841). Six patients (22%) were unstable and required emergency surgery. One of these patients presented with a tension pneumopericardium. Twenty-one patients were initially stable. Two of these (10%) patients later developed a tension pneumopericardium within 24-hours and were taken to theatre. The remaining 19 patients were managed with a subxiphoid pericardial window (SPW) at between 24-48 hours post admission. Ten of these 19 patients (52%) were positive for blood. Only 4 of the 19 underwent a sternotomy and only two of these had cardiac injuries that had sealed. There were no deaths in this series.

Conclusion

Patients with a penetrating chest injury with a pneumopericardium who are unstable require emergency surgery. A delayed tension pneumopericardium developed in 10% of patients who were initially stable. It is our recommendation that all stable patients with a pneumopericardium after penetrating chest trauma should undergo a SPW. A sternotomy is not required in stable patients.

Management of the Missed Cardiac Injury.

Introduction:

There is real concern in all clinicians treating penetrating chest injuries that they may miss cardiac injuries. The difficulty in making the diagnosis in patients presenting haemodynamically stable to the emergency units has been stressed. Yet there are no prospective series dealing with the issue of missed cardiac injuries. The aim of this study was to determine the number and complications of missed cardiac injuries.

Methods:

All cardiac injuries which were not initially identified and were admitted between November 2001 till February 2009 were included in this study. The delay to diagnosis, site of injury, mechanism, revised trauma score, clinical presentation, special investigations, surgical management, hospital stay and outcome were documented in each patient.

Results:

During the 7 years study period 11 patients with a missed cardiac injury were seen. The mechanism of injury was a stab wound in ten and a gunshot wound precordium in one patient. Two patients with cardiac injuries were missed at our own institution (one had a normal CT pericardium and the other had two normal pericardial ultrasounds), and nine patients had been initially treated and discharged from surrounding hospitals (no ultrasounds of the pericardium were performed).

The commonest presentation was that of a symptomatic pericardial effusion in 7 patients, a septic pericarditis in 4 with two of these patients demonstrating features of cardiac tamponade. Seven patients underwent subxiphoid window and drainage, two underwent subxiphoid window followed by sternotomy, and 2 patients had a thoracotomy with evacuation of large pleural collections and a pericardiotomy. There was no mortality.

Conclusion:

All penetrating precordial injuries in haemodynamically stable patients must be evaluated with a CXR, ECG and a pericardial ultrasound. Other clinical signs such as a straight left heart border and J waves should be used in addition to pericardial ultrasound. Missed cardiac injuries may result in serious complications.

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