PENETRATING INJURIES OF THE THORACIC AORTA AND ITS BRANCHES

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THESIS FOR MASTER OF MEDICINE PART III IN CARDIOTHORACIC SURGERY

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DEDICATION:

I would like to thank my wife Yolande and my children Craig, Angela and Michael, for their patience, understanding and support over the last 5 years.

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INTRODUCTION

Penetrating injuries of the intrathoracic great vessels are well recognized although uncommon. In the First World War no survivors with thoracic vascular injury were recorded among soldiers treated with penetrating injuries to the chest as recorded by Makins (1). The first record of successful repair of a penetrating thoracic aortic injury was in 1922 by Dshanelidze in Russia (2). Similar to Makins' experience, De Bakey and Simeone in the Second World War recorded no surviving patients with involvement of the thoracic aorta and its branches among American soldiers(3). Furthermore, no injuries to the thoracic aorta and its branches were recorded in Korean war soldiers undergoing vascular surgery by both Jahnke (4) and Hughes (5). Rich reported 3 survivors of aortic injuries in the Vietnam war among 1000 patients with vascular injuries (6). By 1969 only 43 successfully treated cases had been reported (7) but increasing numbers of patients sustaining injuries to the great arteries at the level of the thoracic inlet have been reported subsequently in civilian practice (8-18). Experience has grown over the years but patient numbers remain small and individual surgeons may only manage 2 or 3 of these patients in his life time. The largest single reported series consists of 93 patients in Memphis over a 13 year period (18). All victims were rapidly transported to hospital and were resuscitated en route. As a consequence, a large number critically ill patients reached hospital who may have died in earlier years. However some of these patients inevitably died in hospital contributing to the high mortality of 16,7% reported. Our experience is different in that most of our victims who reach hospital will survive as poor community triage facilities prevent more than 95% of penetrating thoracic vascular trauma victims reaching hospital alive, hence we have a selection of less severely injured patients who eventually reach our hospital alive producing our mortality rate of 5% (19,20). Another important difference is that most of our patients suffered stab wounds as compared to gunshot wounds noted in the Memphis. Buchan and Robbs in Durban reported on 52 patients who had penetrating cervicomediastinal vascular injury with a remarkably similar experience to our own in Cape Town with the exception of a larger number of aortic injuries (21 out of 52 patients) recorded and a higher mortality rate of 17% as a result of these aortic injuries(21).

PUBLISHED PAPERS RELATING TO PENETRATING INJURIES OF THE THORACIC AORTA AND ITS BRANCHES.

TITLE:

PENETRATING INJURIES INVOLVING THE INTRATHORACIC GREAT VESSELS

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SUMMARY

Forty-four consecutive patients with injuries to the intrathoracic great vessels admitted to our department from January 1982 to June 1994 were reviewed retrospectively. Forty-two patients (95%) sustained stab wounds and 2 (5%) patients had gunshot wounds. The most frequent radiological abnormality was mediastinal widening in 26 patients (59%). Eighteen patients (41%) were haemodynamically stable on admission with the remainder being unstable (46%), agonal (11%) or lifeless (2%). Twenty-two patients (50%) underwent angiography with one false negative study. A total of 48 arterial and 16 venous injuries were identified with the innominate artery (n=17, 39% of patients) and left innominate vein (n=8, 18% of patients) the most frequently injured structures. Associated injuries to thoracic viscera occurred in 13 patients (30%). Two patients required cardiopulmonary bypass to repair their injuries. Arterial shunts were not used in any case. Overall mortality was 5% (2/44) and complications occurred in 7 patients (16%).

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INTRODUCTION

Penetrating injury to the intrathoracic great vessels is frequently a lethal event. In South Africa, penetrating chest injuries comprise a large proportion of patients seen in the trauma units yet intrathoracic major vascular injury appears to be relatively infrequent compared to injury to other intrathoracic viscera.(1) Hospital mortality rates are between 15% and 30% in studies of similar injuries in first world countries with rapid transport, good triage and resuscitation facilities.(2,3) We have evaluated our local experience and compared it to the results of recent studies elsewhere.

MATERIALS AND METHODS

We retrospectively reviewed all patients referred to the department of cardiothoracic surgery at Groote Schuur Hospital between January 1,1982 and June 30,1994 with proven major vascular injuries. Excluded were patients with cardiac and major pulmonary vessel injuries and those failing initial resuscitation. We reviewed their hospital records in regard to the mechanism and external location of injury, clinical status on admission, radiological features, vessels injured, surgical approaches, method of repair and outcome. The patients were classified as stable, haemodynamically unstable (blood pressure of < 90/60 mm Hg with signs of peripheral hypoperfusion), moribund (unrecordable blood pressure with either spontaneous respiratory, cardiac or neurological activity on admission) or lifeless (no cardiac or respiratory activity on admission).

RESULTS

Forty four patients with major penetrating intrathoracic injuries were treated during this 12 year period. Their age ranged between 18 and 36 years (mean age 26 years) with 40 being males (90%) and 4 females (10%). Forty two patients (95%) sustained stab wounds and only 2 (5%) had low velocity gunshot wounds

HAEMODYNAMIC STATUS ON ADMISSION TO HOSPITAL

Patients were initially assessed by the trauma unit staff and referred to our department if a major vessel injury was suspected. Of the patients identified with vascular injuries, 6 patients (13%) were moribund or

lifeless. 20 patients (46%) were in hypovolaemic shock and 18 (41%) were haemodynamically stable. (Table I).

All 18 stable patients had chest X-rays and subsequent angiography. Patients who were haemodynamically unstable underwent volume resuscitation and invasive monitoring. Four of these 20 patients responded rapidly to initial resuscitation and subsequently underwent angiography.

Immediate resuscitation was commenced in the 5 moribund patients and 2 were felt to be stable enough to undergo definitive surgery in the operating theater, while 3 patients underwent emergency room resuscitative thoracotomy.

The solitary lifeless patient underwent immediate thoracotomy on arrival in the trauma unit. This patient exhibited signs of life minutes before arrival in hospital.

DIAGNOSIS AND INDICATION FOR SURGICAL REFERRAL AND EXPLORATION

The external entry site of the injury was the neck in 31 (70%) of patients and chest wall in 13(30%). (Figure 1) Pulse deficits were noted in only 4 patients (9%) and all had subclavian artery injuries.

Thirty-seven patients underwent chest radiography and the findings are noted in Table II. The 2 patients with no chest radiological abnormality had injuries of the aortic arch and subclavian artery respectively. Seven patients were judged too unstable to undergo any preoperative chest X-ray and were operated on immediately. Widening of the mediastinum (>8cm) was the most prevalent abnormality occurring in 26/37 (70%) of patients and was the indication for requesting subsequent angiography in 22 of these patients. Angiography showed a false aneurysm, extravasation of contrast medium or an arteriovenous fistula in 21 patients (Table III). There was one patient with a false negative angiogram who was subsequently shown to have an injury to the left subclavian artery. The procedural delay for performing of angiography resulted in one patient decompensating in the angiography suite but without major sequelae following resuscitation and thoracotomy for repair of a wound to the descending aorta.

SURGICAL APPROACH AND FINDINGS (Table IV)

Median sternotomy with or without extension into the neck was the most commonly used incision (32 patients, 73%) which provided excellent exposure for injuries in the superior mediastinum. Posterolateral thoracotomy was used in 7 patients (16%), for repair of the descending thoracic aorta in 5, for repair of superior vena cava and azygous vein in one, and repair of the aortic arch in one. A "trapdoor" incision (partial sternotomy with a third interspace anterolateral thoracotomy and a supraclavicular counter incision) was used in 2 patients with left subclavian arterial injuries. A supraclavicular approach was used as the only incision in 2 additional patients with subclavian arterial laceration only.

Four patients underwent emergency room anterolateral thoracotomies for control of exsanguinating hemorrhage. Two of these patients had injuries to the left subclavian artery and 2 had aortic injuries. Of these 4 patients, 3 required further exposure for definitive management of their vascular injuries. Additional incisions employed were sternotomy in 2 and the "trapdoor" incision in another.

Cardiopulmonary bypass with hypothermic circulatory arrest was used in 2 patients - for repair of complex injury involving the innominate artery, left common carotid artery and the internal jugular vein in one and repair of the descending aorta in another. These injuries were delineated by prior angiography and allowed careful planning of their operations and preoperative preparation for cardiopulmonary bypass.

Vessel injuries sustained are illustrated in Figure 2. The innominate artery was injured in 39% of patients, making it the most frequently injured vascular structure. The left innominate vein was the most frequently injured venous structure (18%). Fourteen patients (32%) sustained injuries to 2 vessels and while 3 patients (7%) had 3 vessels injured. Only 3 patients (7%) had isolated venous injury and all presented in a hypovolaemic shocked state with hemorrhage into a chest cavity.

The mode of repair is illustrated in Figure 3. Thirty-nine (89%) of the patients' injuries were repaired by direct suture or re-anastamosis. In four patients (9%), interposition grafts of polytetraflouroetheylene (PTFE) were inserted for transections of the left subclavian artery in 2, transection of the left common

carotid artery in one, and of the innominate artery in another. In one patient the innominate vein was ligated.

ASSOCIATED INJURIES AND OUTCOME

Injuries to thoracic viscera were noted in 13 patients (30%) patients. Penetration of the esophagus (n=1), trachea (n=2) and heart (n=1) was noted during surgery and repaired immediately without morbidity. In 9 patients there were associated minor laceration of a lung that did not require surgical repair and closed with thoracostomy tube drainage only.

Death occurred in 2 patients who had suffered hypoxic brain injury from sustained hypotension prior to admission and did not regain consciousness post-operatively, for a mortality rate of 5%.

Seven patients (16%) suffered significant complications. Two patients developed a disseminated intravascular coagulopathy secondary to massive blood loss and transfusion, one of whom required reopening of his thoracotomy for ongoing surgical bleeding. Both patients recovered completely. One patient developed a transient left hemiparesis following repair of a transected innominate artery and subsequently recovered completely. A further 2 patients developed sternal sepsis and post-operative pneumonia respectively, which resulted in a prolongation of their hospital stay. One patient sustained paraplegia from a low velocity gunshot wound to his chest and spine while another had a brachial plexus injury from his stab wound, both with limited recovery.

DISCUSSION

Intrathoracic great vessel injury continues to be a challenging problem. This in an uncommonly encountered injury clinically due to the small target area, the protective barrier of the skeletal structures of the thoracic inlet and the lethal nature of such injuries. Over a 6 month period in 1991, 6 out of 491 patients (1,2%) seen at our trauma unit with penetrating trauma had injuries to the non pulmonary great vessels, of which only 1 survived.(1) A survey performed over the same period at our regional mortuary produced 67 victims who died from the same type of injuries. This would indicate a survival rate of 1,4% (1/73), emphasizing the lethality of such injuries. In hospital mortality for penetrating arterial injury of the aorta and its branches is reported as 16,7% in the most recent reported series (2). Earlier mortality

rates were as high as 30% (3). Rapid transport to hospital and adequate resuscitation, which may include resuscitative thoracotomy, remains the key to satisfactory outcome. The mortality figures for our patients is low at 5% and several factors contribute to this. Patients who underwent failed resuscitative thoracotomies are not included which accounted for 12,9% of the patients in the Memphis study (2). These patients were managed by the trauma unit staff and were only referred to our department if resuscitative thoracotomy was successful in salvaging the patient. As well, in our population, delay in transport may select a subset of stable patients with salvageable injuries. As yet in South Africa the proportion of gun shot wounds to stab wounds remains low although this is not true for all areas.(4,5) The more lethal nature of gunshot wounds in regard to vascular trauma is well known. Only 4,8% of our patients sustained gunshot wounds while in the Memphis series (2) this figure was 63,5% and is as high as 79% in Houston(6). Mortuary statistics are presently being evaluated for comparison. Our low mortality may thus reflect a natural preselection of less severely injured patients who are able to reach hospital alive.

The majority of patients were young male victims of assault. The site of injury was the neck in 70% of patients, as the assailant presumably stabs in a downward direction resulting in injury to the vessels of the mediastinum via the neck. When such an injury is combined with hypovolaemic shock as a result of internal or external hemorrhage and either evidence of ongoing hemorrhage or with radiological abnormalities suggestive of mediastinal penetration, then surgical exploration should be immediate. The seriousness of the injury may not be recognized unless a high index of suspicion is maintained as up to 32% of patients with significant vascular injury have no specific clinical signs.(3)

Of the patients having chest X-rays, 95% had some abnormality with the most useful predictive radiological feature being widening of the mediastinum, which was noted in 59% of our patients. However these findings are non specific and angiography is therefore required in the stable patient to confirm the diagnosis and to allow planning of surgical approaches. It must be emphasized that it should be done expediently so as not to delay surgical intervention in what may be a temporary stable situation.(8) False negative studies do occur in up to 23% of injuries studied and if there is still suspicion

of significant vascular injury after angiography, exploration must be considered.(9) Urgent surgical repair rather than angiography is indicated in the unstable patient.

Numerous surgical approaches are advocated for repair of these injuries . Median sternotomy with or without neck extension was suitable for 73% of patients and superior mediastinal injuries involving the right subclavian artery, innominate artery, both common carotid arteries, ascending aorta and aortic arch can be easily controlled through this incision. This concurs with the experience in other centers (2-4,7,10). In addition cardiopulmonary bypass can be instituted through the same incision if uncontrolled hemorrhage is encountered and if angiography suggests that occlusion of both carotid arteries is anticipated or in complex injuries involving the aortic arch and the origin of the head and neck vessels.(10) Left subclavian arterial injuries can be managed through a variety of incisions, either a "trapdoor incision", median sternotomy, anterolateral thoracotomy with or without a supraclavicular incision or through a posterolateral thoracotomy.(2,4,8,13) As 38% of our patients had injuries to more than one vessel we feel that the trapdoor incision to be the more versatile of these options. A limited supraclavicular incision was used successfully in 2 patients, however adequate proximal and distal control may be difficult to obtain.(8)

Descending thoracic aortic injuries are best approached through a posterolateral thoracotomy.(13) If an emergency anterolateral thoracotomy was required for resuscitation then this incision can be extended laterally to allow adequate access in most cases. Resuscitative thoracotomy is indicated for patients with vital signs present immediately prior to admission or the witnessed cardiorespiratory arrest, otherwise the salvage rate is extremely poor.

The use of temporary vascular shunts in order to prevent interruption of cerebral blood flow are advocated by some for injuries of the carotid or innominate arteries.(2,12,14) However, Johnston et al. routinely use permanent bypass shunting for repair of innominate arterial injuries.(15) We have not used shunts for distal perfusion but experience in other centers suggests that their application with such injuries is attractive to prevent neurological damage. In addition there is consensus in the literature that carotid arterial injuries should be repaired even in the presence of neurological deficit (10,16,17). The

neurological signs encountered in these patients are most likely due to hemispherical hypoperfusion and restoration of flow should be accomplished as soon as possible. Patients in coma, however have a poor prognosis regardless as to whether ligation or reconstruction of the carotid arteries is undertaken.(17) We have reservations about the use of prosthetic graft material implantation in the presence of potential sepsis, particularly if there is associated hollow viscus injury, and would prefer to use autogenous vein. In practice we have used PTFE without any infective complications.

Although the subclavian arteries can be ligated fairly safely (3), we have not found this necessary in the incised and low velocity injuries seen, as interposition grafts are readily available for reconstruction if direct repair cannot be undertaken.

Venous injuries are associated with a significant mortality, accounting for 22% (16/73) of fatalities in victims of penetrating chest injuries of the major vessels of the thorax (1). These patients may present with exsanguination into a chest cavity. Ligation of the innominate and subclavian veins is associated with some morbidity in terms of transient swelling but no long term problems occur in most cases.(18) Repair of these delicate structures can be difficult in the presence of massive hemorrhage from associated arterial lacerations and it may be expedient to ligate these venous structures.

In conclusion, intrathoracic major vascular injury is an uncommon but important surgical problem and requires early recognition and treatment. Approaches have been refined over the years and there is presently a high degree of consensus among authorities on this subject. Useful adjuncts which make the operative procedure safer include the use of shunts in innominate artery and carotid injury , as well as cardiopulmonary bypass with hypothermia for complex injuries or partial heparinless bypass for descending aortic injuries requiring aortic cross clamping.

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Table I

Admission Status and Outcome.

ADMISSION STATUS	DEFINITION	N (%)	COMPLICATIONS	DEATHS
LIFELESS	ABSENT CARDIAC AND RESPIRATORY ACTIVITY	1(2%)	NIL	NIL (survived)
MORIBUND	UNRECORDABLE BLOOD PRESSURE AND REDUCED LEVEL OF CONSCIOUSNESS	5(11%)	N=3: -DIC, -STERNAL SEPSIS, -REOPERATION.	1
UNSTABLE	BLOOD PRESSURE < 90/60, POOR PERIPHERAL PERFUSION	20(46%)	N=5: -HEMIPLEGIA -DIC -PARAPLEGIA -BRACHIAL PLEXUS INJURY -PNEUMONIA	1
STABLE		18(41%)	NIL	NIL;
TOTAL		44	8 (16%)*	2 (5%)

- One patient had 2 complications- 7/44 patients to give a rate of 16%

Table II

Chest X-Ray Features of Patients on Admission.

CHEST-XRAY FEATURES	n=37
NORMAL	2 (5%)
PNEUMOTHORAX	1 (2,5%)
WIDENED PARATRACHEAL STRIPE	1 (2,5%)
WIDENED MEDIASTINUM	26 (59%)
HAEMOTHORAX	12 (27%)

(5 patients had more than 1 radiological abnormality)

Table III

ANGIOGRAPHIC FINDINGS	N=22
FALSE ANEURYSM	10
EXTRAVASATION OF CONTRAST	6
AV FISTULAE	5
FALSE NEGATIVE	1

Table IV

SURGICAL APPROACH	n=47
MEDIAN STERNOTOMY	24
MEDIAN STERNOTOMY + NECK EXTENSION	8
POSTEROLATERAL THORACOTOMY	7
TRAPDOOR	2
SUPRACLAVICULAR INCISION	2
EMERGENCY ROOM THORACOTOMY	4

Figure 1

Site of External Injury.

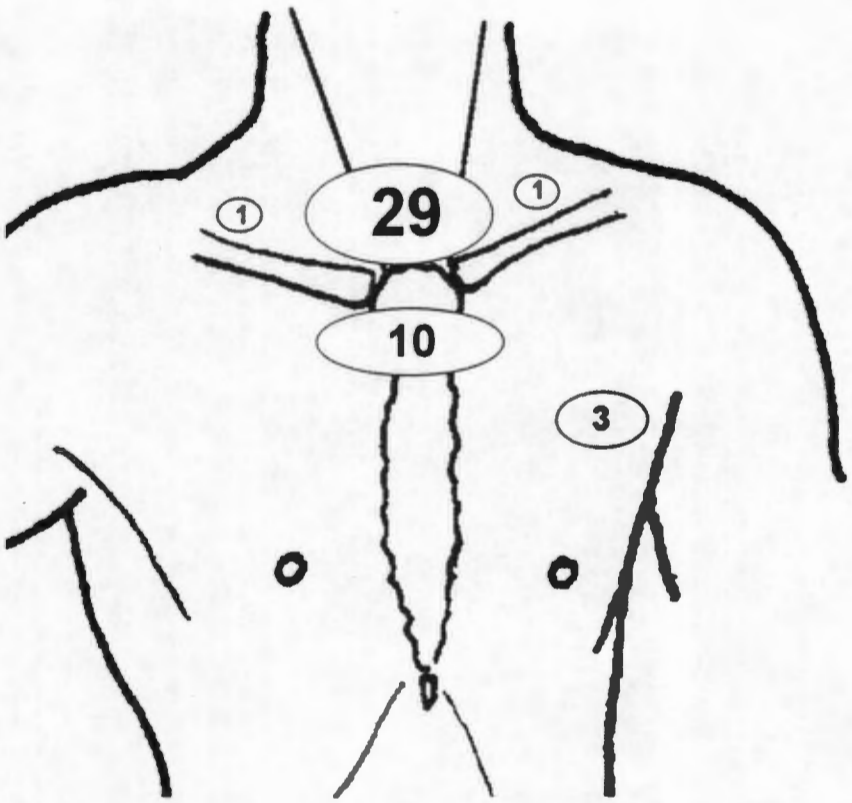


Figure 2

Vascular Injuries Noted at Surgery.

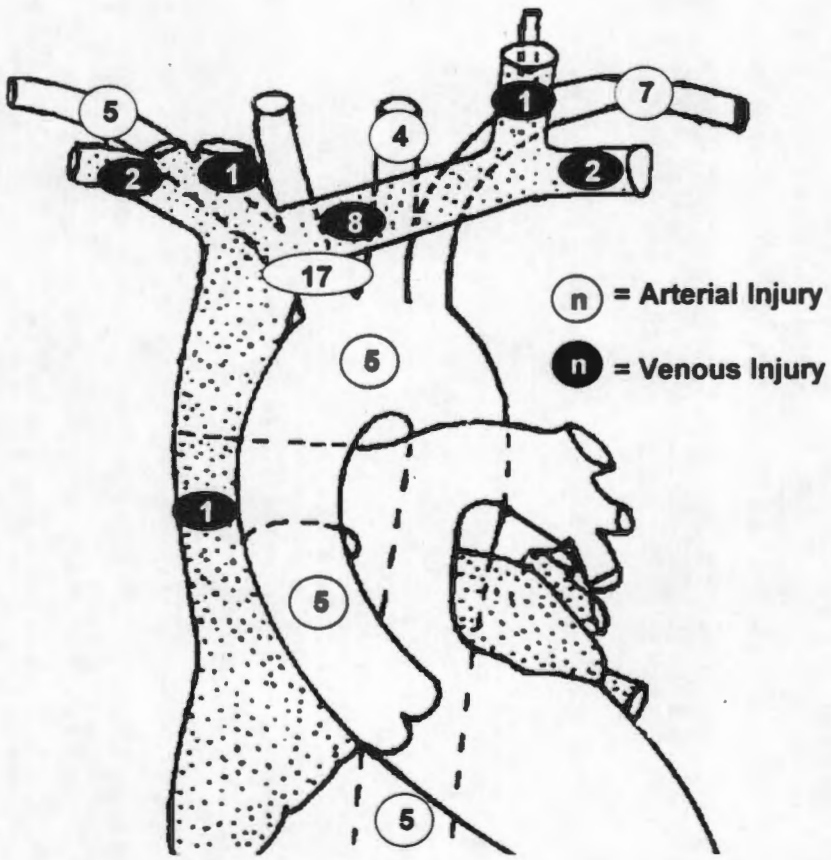
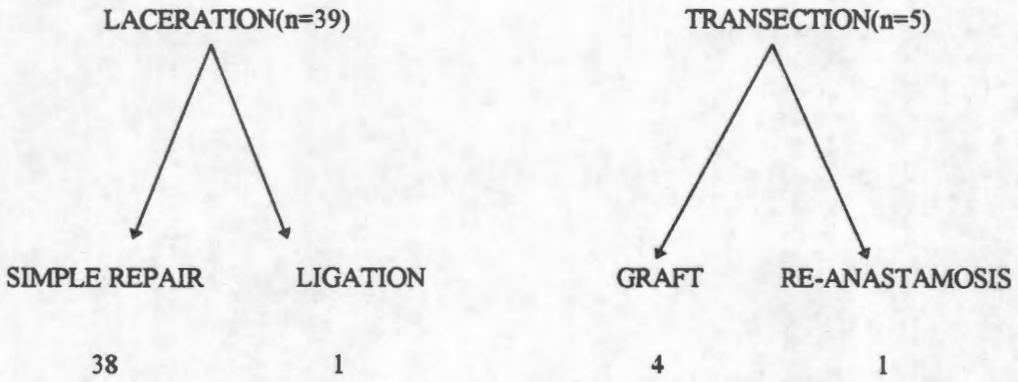


Figure 3

Methods of Repair Employed to Major Vessel Injured.



TITLE

STAB WOUNDS OF THE INNOMINATE ARTERY

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ABSTRACT

Background: Innominate artery stab wounds are rarely encountered and the optimal management of this injury is different to blunt innominate injury in that permanent bypass shunting should not be necessary.

Methods: The records of nineteen patients with stab wounds of the innominate artery who were treated by our department from January 1982 to June 1995 were reviewed.

Results: Eighteen patients (95%) sustained zone 1 neck stabs with a similar proportion having only a single stab wound. Seventeen (89%) of the 18 patients having chest X-rays had mediastinal widening. Thirteen patients (68%) were hemodynamically stable on admission with the remainder being unstable (26%) or moribund (5%). Fourteen patients (74%) underwent angiography with no false negative studies for arterial injury. Associated injuries to thoracic viscera occurred in 4 patients (21%). All injuries were repaired with either direct suture (18/19) or with prosthetic interposition grafting (1/19). One patient required cardiopulmonary bypass to repair complex injuries. Overall mortality was 5% (1/19) and complications occurred in 2 patients (11%).

Conclusions: Innominate artery stab wounds can be successfully managed without permanent bypass shunting and with a low mortality

KEY WORDS: Innominate artery, stab wounds, repair.

RUNNING TITLE: Innominate artery stab wounds.

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INTRODUCTION

Innominate arterial injuries are uncommon. None were documented in large series' of vascular injuries in both World War I and II (1,2), while Rich and his colleagues documented only 3 innominate artery injuries during the Vietnam war.(3) However, in civilian practice in the United States, injuries to the innominate artery have been well documented, although infrequently. The most common mechanism of injury is low velocity gunshot wounds followed by stab wounds.(4 -16) As a result the experience with stab wounds to the innominate artery is limited and so it is difficult to establish whether permanent bypass shunting as recommended in 2 recent studies should be performed in all of these injuries.(4,5) We have therefore evaluated our results to attempt to clarify this issue.

MATERIALS AND METHODS

We retrospectively reviewed all patients treated by the department of cardiothoracic surgery at Groote Schuur Hospital between January 1,1982 and June 30,1995 with innominate arterial injuries. We reviewed their hospital records in regard to the mechanism and external location of injury, clinical status on admission, radiological features, vessels injured, surgical approaches, method of repair and outcome. Records of all patients treated by the department of cardiothoracic are kept on a computerized data base and allowed for sourcing of the patients' records.

RESULTS

Nineteen patients with innominate arterial stab wounds were treated during this 13 year period. Their age ranged between 18 and 46 years (mean age 26 years) with 17 being males (90%) and 2 females (10%).

CLINICAL STATUS ON ADMISSION

Thirteen patients (69%) were hemodynamically stable on admission, 5 (26%) patients were in shock (defined as blood pressure < 90/60 and signs of hypovolemia) and one patient (5%) was moribund. All patients were immediately assessed and resuscitated by the trauma unit staff and referred to the department of cardiothoracic surgery. No patient required resuscitative thoracotomy.

The site of entry of the stab wound was zone 1 of the neck in 18 patients (95%) with another patient having an entry wound immediately adjacent to the left side of the manubrium. No patients had pulse deficits or neurological impairment on admission.

All patients except the moribund patient had chest X-rays prior to surgery. A widened mediastinum was apparent in 18 patients (89%) including 6 patients with a hemothorax in addition to mediastinal widening. One patient (5%) had an isolated hemothorax without other abnormalities. Fourteen patients (73%) underwent angiography. All fourteen angiograms were abnormal revealing extravasation of contrast in 4 (29%), false aneurysm formation in 7 (50%) and arteriovenous fistulae in 3 (21%). All patients underwent surgery expediently.

SURGICAL APPROACH AND FINDINGS

Median sternotomy alone was used in 12 patients (64%), median sternotomy with neck extension in 6 (32%) and a trapdoor incision (anterolateral thoracotomy combined with partial sternotomy and supraclavicular incision) in 1 patient (5%). Injuries to other vascular structures was noted in 9 patients (50%). (Figure 1)

In all patients proximal and distal control with clamping of the innominate artery was necessary. Direct suture repair was possible in 18 (95%) with interposition graft of Goretex necessary in 1 patient (5%) with transection of the innominate artery. Cardiopulmonary bypass with deep hypothermia and total circulatory arrest was used in one patient with injuries to the internal jugular vein and left common carotid as well as the innominate artery. Temporary shunting was not used in any patient while the innominate artery was clamped.

Associated injuries to the intrathoracic viscera occurred in 4 patients (20%). Penetration of the esophagus (n=1) and trachea (n=2) was noted during surgery and repaired immediately without morbidity. The lung was injured in 2 patients and this was not repaired but managed with tube thoracostomy only.

Death occurred in 1 patient who had suffered hypoxic brain injury from sustained hypotension prior to admission and did not regain consciousness post-operatively, for a mortality rate of 5%.

One patient developed a transient left hemiparesis following repair of his transected innominate artery and subsequently recovered completely. Otherwise all patients made an uncomplicated recovery.

DISCUSSION

Penetrating innominate artery injury is a rarely encountered clinically due to the small target area, the protective barrier of the skeletal structures of the thoracic inlet and the lethal nature of such injuries. Stab wounds of the innominate artery were responsible for only 8 out of 5760 vascular injuries over a 30 year period in Mattox's study.(17) The 19 patients treated by us is the largest group of surviving patients with stab wounds of the innominate artery in the available literature. Stab wounds accounted for 7 patients in Johnston's study, with 3 deaths for a mortality rate of 42,9% against a mortality rate of 24% for gunshot wounds and 14,3% for blunt trauma, suggesting that stab wounds carry a higher mortality compared to other mechanisms of injury.(5) This may be as a result of low velocity gunshot wounds tending to cause more severe arterial injury (i.e. transection) and resultant vasospasm preventing exsanguination.(6) Stab wounds result in local incised injury and less vasospasm with consequent ongoing bleeding. Our mortality rate of 5% is low and several factors could account for our discrepant experience. The poor availability of rapid transport and early resuscitation facilities result in deaths prior to reaching hospital. In addition, most bullet wounds in our experience are medium or high velocity and are rapidly fatal when there is mediastinal penetration. Furthermore, a lower incidence of hemodynamic instability (31% as compared to between 43-76% in other studies (5,7)) in our patients suggests selection of the less severely injured patients reaching hospital.

Zone 1 neck stabs should alert the surgeon to the possibility of innominate arterial injury, as this was the case in 95% of our patients. Other clinical signs such as pulse deficit and neurological fallout are unreliable indicators of major thoracic vascular injury.(7) The high incidence of associated vascular and visceral injury with these wounds is not surprising as the close proximity of these structures to one another at the thoracic inlet is well known. Our findings of associated tracheal, esophageal, pulmonary and vascular injury in 60% of patients is consistent others experience.(5,7,8,16) This mandates that the surgeon must meticulously explore the tract of the wounding instrument to avoid missing occult injury.

Preoperative esophagograms are not necessary if surgical exploration is indicated and only delays definitive management.

Although 90% of patients had a widened mediastinum on its own or with other abnormalities on chest X-ray, it is a nonspecific finding but should alert one to the presence of possible significant vascular injury. All 14 patients undergoing angiography had recognized vascular injury. Although a false negative arteriography study rate of up to 23% is reported in penetrating arterial injury, it remains an essential investigation in the stable patient in order to plan surgery.(13,15)

The surgical approach advocated for repair of these injuries is median sternotomy with or without neck extension.(4,5,6,7-16) This incision was used in all but one patient with excellent exposure and allows repair of both vascular and visceral injuries. In addition cardiopulmonary bypass can be instituted through the same incision in the event of complex vascular injuries. We discourage the use of a partial sternotomy is advocated by some authors.(6) Although there may be increased morbidity with a full sternotomy, all patients were still discharged within 10 days of admission.

When the surgeon is faced with a large mediastinal hematoma and ongoing bleeding, digital pressure with simultaneous opening the pericardium and following the ascending aorta cephalad allows location of the innominate artery at its origin from the aortic arch and proximal vascular control.(9)

Ninety five percent of injuries were repaired with direct suture using a non absorbable monofilament suture. The clean incised injuries to the vessels encountered in stab wounds are usually easily identified and repaired with this method. In a single patient with a transected innominate artery, an interposition graft of polytetraflouroethylene was used. This patient had a transient hemiparesis which recovered completely. We were unable to be certain that this deficit did not exist preoperatively owing to the shocked and intoxicated state of the patient. In no case did we use temporary shunting to the common carotid artery as is advocated by some authors.(4,12) The use of shunts for cerebral perfusion is attractive but when faced with copious hemorrhage, time may be wasted inserting a shunt. We agree with Grahams recommendation that intra-arterial shunting should be reserved for those cases where simultaneous occlusion of both the innominate and left carotid arteries may be necessary.(8) The approach to routinely

use permanent bypass shunting for repair of all innominate arterial injuries is not necessary for stab wounds. However, in stab wounds with involvement of the innominate artery close to its origin from the aortic arch, this approach is useful but cardiopulmonary bypass with hypothermia could be used in preference if the location of injury is known preoperatively.(4) In most patients we have encountered active bleeding on opening the chest and rapid control of hemorrhage is required. Once vascular control is obtained, repair of the injury can be accomplished in an orderly manner.

In conclusion, an individualized approach to this uncommon injury is essential. The surgeon must take into account the mechanism and site of injury, the patients hemodynamic status and associated injuries to manage innominate arterial injuries safely. He should also be familiar with all the adjunctive modalities available for the surgical management of these rare injuries in order to carry out the most appropriate surgical treatment.

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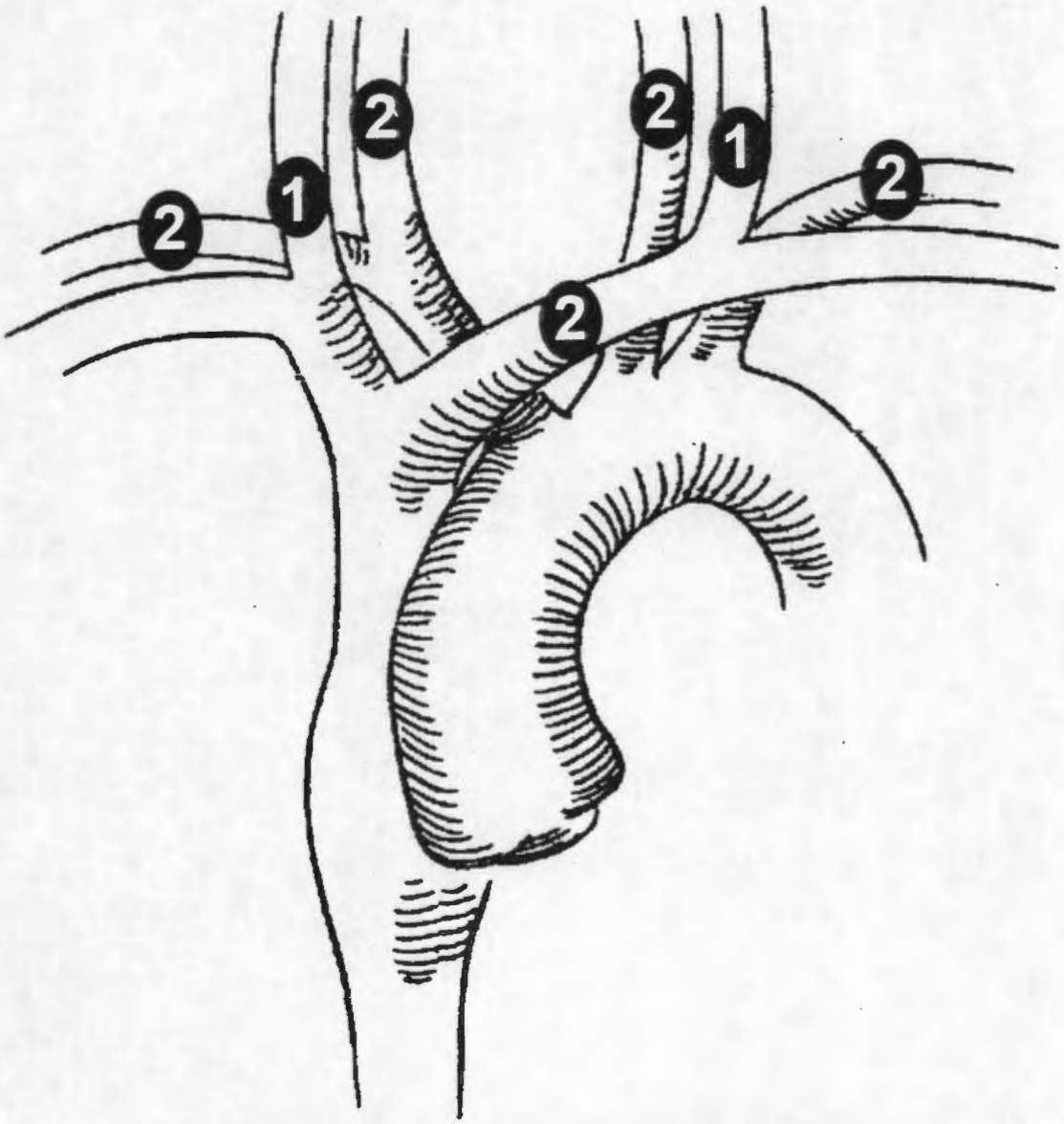
FIGURE 1:

Twelve associated vascular injuries involving 7 vessels which occurred in 9 patients - one patient had 3 vessel injuries and another 2 vessel injuries.



Case Report

COMPLEX THORACIC VASCULAR INJURY REPAIR USING DEEP HYPOTHERMIA AND CIRCULATORY ARREST

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ABSTRACT:

A 61 year old man with a penetrating injury to the innominate artery, left common carotid artery and left subclavian artery at their origins from the aortic arch with associated injuries to both innominate veins and an innominate artery to vein fistula following a single stab wound is described. The patient was managed successfully using cardiopulmonary bypass together with deep hypothermia and circulatory arrest (DHCA). Presentation and management are discussed.

Key words: Aortic arch vessels, penetrating vascular injury, hypothermic circulatory arrest.

Running title: Complex vascular injury.

Annals of Thoracic Surgery-in press-1996.

INTRODUCTION:

Few patients with extensive injuries to the major arterial structures at the thoracic inlet have been reported, as rapid exsanguination into the pleural cavity or externally through the wound usually follows.(1-4) Injuries of the aortic arch vessels close to their origins are particularly difficult to control and cardiopulmonary bypass with systemic hypothermia is an important adjunct to ensure a successful outcome.(1,3,4) We describe a patient with involvement of all three branches of the aortic arch and of both the major veins of the thoracic inlet who was managed successfully.

CASE REPORT:

A 61 year old black male was referred to the Department of Cardiothoracic Surgery at Groote Schuur Hospital, University of Cape Town from a peripheral hospital following a stab wound to his right chest at the level of the second right intercostal space parasternally. On arrival at our hospital 28 hours after his injury he was hemodynamically stable with a continuous murmur at the right parasternal border and his chest X-ray revealed a widened mediastinum with evidence of previous lung and pleural disease involving his right lung. He had undergone a previous right thoracotomy for empyema thoracis 18 years previously. An aortic arch angiogram was ordered and is illustrated in figure 1, showing the extensive vascular injuries.

The patient was taken to the operating room and under general anesthesia, the left femoral vein and artery were exposed. The vessels were cannulated and cardiopulmonary bypass with systemic hypothermia was commenced. Inadequate venous drainage resulted in only 50% of target pump flows being used initially but systemic perfusion pressures remained adequate during initial cooling. Ventricular fibrillation occurred at 28 degrees C which necessitated immediate median sternotomy due to systemic hypotension. Torrential hemorrhage was encountered and a brief period of circulatory arrest was needed to allow insertion of a second venous cannula into the right atrium. Full cardiopulmonary bypass was then resumed with digital compression of the bleeding areas with cooling to 20 degrees Celsius. Active hemorrhage continued during this cooling phase. At 20 degrees Celsius, circulatory arrest was resumed and the ascending aorta was cross clamped and cold crystalloid cardioplegia was administered via the aortic root.

The innominate artery was lacerated though two thirds of its circumference and the left common carotid and left subclavian arteries sustained through and through lacerations in close proximity to their origins from the aortic arch. The left innominate vein was lacerated in close proximity to the innominate artery laceration, resulting in an arteriovenous fistula and the right innominate vein was lacerated at the site of entry of the subclavian vein. Adequate exposure for repair of the arterial injuries could not be accomplished from an extraluminal approach due to the proximity of the injuries to their origins from the aortic arch and extensive hematoma in the adventitial planes. An anterior longitudinal incision in the aortic arch incorporating the innominate artery laceration was employed to facilitate transluminal repair. The lacerations in the subclavian and carotid arteries were repaired with continuous 5/0 polypropylene sutures from inside the aortic lumen while the innominate artery repair was included in the closure of the aortotomy incision using 4/0 polypropylene. Prior to tying this aortotomy suture, the patient was placed in steep Trendelenberg position and cardiopulmonary bypass was recommenced at low flows to facilitate deairing of the aorta and head and neck vessels. Full cardiopulmonary bypass was then reinstituted with rewarming to normothermia and the aortic crossclamp was released. Repair of the innominate veins was then accomplished using 5/0 polypropylene sutures. The right internal mammary vein, which was also lacerated, was ligated. At a temperature of 25 degrees Celsius normal sinus cardiac rhythm ensued and weaning off cardiopulmonary bypass occurred at normothermia without difficulty. Decannulation of the right atrium and femoral vessels followed. Closure of the sternum and groin incisions was accomplished in routine fashion.

Total circulatory arrest time was 40 minutes.

The patient was ventilated overnight and was extubated the following morning with no neurological deficit apparent. His recovery was otherwise uneventful and he was discharged home on the 10th post operative day. At a follow up visit 2 weeks later he remained in good health.

DISCUSSION:

Injuries to the major vascular structures of the thoracic inlet are well described.(1-5) Complex injuries similar to the one described in this patient are exceedingly rare and usually cannot be repaired without the adjunct of cardiopulmonary bypass. The usual mode of presentation is that of

hypovolemic shock and rapid exsanguination at the scene of injury and even with rapid resuscitation and transport facilities, the likelihood of survival is remote. The presence of dense pleural adhesions in his right chest from his previous suppurative lung disease and subsequent thoracotomy probably prevented exsanguination in this patient. A massive mediastinal hematoma tamponaded further bleeding. We also speculate that the arteriovenous fistula between the innominate artery and left innominate vein resulted in reduction of the tendency of these vessels to bleed further into the mediastinum. Hemodynamic stability allowed angiography to delineate the severe nature of his injuries. Without this knowledge, rapid demise from bleeding would certainly have followed median sternotomy.

Even on cardiopulmonary bypass, torrential hemorrhage was encountered at sternotomy necessitating the use of deep hypothermia and periods of circulatory arrest. This technique has found increasing use since first instituted for aortic surgery in adults by Griepp and provides for a safe period of 45 minutes of circulatory arrest.(6) The extension of this safe period of arrest with antegrade or retrograde cerebral perfusion could not be accomplished in this patient due to the extensive nature of his arterial and venous injuries and surrounding hematoma. Cardiopulmonary bypass with systemic hypothermia is also advised in patients where occlusion of both innominate and left common carotid arteries with interruption of cerebral blood flow is anticipated, as well as in injuries close to origins of the head and neck vessels from the aortic arch. Major injury to the aortic arch itself usually requires cardiopulmonary bypass with deep hypothermia and periods of circulatory arrest for successful repair.(1,4) Unfortunately in the setting of the unstable patient, other techniques have to be used as rapid institution of cardiopulmonary bypass is not possible in many trauma operating rooms.(1,3,4)

The repair of the lacerations to the origins of these vessels could only be accomplished with the use of DHCA as extensive hemorrhage and hematoma prevents adequate exposure of the vessels and their sites of injury while the circulation is maintained.

The use of a transluminal approach in this patient resulted in superior exposure of the injuries and thus greatly facilitated repair. Extensive mobilization of the peri-aortic soft tissues to identify the sites of injury in the extensive surrounding hematoma is often difficult and can result in injury to non-

vascular structures. Injuries to the posterior aortic wall (including through and through injuries) and the inferior surface of the aortic arch could also be repaired in this fashion

In conclusion, we recommend cardiopulmonary bypass and DHCA in the management of complex vascular injuries of the thoracic inlet with angiography to allow adequate planning of surgery in the patient who is hemodynamically stable. In the unstable patient, when such extensive injury is suspected, the expeditious institution of femoro-femoral cardiopulmonary bypass (without prior angiography) with systemic cooling, DHCA and the identification and repair of vascular injuries may be the only recourse for a successful outcome. When isolated single major vascular injuries of the thoracic inlet are confirmed on angiography, these can be repaired without the adjunct of cardiopulmonary bypass.(1-4)

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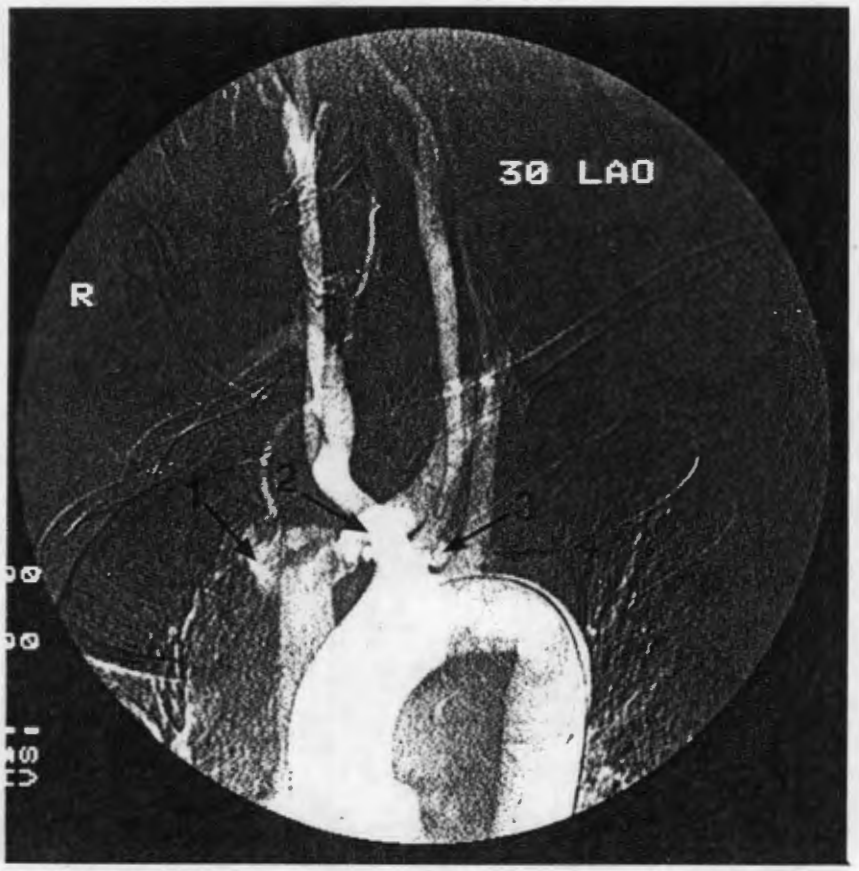
Figure 1

Arch: angiography illustrating all the injuries:(1): right innominate vein; (2): innominate artery false aneurysm with innominate artery to left innominate vein fistula with opacification of the great veins; (3): false aneurysm of the origin of the left common carotid artery; (4): false aneurysm of the origin of the left subclavian artery.



Case Report

PROFOUND HYPOTHERMIA AND TOTAL CIRCULATORY ARREST IN THE MANAGEMENT OF A MASSIVE FALSE ANEURYSM OF THE SUBCLAVIAN ARTERY.

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ABSTRACT:

The surgical management of a massive traumatic false aneurysm of the junction of the right subclavian artery with the innominate artery following a stab wound 4 months prior is described. Surgical alternatives are discussed.

Key words: subclavian artery, false aneurysm, hypothermic circulatory arrest

Vascular Surgery-in press-1996.

INTRODUCTION:

Chronic false aneurysms of the first part of the subclavian artery are infrequent following zone 1 neck stabs and usually do not attain huge proportions as hemorrhage or compressive symptoms supervene, with resultant early surgical intervention.(1) A patient with a 15 cm by 10 cm false aneurysm of his right subclavian artery-innominate artery junction is described and the surgical management of this problem is detailed because of extensive mediastinal involvement.

CASE REPORT:

A 43 year old African male was referred to the vascular service at Groote Schuur Hospital from an outlying hospital with a pulsatile mass in his anterior neck. He had been stabbed 4 months earlier in his suprasternal notch and had sought medical attention at that time. The wound was not thought to be significant and was sutured prior to his discharge home. The patient first noticed swelling in the region of his wound one month later which gradually progressed such that he was unable to turn his head to the side of the swelling and had experienced intermittent difficulty with breathing and odynophagia for a few days prior to referral to our unit. Of note was that he had been stabbed some years previously in his right chest and had required tube thoracostomy drainage.

On examination there was a large pulsatile swelling of the anterior neck extending into the right posterior triangle of the neck with displacement of the trachea to the left, and a loud systolic bruit. The patient was not in any respiratory distress and his pulse was 64 per minute with a blood pressure of 110/80. The right radial pulse was normal as was the remainder of his cardiovascular examination. On auscultation of his chest there was poor air entry to the base of his right lung with fine crepitations.

Laboratory investigation with a full blood count, INR, serum chemistry and arterial blood gas analysis was normal. His chest X-ray is shown in Figure 1 with a large well circumscribed mass located in the apex of his right hemithorax, with mediastinal shift to the left and elevation of the right hemidiaphragm due to phrenic nerve compression or transection. Computerized tomography at the level the thoracic inlet (7^{th} cervical vertebra) was then requested showing the false aneurysm with surrounding clot in the neck (Fig. 2). Marked deviation and compression of the trachea is evident.

Angiography was then undertaken and this is shown in Figure 3, confirming a false aneurysm arising from the origin of his right subclavian artery.

The patient complained of increasing shortness of breath and surgery was undertaken urgently. The only safe option was the use of hypothermic circulatory arrest for exposure of the aneurysm.

OPERATIVE PROCEDURE:

Under general anesthesia and full heparinisation, femoral vein-femoral artery cardiopulmonary bypass was commenced. The patient was cooled to 20 degrees Celsius prior to any attempt to expose the aneurysm. Once at the desired temperature, an incision 10 cm long and 1 cm above and parallel to the medial half of the clavicle was made. The sternocleidomastoid was divided at its insertion to the clavicle and the cardiopulmonary bypass flow was reduced to 300 mls per minute. At this point the aneurysm was entered and a large amount of clot was evacuated. The aneurysm cavity measured 15 cm in diameter. Clearly visible was an opening at the origin of the right subclavian artery from the innominate artery. The defect was about 1,5 cms by 1,5 cms on the antero-inferior surface of the junction of the innominate and subclavian arteries. This defect was repaired with a PTFE patch sutured in place with a continuous 6-0 polypropylene suture. After a total of 17 minutes of low flow and short periods of total circulatory arrest, full cardiopulmonary bypass flow with rewarming to normothermia was commenced. The aneurysm cavity was washed out and a drain was inserted through a separate incision, following which the wound was closed in layers. Once at normothermia, cardiopulmonary bypass was discontinued and the femoral vessels were decannulated and repaired, with subsequent closure of the groin wound in layers.

POSOPERATIVE COURSE:

The patient was ventilated electively overnight after surgery and was extubated without sequelae. He recovered well apart from right basal atelectasis which resolved prior to discharge following physiotherapy and oral broad spectrum antibiotics. The previous aneurysm cavity had reduced considerably with resolution of his airway compression as well as his diaphragmatic paresis. He had good radial and carotid pulses with no neurological deficit at discharge.

DISCUSSION

False aneurysms of the subclavian artery are well recognized complications following penetrating trauma to zone 1 of the neck, usually involving the second and third parts of the vessel.(1-3) However, the involvement of the takeoff of the subclavian artery by penetrating injury is rare, usually resulting in rapid exsanguination into the chest cavity, which is usually breached, or through the entry wound, which is most commonly in the neck.(4,5) In the small number of patients with penetrating injuries involving the intrathoracic great vessels at the thoracic outlet who reach the hospital alive, hemodynamic instability, airway compression, neurological deficit or significant radiological abnormality usually result in early diagnosis, investigation (if stable) and surgical treatment.

In our patient the prior stab wound to his right chest, which had necessitated a thoracostomy tube had probably obliterated his pleural space. When he sustained his proximal subclavian artery stab, the pleural adhesions or mediastinal structures tamponaded the injury resulting in the patients' survival and contributing to his original misdiagnosis. The large defect in the artery resulted in ongoing enlargement of the false aneurysm with tracking of the hematoma into the neck with significant compression of surrounding structures. Diagnosis was obvious at the time of referral and was confirmed by angiography and CT scan but the mediastinal extent of the aneurysm was not suspected and this limited management options

The significant degree of airway compression necessitated early surgical intervention.

The only safe surgical approaches were a median sternotomy with neck extension or femoral vein to femoral artery cardiopulmonary bypass with profound hypothermia together with a direct approach to the aneurysm (1,2,4,5). In the acute presentation the best exposure and most satisfactory control is achieved by median sternotomy with neck dissection in injuries of vessels at the thoracic outlet.(4,5) However in this patient, sternotomy would have been difficult without breaching the aneurysm with subsequent hemorrhage. The use of transluminally placed endovascular stenting has been described in the recent literature. In this case endovascular treatment was considered too hazardous due to the location of the aneurysm close to the origin of the carotid and vertebral arteries, which may have been compromised by the stent.(6)

We elected to use femoral arterial and venous cannulation, partial cardiopulmonary bypass and profound hypothermia (less than 20 degrees Celsius) with the adjunct of total circulatory arrest. Optimal operative control was then obtained which allowed the orderly conduct of the aneurysm repair without blood flooding the operative field and no significantly increased operative risk to the patient. This technique is used in aortic surgery and has been used extensively in pediatric cardiac surgery and has proved to be useful and safe.(7) At temperatures of less than 20 degrees Celsius, 45 minutes of circulatory arrest is regarded as safe in that the patient is unlikely to suffer deleterious neurological effects.(8) This was ample time to carry out the necessary vascular repair needed in our patient. Additional techniques can extend this safe period if prolonged vascular reconstruction is needed.(8)

The use of partial cardiopulmonary bypass with hypothermia and total circulatory arrest in this patient with a surgically difficult problem represents a logical extension of its use, with a satisfactory outcome.

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Figure 1:

Preoperative chest radiograph illustrating the false aneurysm of the subclavian artery with associated elevation of the right hemidiaphragm and basal atelectasis.

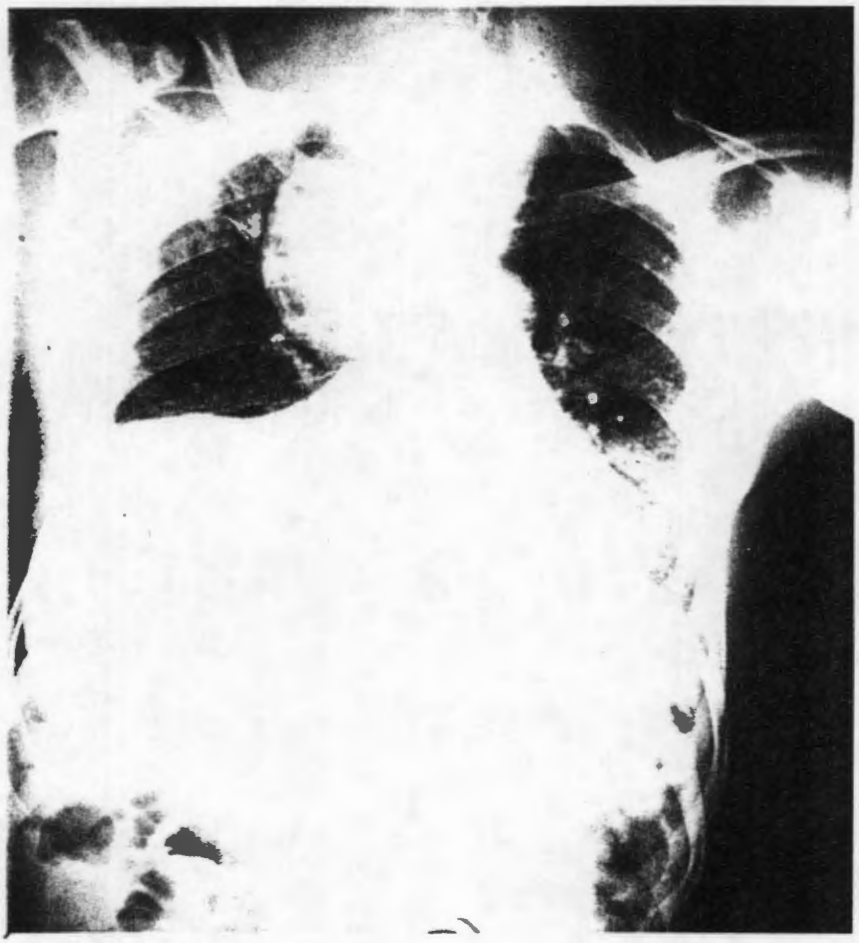


Figure 2:

CT scan at the level of the thoracic inlet demonstrating the large subclavian aneurysm (FA) with central contrast enhancement with tracheal (T) deviation and compression evident.

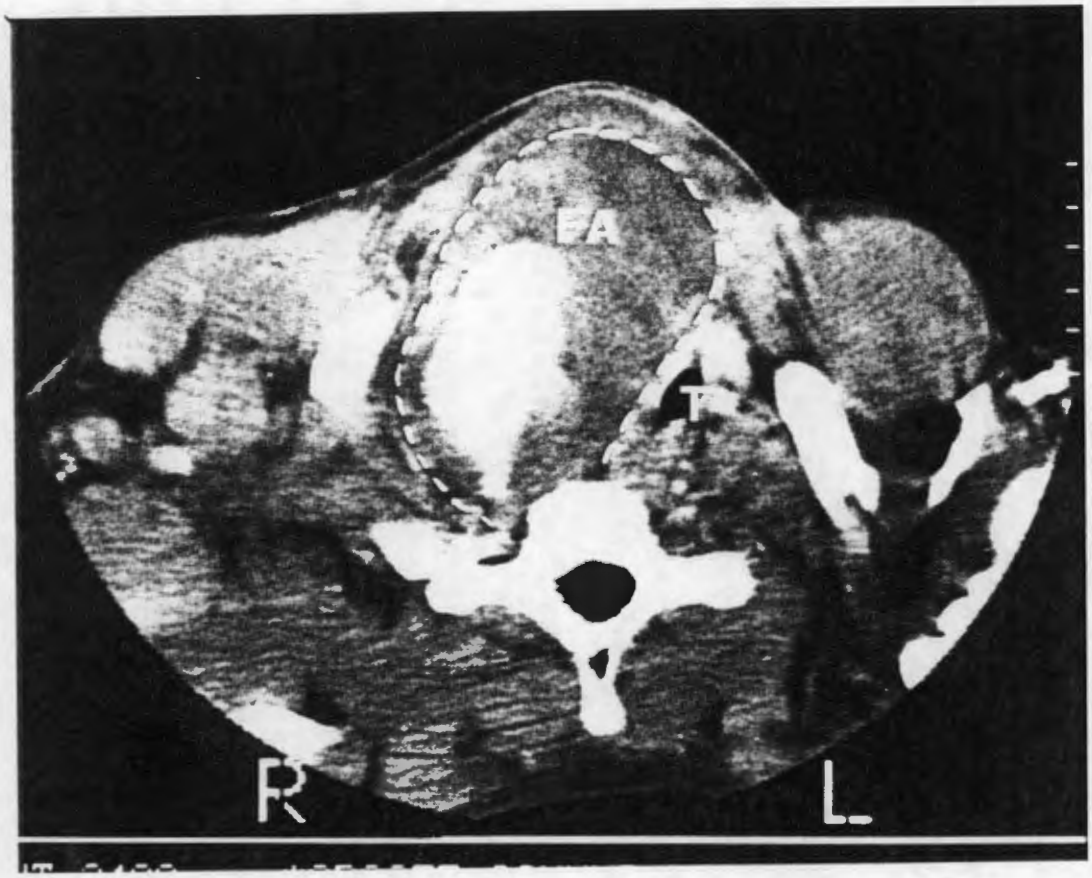
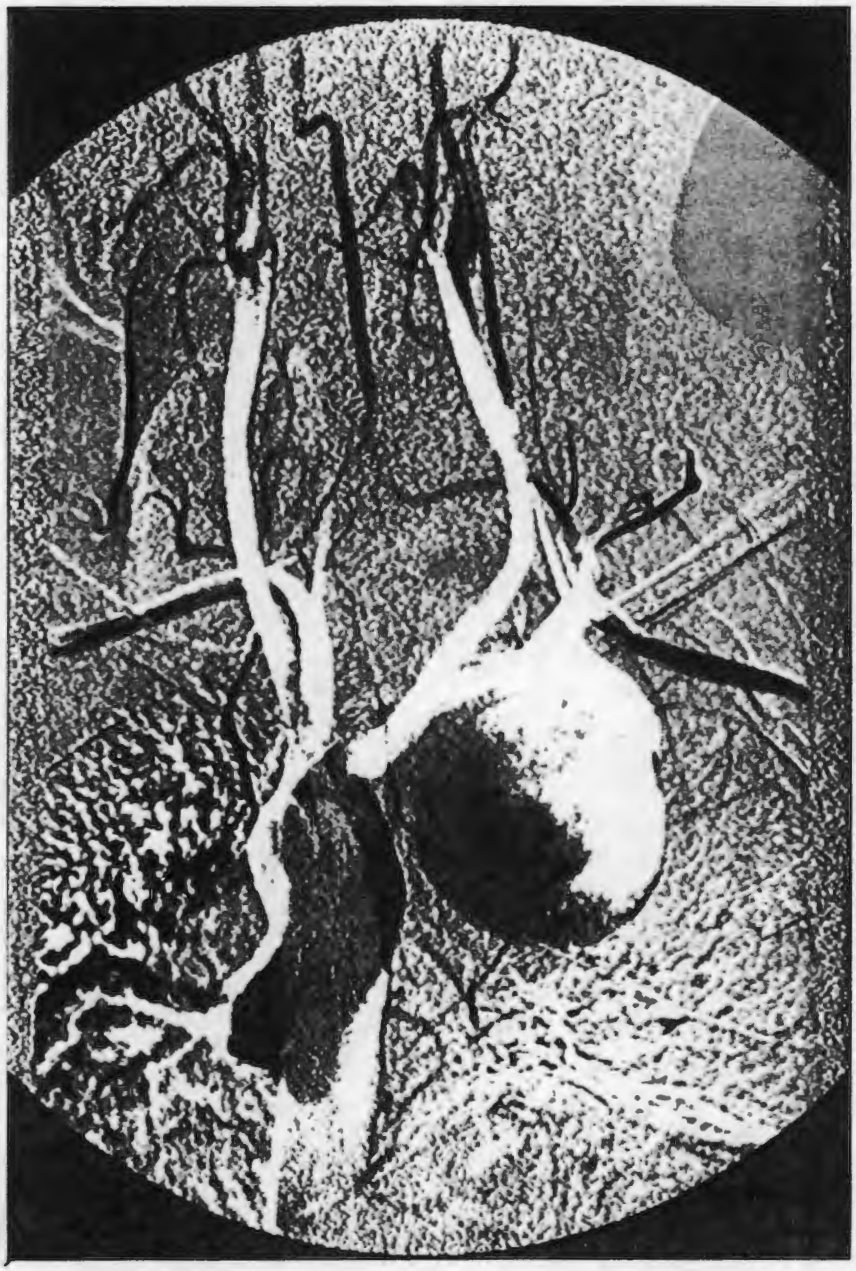


Figure 3:

Arteriogram (RAO view) clearly delineating the subclavian aneurysm expanding into the right hemithorax.



(3)

CONCLUSIONS

Management of penetrating injuries of the aortic arch and its branches has evolved over the last 40 years. The application of modern surgical techniques has reduced the in hospital mortality of these injuries from more than 30% 2 or 3 decades ago to less than 10% currently. The high mortality associated with major thoracic arterial injury is as a consequence of rapid exsanguination which follows (7,17,18,21). Numerous surgical maneuvers are described to assist the surgeon in repairing these injuries (18,22,23).

Surgical approaches to these injuries has been improved and consensus prevails in most clinical series. In the patient who is moribund, unresponsive to resuscitation or whose vital signs disappear in the resuscitation area, the surgical approach is an immediate resuscitative anterolateral thoracotomy. Additional incisions can be employed to improve exposure after initial control and will be determined by the particular vessels injured.

The patient who presents with shock and partially responds to resuscitation but cannot undergo angiography, should be immediately transported to the operating theatre. The incision of choice is determined by the suspected vascular injury. If the site of the external wound suggests penetration of the superior mediastinum (i.e. external wound located at base of the neck, adjacent to the manubrium sterni or gunshot wounds traversing the superior mediastinum) then a median sternotomy with an additional neck incision, if needed, is sufficient for exposure. If the patient presents with a penetrating chest wound lateral to the midclavicular lines and with an associated massive haemothorax, then the preferred operative approach will be a thoracotomy on the same side as the penetrating injury.

In patients who are stable enough to undergo angiography, the operative approach is then dictated by the vessel injury detected. Median sternotomy with or without neck extension is suitable for all injuries except proximal left subclavian artery, descending thoracic aortic and distal aortic arch injuries (9,10,12,18). A notable exception in the literature is the partial sternotomy approach advocated by Robbs et al as opposed to full sternotomy advocated by most authors (24). While this is an acceptable approach, the main objection to this incision is the limited exposure provided in patients who frequently have multiple vascular and visceral injuries. Other advantages of full sternotomy include access to the pericardial space, the easy institution of cardiopulmonary bypass, the adjuncts of

caval inflow occlusion with or without aortic clamping (18,22). Additionally, the easy location of the distal pericardial reflection on the ascending aorta as a landmark to locate the origins of the head and neck vessel from the aortic arch is possible through a median sternotomy (20). Artificially induced ventricular fibrillation may be initiated in the management of through and through aortic injuries via this incision as well (23). In the stable patient with proximal left subclavian artery injuries, distal aortic arch and descending aortic injuries as determined by angiography must be approached via a posterolateral thoracotomy. In more distal subclavian artery injuries, the trapdoor incision, which combines the advantages of a median sternotomy, an anterolateral thoracotomy and a supraclavicular incision is preferred (25).

Brachiocephalic artery injury is the most frequent major vascular injury in victims of penetrating thoracic vascular trauma (20,21). Our experience with stab wounds appears to differ from that reported from Baylor University in Houston who found a higher mortality for stab wounds of the brachiocephalic artery than for gunshot wounds (26). We reported our experience with brachiocephalic artery stab wounds (27) and emphasised our lower mortality rate as well as the rare use of permanent bypass shunting as has been advocated in both Memphis and Houston (18,26). Our belief is that the more frequent occurrence of gunshot wounds in the United States and the resultant extensive injuries sustained by these victims would favour bypass shunting as direct repair of the friable arterial tissue may be difficult owing to the blast effect of the missile. Stab wounds tend to produce clean cut ends that are more suitable for rapid direct repair. However in the patients with brachiocephalic arterial injuries close to their origins from the aorta, permanent bypass grafting from the intrapericardial ascending aorta to the right common carotid and subclavian arteries should be performed as proximal control may be difficult and prolonged occlusion of the brachiocephalic artery may ensue with the risk of cerebral ischaemia (21,26). Temporary shunting (e.g. Javid shunt) to ensure cerebral blood flow is also useful (7,8,18). We have not found this to be necessary as simple vessel repair can be accomplished in less than 10 minutes (27). Although only 20-50% of individuals have a complete functioning circle of Willis (28,30) neurological deficit has not been noted any patient following short periods of brachiocephalic occlusion (up to 20 minutes) (27,28). While this approach carries the risk of cerebral infarction, control of haemorrhage in the exsanguinating patient is the priority and prolonged vessel occlusion may occur once control is obtained. In the patient who

has undergone preoperative angiography, the operation may be planned according to the location and extent of the brachiocephalic or carotid injury. Test clamping of the brachiocephalic or common carotid artery, if there is a stable mediastinal haematoma, together with the measurement of distal stump pressure can be employed. If the distal stump pressure exceeds 55 mm Hg then continued occlusion of the vessel is probably safe. In the instance of vessel transection or extensive injuries and the need for interposition grafting with prolonged brachiocephalic or common carotid arterial occlusion, a temporary shunt should be used once vascular control is obtained. The presence of neurological deficits in patients with common carotid or brachiocephalic artery injuries usually indicates hemispherical cerebral hypoperfusion and repair of the arterial injury should be undertaken as soon as possible as recovery can occur with restoration of cerebral perfusion (28-30). Preoperative neurological deficit in patients with carotid injury is not a contraindication to repair. The fear of secondary cerebral haemorrhage in patients who undergo repair of carotid artery injury in the presence of neurological deficit has not been validated (29). In patients admitted with coma the prognosis is poor regardless as to whether ligation or reconstruction of the carotid artery is undertaken (26,29).

Direct suture repair of stab wounds is advocated were possible and to only resort to permanent bypass shunting in brachiocephalic arterial injuries close to the aortic arch or in patients with gunshot wounds involving the brachiocephalic artery. Temporary bypass shunting can be used in this setting as well as in common carotid injuries. Otherwise the principles of vascular surgery are applied in the management of these injuries which include tamponade of active bleeding points, proximal and distal vascular control and then full assessment of the vascular injury. In patients with minor vessel injury following gunshot wounds, direct repair is possible and likewise patients with extensive vessel injuries following stab wounds, permanent bypass shunting is preferable The intraoperative assessment of the extent of the injury is critical and the surgeon needs to be aware of all management options and the advantages and disadvantages of each.

Thoracic venous injury can present as exsanguination into the pleural space, as an arteriovenous fistula or as venous haemorrhage in a patient with associated arterial injury. Isolated venous injury in patients with an intact pleura does not require surgery as the mediastinal tissues tamponade the

venous bleeding. Rarely in the patient with a large penetrating wound, significant external haemorrhage from a venous injury may occur and exploration is indicated. Air embolism is also associated with major thoracic venous injury. All thoracic venous injuries should be repaired where feasible. In the patient who has massive haemorrhage from associated arterial and venous injuries, often with associated obliteration of the anatomical tissue planes, it may be expedient to suture ligate the injured great veins. The venae cavae must never be ligated. Ligation of the brachiocephalic and subclavian veins is associated with transient post operative upper limb oedema, usually necessitating arm elevation and local therapy, but with few long term sequelae (31,32).

Arteriovenous fistulae between the aorta and the major intrathoracic great veins should be repaired with the use of cardiopulmonary bypass. Similarly, fistulae between the **proximal** brachiocephalic artery and the brachiocephalic vein should be repaired with cardiopulmonary bypass as proximal control of the brachiocephalic artery can be difficult. For fistulae between the more distal major arteries and veins, provided proximal and distal control can be obtained, repair without the use of cardiopulmonary bypass is usually feasible and safe.

Certain injuries to the thoracic vascular structures, which are listed below, are not amenable to repair with conventional techniques. Ill advised surgery on these patients without the adjunct of cardiopulmonary bypass usually would result in rapid exsanguination. Cardiopulmonary bypass via the femoral vessels with deep hypothermia and circulatory arrest has allowed us to repair complex vascular injuries and massive false aneurysms following penetrating injuries of the thoracic arteries (33,34).

Indications for cardiopulmonary bypass are the prescence of angiographically defined injuries of the aortic arch and its branches for the following injuries and anatomical pecularities :

1. Injury to the head and neck vessels close to their origins from the aortic arch where proximal vascular control can be difficult.

2. Through and through injuries of the aorta and those with posterior aortic wall penetration where exposure and control of bleeding is difficult.

3. Injuries in which occlusion of both common carotid arteries is anticipated such as injuries to the brachiocephalic artery and left common carotid artery, the presence of a bicarotid trunk or a bouquet brachiocephalic artery (both carotid arteries and right subclavian arising from a single vessel).

4. Complex vascular injuries which can be defined as angiographically proven major injuries to 2 or more major arterial trunks with or without associated aortic injury. Included in this group would be patient with arteriovenous fistulae between major arteries and veins as well as large false aneurysms which cannot be approached with conventional surgical techniques.

5. Patients with intracardiac injuries needing simultaneous repair.

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