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THORACIC INJURIES

Critical Review*

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The surgical management of chest wounds in war time had a dramatic appeal that secured for it a good deal of highlighting. The rapid transport of chest casualties to specialised centres enabled surgeons not only to reduce the mortality rate to an astoundingly low level, when figures of the second world war are compared with those of the first, but provided a large mass of material for study and documentation. From the experience of the last war thoracic surgeons turned their attention from the almost exclusive problem of the 1914-18 war, namely pleural suppuration, to that of the restoration of lung function. Right through the medical units from the front line to the base, physiological principles were employed. Churchill (1944) always emphasised the existence of two phases of treatment, the first being the immediate correction of profound physiological disturbances by minor or major interventions, and the second the prevention or cure of infection and the restoration of lung and chest wall function. These principles still persist.

In civilian life few surgeons see many patients with chest injuries. When these injuries do occur the problems are often more complex than those encountered in military practice because, almost exclusively, the casualties are the result of road traffic accidents in which severe crushing forces tend to damage the brain, the abdominal viscera and the limbs, in addition to the all-important contents of the thorax. Gissane (1959), in a survey of 845 deaths from all injuries (excluding burns) at the Birmingham Accident Hospital between 1947 and 1956, found that eighty (10 per cent of total deaths) were the result of chest injuries unassociated with any other severe lesion. In the series, however, 370 of the deaths were from chest injuries, although 290 had associated, important lesions. Gissane indicated that one to two serious chest injuries occur each week in Birmingham (a population of about 1½ millions) and four times that number in the midland region (a population of 4½ millions).

More recently London (1963) from the same hospital analysed 551 casualties admitted in one year to the emergency resuscitation unit; ninety-three had chest injuries. Table I indicates the complexity of those problems and provides a picture very different from that seen in war time.

In considering the type of chest injury seen in civilian hospitals it must also be remembered that the patients are not fit young soldiers but include persons of all ages. Undoubtedly the co-existence of lung and cardiac disease, especially chronic bronchitis and emphysema, adds considerably to a higher mortality figure; the motor car is a more lethal weapon in these circumstances than the bullet. The car accident to the chest provides a force that spreads over a wide area of the chest; in fatal cases both sides of the thorax are often involved or the sternum is fractured, as in the case of the classical steering wheel impact.

In planning the management of the chest casualty it is important from the outset to dispel the persisting "mystique" that has so often clouded judgement. The mechanical action of the heart and the lungs is in essence simple enough: blood and air circulations are often

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hampered by readily correctable impedances. The immediate replacement of lost blood is just as important in the correction of dangerous oligæmia in chest wall injuries as in those involving the muscle masses of the limbs after these have been severely crushed. The maintenance of a clear airway and the provision of adequate ventilation of the lungs is as important in chest injuries as during the course of an anaesthetic or in the treatment of respiratory paralysis due to neurological damage: the same techniques are available in the treatment of respiratory embarrassment in chest trauma but are often employed too late. The causes of death in chest injuries are clearly understood, "the lethal triad, bleeding, drowning and suffocation" (Abrams 1961*b*). The surgeon confronted with severe limb injury associated with a head injury causing coma has no doubts as to his duty: he replaces the estimated blood loss and performs a tracheostomy. At times, confronted with a limb injury associated with severe thoracic derangement, he is inclined to falter. Somewhere in the past he has heard of the dangers of over-transfusion of blood in cardiac and pulmonary disease, and in consequence he tends to under-transfuse the chest casualty. A moment's reflection on the amount of blood that is lost, when not only the ribs have been broken by impact but the

TABLE I
NINETY-THREE PATIENTS WITH CHEST INJURIES

Chest injury only	25	Other injuries:	
Chest injury with		Limbs . . .	52
1 other injury.	36	Head . . .	30
2 other injuries	23	Abdomen . .	15
3 other injuries	6	Pelvis . . .	12
4 other injuries	3	Total . . .	109
Total . . .	93		

tearing of the intercostal muscles and of the great muscles clothing the long cage of the thorax has been extensive, will encourage him to transfuse adequately. If coma due to head injury is a call for tracheostomy, even more so is unconsciousness due to the last stages of respiratory failure.

RESPIRATORY FAILURE

In patients with chest damage respiratory failure is a far commoner cause of death than cardiac failure; no matter how complicated and multiple the associated lesions may be, respiratory failure will be the final killing factor. Failure has been defined simply as "that condition in which the amount of oxygen and carbon dioxide in the blood stream is altered by an abnormality of the respiratory system" (Arnott 1960). In the problems under discussion the patient's failure to secure sufficient oxygen to oxygenate fully the tissues or to expel carbon dioxide is due to 1) blocked airways, large and small, 2) inadequate functioning of the "bellows action" of the diaphragm and respiratory muscles, and 3) an insufficient amount of blood reaching and leaving the lungs. The immediate correction of inadequate pulmonary ventilation must take precedence over any other facet of therapy in the seriously injured patient. This is particularly so in "stove-in" chest injuries. "Patients with multiple injuries, including a stove-in chest, often die without obvious cause. Haemorrhage has been stemmed, transfusions have been given to correct shock, and ample morphine has relieved the sharp edge of pain. The sedated patient lies quietly in bed and his shallow paradoxical movements escape critical notice; but death steps in suddenly, peacefully, naturally and unnecessarily" (Barrett 1960). In this arresting sentence Barrett alerts all to the danger of pulmonary

hypoventilation. An increasing dislike of the use of oxygen tents in thoracic surgical care is based on awareness of the deceptive appearance of a quiet patient with good colour and a good pulse when so nursed, especially if sedatives have been given. It is easy to overlook the fact that the shallow respirations are failing to expel sufficient carbon dioxide. A rise of P_{CO_2} in the early stages tends to maintain or elevate the patient's blood pressure. The high oxygen content of the tent removes the stimulus of O_2 lack to the respiratory centre, which in turn becomes poisoned by the excess of carbon dioxide reaching it via the blood. Sudden death from respiratory failure is the unnecessary sequel.

CORRECTION OF DANGEROUS PHYSIOLOGICAL DERANGEMENTS

Any patient referred to hospital with a chest injury, however trivial when first seen, is assessed in an orderly way which must never omit a radiological examination. No surgeon experienced in traumatic or medico-legal work can forget the tragic, if rare, example of the "missed" ruptured spleen, or of the multiple rib fractures seen in the elderly patient who, after first-aid treatment in a casualty department, has been sent home, only to die a day or so later in respiratory failure. The effects of damage to the chest wall of the elderly "bronchitic" show their malignity hours after the injury when defective coughing allows mucous secretion to block up the bronchial tubes of an already impaired pulmonary system. A well known hazard of the "simple" rib fracture is the insidious development of a haemothorax, not apparent on the first radiograph, but leading to the return of the patient to hospital with dyspnoea, due to the displacing and compressing effect of a blood-stained effusion, which may become infected if not aspirated.

Patients with the more severe types of injury may still be deceptively well after crush injury, with fractures of several ribs, even involving both sides of the chest. Although pulmonary ventilation is clearly defective, the patient, apart from pain, may not appear to be in real difficulty. He may be warm with a good pulse due to slight increase in retained plasma carbon dioxide; the hampering of the breathing and coughing mechanisms in the early hours may not be accompanied by retention of secretions which have not yet reached a level high enough to block off the smaller air passages; it is the later onset of deficient ventilation, with retention of secretions, that causes the clinical deterioration. Coma is usually preceded by a considerable period of mental confusion. The dangers of such a state, as already noticed, may be masked if the patient is in an oxygen tent under sedation. The onset of mental confusion in a patient suffering from a crushed chest is a signal of great danger. It is usually accompanied by cyanosis, not always easy to detect clinically, especially at night, when the patient is not in an intensive therapy unit. Estimation of the oxygen and carbon dioxide content of the blood, together with that of the plasma sodium bicarbonate, obtained from arterial blood samples is often of the greatest value.

If in such a patient there is a co-existent head injury, early manifestations of mental confusion may be ascribed to the cerebral rather than to the respiratory lesion. When chest injuries accompanied a significant head injury Schrire (1962) found that the mortality rate was 31 per cent compared with 9 per cent for head injury alone. In such patients vigorous attempts to maintain efficient pulmonary ventilation are essential and tracheostomy is instituted at an early phase.

Care of patients obviously ill on admission or becoming so later—In penetrating or perforating wounds ventilatory function may be diminished from the effects of open, closed or tension pneumothorax or by the rapid development of a haemothorax. In patients with crushed chest or transverse fractures of the sternum, paradoxical respiration is the chief cause of distress. In both groups the bellows action of the breathing apparatus is impaired so that the effects of anoxia, carbon dioxide retention, lung oedema or collapse become apparent. Whether deficient ventilation is due to 1) compressive influences such as pneumothorax or haemothorax

(they are often combined), 2) airway obstruction (in the large or smaller bronchi) from mucous retention due to inefficient coughing, or 3) paradoxical chest wall movements the results of "flail" chest (Fig. 1), the patho-physiological and clinical effects can be the same. The lung or lungs become rigid because of the excess fluid in all their tissues, the reduction of the pulmonary vascular bed and the development of sudden pulmonary hypertension. Dyspnoea, anxiety, mental confusion and cyanosis provide the clinical picture, the underlying cause of which is arterial under-saturation and carbon dioxide retention. The exaggerated breathing, due to retained carbon dioxide, is replaced later by quieter breathing due to diminished sensitivity of the respiratory centre. The retention by the kidney of the body's sodium bicarbonate, in an effort to buffer retained carbon dioxide, further encourages lung oedema. Although in chest trauma death can follow from "drowning" by the aspiration of stomach contents in the act of vomiting or as a complication of rupture of the left leaf of the diaphragm after a crushing injury with stomach herniation, the usual cause of such a catastrophe is

FIG. 1

Diagram of flail chest. With these types of multiple rib fractures paradoxical breathing follows. With inspiration the black shaded areas are sucked in, and during the expiratory phase they are pushed out. Severe limitation of breathing and coughing mechanisms is obvious. Treatment by strapping is ineffective. Stabilisation by surgical fixation requires major surgery, often inapplicable in a patient with multiple injuries. The floating segment can be steadied by traction applied by attaching a light weight to two or three towel clips closed subcutaneously around appropriate ribs. In most instances severe symptoms are best relieved by tracheostomy.

excessive accumulation of secretions within the bronchial tree and from oedema of the lung. Death under such conditions is from a combination of asphyxia and drowning.

Some practical issues—The immediate treatment of a severely ill patient with respiratory failure involves immediate attention to the airway. Tracheal intubation undoubtedly provides the most rapid way of achieving this. If the patient is unconscious from the effects of a concomitant head injury or is in deep coma due to the extreme degree of respiratory failure an intratracheal tube can be placed without anaesthesia. In the case of a semi-conscious struggling patient or one with oligaemic shock a skilled anaesthetist will best deal with the problem; a small anaesthetic dose of thiopentone (50 milligrams) is followed immediately by the intravenous administration of a short-acting relaxant (such as 50 milligrams of suxamethonium chloride in an adult). The rapid injection of the relaxant will prevent the main danger of the thiopentone, laryngeal spasm. As soon as the tube is in the trachea a rapid bronchial toilet follows in which both main bronchial trees are effectively sucked out. Oxygen alone is administered and a carbon dioxide absorber introduced into the circuit. The lungs are manually ventilated by pressure on the anaesthetic bag. If the patient is struggling nitrous oxide gas and relaxants are added.

If the patient is oligæmic, as is usually the case, a plasma expanding solution is administered intravenously while rapid arrangements are made for blood matching.

It must be stressed that emergency ventilation is truly an emergency rescue. If the intratracheal tube is left in longer than six hours the risks of infection of the tracheo-bronchial tree are greatly increased as a result of the trauma to the laryngeal and tracheal mucous membrane. As soon as possible a decision should be reached about the indications for performing a tracheostomy. If tracheostomy is performed in an unconscious patient a patient-triggered artificial respirator is employed; many conscious patients can soon learn to live temporarily with such a machine (Fig. 2).

Is tracheostomy so simple?—Accepted throughout the world as a life-saving measure, tracheostomy also carries a high mortality; undoubtedly an operation that is carried out as a desperate remedy for grave and widely separated diseases such as barbiturate poisoning, cerebral damage, heart failure, chest trauma, terminal bronchitis, etc., must have a high failure

FIG. 2

Diagrammatic representation of a patient under treatment. There is a flail left chest with haemo-pneumo-thorax which is being drained through two plastic tubes; air and fluid is draining to two water-sealed bottles which are attached to a motor suction pump. The lungs are being ventilated by a patient-triggered machine connected to the tracheostomy tube. Blood replacement is in progress.

rate. Rarely, though unfortunately at times unnecessarily, patients die during the actual performance of what is inherently a simple procedure, because the conditions under which the trachea is exposed are not ideal; with the disappearance of diphtheria as the cause of airway obstruction it is fair to say that few tracheostomies today need to be done under garret-like conditions. Unless there are compelling contra-indications the operation should be conducted in an operation theatre under general anaesthesia. Even in expert hands tracheostomy conducted under local anaesthesia is a difficult procedure, harrowing both to patient and surgeon. Mercifully, thiopentone, relaxants, nitrous oxide and oxygen, and the intratracheal tube have allowed us to perform this precise and life-saving operation without haste or anxiety.

The main cause of the mortality rate, as seen at necropsy, is undoubtedly tracheal, bronchial and pulmonary infection, not infrequently due to the particular staphylococcus of the individual hospital. Continued local trauma from an ill-placed tube of inconvenient calibre, associated with a slovenly "septic" technique over such procedures as the all-important manoeuvres associated with repeated clearing of the bronchi by suction, plays a large part in the advent of the dreaded "hospital fever" within the lung and its air passages. Ideally every patient with a tracheostomy should be treated with all the care devoted to a patient

requiring intensive nursing therapy. Death can follow neglect of the principles of post-operative care as easily after a tracheostomy as after an open cardiac operation. It is to stress this rather obvious point that more space is devoted in this article to this problem than to the operative procedures carried out by open thoracotomy.

The beneficial effects of tracheostomy in chest trauma—Fewer and fewer operative fixations of displaced ribs in patients with flail or stove-in chests are being performed today because tracheostomy relieves the dyspnoea, maintains a near normal oxygen-carbon dioxide ratio in the blood, and prevents blockage of airways because repeated suction of retained secretions is possible.

As tracheostomy greatly reduces the dead space so that a greater proportion of each breath reaches the alveoli, the entry of oxygen and the escape of carbon dioxide is augmented, for less muscular work is done by the diaphragm and chest wall muscles. Ventilation becomes more efficient and respiratory distress is relieved because of the reduction in the work done by the muscles as a result of the decrease in demand for oxygen, the result of greater alveolar efficiency.

Finally a tracheostomy permits good oxygen administration and the use of intermittent positive pressure ventilation.

The dangers of tracheostomy—As a tracheostomy prevents the patient from building up a high intrabronchial pressure, the cough mechanism is weakened. Careful suction is required to overcome this disadvantage. Greater drawbacks are the ease with which infection can pass into the trachea and the loss of the normal mechanisms for moistening the inspired air. Infection is combated by scrupulously aseptic techniques—for instance, the wearing of masks and gloves and the use of sterile suction tubes during each gentle attempt at bronchial toilet—by the use of antibiotics and by the taking of bacteriological swabs every other day to decide upon sensitivities—the use of humidifying agents. An efficient and simple method of humidifying the air passages, especially if the intrabronchial secretions are thick, is to instil small quantities (1–2 millilitres) of sterile isotonic saline before and after each bronchial suction. If oxygen is being administered through the tracheostomy it should be humidified. In patients with broncho-spasm, iso-prenaline 1:500,000 can be instilled.

Some points concerning the technique of tracheostomy (Figs. 3 to 5)—The reported complications of tracheostomy include death from haemorrhage due to damage to the carotid arteries, the jugular or innominate vein or even of a highly placed aortic arch. Common complications are those due to the slipping out of the tube from the tracheostome, after the return of the patient to bed. This may be overlooked if reliance is placed on assuming that the tube is in its correct place because of the presence of the characteristic noise of breathing through a tracheal opening—such a noise is still audible even when the tube is lying in the subcutaneous tissue. The danger signal is the recurrence of dyspnoea and cyanosis in a patient previously at comfort and with a good colour; subcutaneous emphysema is a late and obvious indication of tube displacement. Pneumothorax has been recorded and has been ascribed to the rupture of imprisoned air into one or both pleural cavities.

Because of the dreadful dangers of tube displacement, Björk and Engström (1955) have devised a technique of great value; it is being increasingly adopted throughout the world.

THE OPERATION

With the patient anaesthetised and with an intratracheal tube in position, he is positioned on the table with the shoulders lifted forward by appropriate pads. The neck is extended. A *high* tracheostomy is always done but the first ring of the trachea must never be incised because this increases the risk of subsequent tracheal stenosis. A transverse incision is placed just below the cricoid cartilage: the strap muscles are retracted. If the isthmus of the thyroid gland is small it can be retracted downwards. If, however, this does not provide a good view

of the upper three rings of the trachea the isthmus is divided between two artery forceps (Fig. 3). If these two forceps are rolled apart the trachea is lifted up into the wound. Björk's technique involves the fashioning of a tracheal flap, which is hinged downwards in a U-shaped manner, and is sutured to the dermis of the lower lip of the transverse skin incision (Figs. 4 and 5) with a few interrupted sutures. The tracheostomy tube should be large enough

FIG. 3

A surgical step sometimes required in tracheostomy. The isthmus of the thyroid will be divided between the two artery forceps. Subsequently these will be used as "retractors" to lift the trachea into the wound.

FIG. 4

FIG. 5

Björk's tracheostomy. Figure 4—The U-shaped flap is made by incising the area above the second tracheal cartilage and carrying the incision downwards through the second ring and a large part or the whole of the third ring. The flap of tracheal wall is then sutured to the dermis of the lower lip of the incision as shown in the lateral view. Figure 5—An oblique view of the completed tracheostomy.

to provide a really good airway without producing any pressure on the tracheal wall. The curve of the tube must be such that it does not impinge on the anterior wall of the trachea; it must not be long enough to reach the carina or enter one or other bronchus. The intratracheal tube is not removed by the anaesthetist until the flap has been sutured down into its correct site. The tracheostomy tube is then placed in position.

FIG. 6
Radiograph of an injured chest taken in the prone position.

FIG. 7
Radiograph of the same patient as depicted in Figure 6: the patient is now lying on the left side. At once the air, not seen in Figure 6, is clearly seen in this extensive haemo-pneumo-thorax. Severe dyspnoea was instantly relieved by the prompt institution of water-sealed catheter drainage.

Post-operative care of the tracheostomy—Constant vigilance is possible only if the patient is nursed where there is good illumination by night and day. Cyanosis, noisy breathing and the presence of moist sounds in the lungs detected by auscultation, are indications of blocking secretions calling for meticulous aspiration by the sucker.

The type of tracheostomy described allows the tracheostomy tube to be removed with no suggestion of haste because the tracheostome will remain open without obstruction to respiration.

If it is thought that the patient has difficulty in swallowing after the operation, a cuffed tracheostomy tube should be used to prevent aspiration of food and fluid into the trachea. The cuff of the tube can cause necrosis of the tracheal wall; it must not be over-inflated and periodically must be deflated.

FIG. 8

Some possible lesions and complications that may follow closed trunk injuries. (By kind permission of Butterworth & Co. (Publishers) Ltd., *Modern Trends in Accident Surgery and Medicine*. London, 1959.)

When the patient can breathe well even if the tracheal tube is temporarily blocked it may be removed. The sutures are removed from the area of attachment of the tracheal flap to the lower lip of the incision; this type of flap tracheostomy has the advantage of delayed stomal closure. Such delayed closure allows bronchial suction to be continued if required after removal of the tracheostomy tube.

In a short review such as this it might be said that these reflections are disproportionately long. The excuse offered is a belief that in the treatment of civil chest injuries tracheostomy plays a great part in saving the lives of critically ill patients and exceeds in importance the performance of major operations, such as thoracotomy and stabilising operations on the disrupted rib cage.

DETAILED CLINICAL ASSESSMENT

In compression injuries of the chest as seen today, other structures, especially the limbs and the head, are often seriously damaged. Hypotensive phenomena, distress, tachypnoea and tachycardia may well be ascribed to these other injuries and serious thoracic injury may be overlooked, especially in heavily built men. In compression of the chest wall the burst is outwards and the rib angles or necks on both sides are fractured, sometimes with disruption of the costo-sternal cartilages anteriorly. The fourth to the ninth ribs are those usually involved and transverse fractures of the sternum are seen. Even with such gross involvements an examination made in cursory fashion may overlook the paradoxical movement. As many of the patients are so ill, radiological examination may be carried out in the prone position, and radiographs taken in such a position may be seriously misleading. As soon as resuscitative measures have improved the general state, radiographic examination with the patient in different positions is essential (Figs. 6 and 7). If it sounds trite to say that in a patient with multiple injuries it is easy to overlook gross chest wall disruptions, the writer may still be forgiven if he says spinal and abdominal injuries are not uncommon in grave compression injuries. A glance at Figure 8 may serve to indicate what can happen to the thorax and upper abdomen in such conditions. Those with war-time experience will remember that gunshot wounds frequently caused multiple injuries of the kind illustrated. The exclusion of tears of the liver or spleen is by no means an easy task, the confusing factor being the upper abdominal rigidity that so often accompanies fractured ribs and haemothorax. Clarke (1959) gave a valuable account of the problem.

SURGICAL MEASURES IN THE TREATMENT OF CHEST INJURIES

Current opinion favours the use of tracheostomy together, in some instances, with the use of controlled or artificial respiration, oxygen therapy and vigorous efforts to prevent or combat infection, rather than the use of major surgical procedures, in the treatment of critically ill patients with severe chest-wall damage. No surgeon experienced in the treatment of the crushed chest would, however, deny the place of active measures in many circumstances. Fortunately, most of the measures required are simple enough, requiring the removal of intrapleural blood or air by needle aspiration or by water-sealed catheter drainage. The treatment of haemo-pneumo-thorax is by far the most important measure required in the treatment of chest injury, whether it be due to crushing or to a penetrating wound. It is dangerous to allow preoccupation with extensive rib fractures to let us forget that a large quantity of blood is usually present in the pleural cavity and in the intermuscular spaces around the bony injury. If haemothoraces are present in a patient with respiratory difficulties who is not in grave danger the compressing effect of air and blood on the lungs must be removed; this frequently averts the need for tracheostomy. It is seldom possible to know when thoracotomy or deliberate fixation of rib fractures will be needed until full resuscitation has restored a proper oxygen supply to the tissues in the presence of an adequate circulating blood volume. The main measures employed to achieve this restoration of safe cardio-respiratory physiology are 1) adequate blood transfusion, 2) establishment of a good airway by the removal of bronchial secretions by suction, tracheal intubation or tracheostomy, 3) oxygen therapy, and 4) the removal of intrapleural compression, as by blood or air.

A brief summary of the measures employed in the management of haemorrhage, pneumothorax and injuries to the chest wall follows.

Haemothorax and haemo-pneumothorax—This is the most common complication of chest injury, military or civil. In 1,000 consecutive chest wounds seen personally in the last war 839 had a haemothorax which required aspiration or surgery. Blood and air in the pleural cavity produce immediate and late undesirable effects upon the lung, chest wall and mediastinum and if left can be a serious cause of infection. Bleeding into the pleural cavity

may be from the lung or from systemic vessels (intercostal or internal mammary). Undoubtedly this is the usual source. As the pressure in the pulmonary vessels is low (20–30 millimetres HG) bleeding from them is usually self-arresting except in stab or bullet wounds involving large vessels. It is accepted throughout the world literature that the treatment of haemo-pneumothorax is by needle aspiration as soon as possible; this not only encourages early and rapid re-expansion of the lung and diminishes the risk of subsequent infection but plays an important part in the early phase of resuscitation. Should the haemothorax re-accumulate rapidly with a deterioration in the condition of the patient, intrathoracic bleeding may be regarded as continuing and surgical exploration may be required. At such exploration the bleeding will usually be found to be coming from chest wall vessels. Occasionally it may be from a large pulmonary vessel in penetrating or perforating wounds, or from the aorta in

FIG. 9

A traumatic "false" aneurysm of the aorta. A classical site.

crush injuries; in the latter incidence it is usually from the aorta in the region of the left subclavian artery. Tears of the aorta in this region may be self-sealing with the formation of a false aneurysm which today is amenable to surgery (Fig. 9). Traumatic rupture of the aorta results from a sudden deceleration or direct injury to the chest and in 80 per cent of cases the cause is an automobile accident (Jahnke, Fisher and Jones 1964). The isthmic portion of the aorta immediately distal to the left subclavian is most commonly involved, and the lesion varies from an internal tear to complete transection. There may be associated thoracic injuries such as fracture of the sternum and ribs, but often there are no external signs of injury at all. The only sign of value is widening of the mediastinum seen radiographically, and if this is present the diagnosis should be established by aortography.

Some 20 per cent of patients will survive the injury initially, and of these only a few die within twelve hours of admission to hospital; the remainder usually die during the next two to three weeks, but there are records of survival up to twenty-seven years after the accident (Steinberg 1957; Parmley, Mattingly, Manion and Jahnke 1958). Since this lesion is now eminently suitable for surgical correction the diagnosis should be suspected in every case undergoing a deceleration injury and chest radiology is mandatory.

FIG. 10

Calcification around a chronic haemo-pneumo-thorax. The chest injury was sustained twenty years previously.

If a large haemothorax is left unaspirated, crippling effects on respiratory function may ensue. Such collections will clot; a rigid wall of fibrin forms on the lung and on the parietal pleura, and gravely endangers the functions of both, sometimes for life; the chest wall becomes shrunk and immobile and ventilatory function is greatly decreased. It is rarely seen today because early aspiration of the haemothorax is practised. The lessons of the last war have been learnt. Occasions still present, however, when a neglected haemothorax is seen with a secondarily infected haemothorax in an ill patient. If the haemothorax has clotted, the chest is

opened two to six weeks after the injury, the fibrin masses within the pleura are removed and the lung is decorticated. The thickened fibrinous deposit can be peeled readily from the underlying shiny visceral pleura. Little or no modification in the technique of this operation has taken place since the last war (Price Thomas and Cleland 1945, Samson and Burford 1947, d'Abreu 1958). An example of an untreated clotted haemothorax can be seen in Figure 10. The original injury occurred twenty years previously; calcification has developed in the walls of the haemothorax pocket. Daily radiological control of the state of the lung and pleura will determine the need for repetition of the aspiration of a haemothorax; the radiograph should always be available at the time of aspiration. Careful studies of the radiographs, a large-bore

FIG. 11

Right pneumothorax from a perforating bullet wound. The patient was admitted with intense dyspnoea which was relieved in minutes after a catheter was introduced by the trocar cannula method and connected to a water-sealed bottle. The lower lobe is totally collapsed and airless. The upper lobe is held out by long-standing adhesions. A tension pneumothorax was present. The lower lobe re-expanded rapidly. An example of a simple procedure relieving dangerous respiratory failure.

aspiration needle and the avoidance of too low a site for the puncture are cardinal rules. If the patient is too ill, from concomitant injuries, to withstand the ordeal of repeated aspirations there need be no hesitation in employing catheter drainage (Fig. 2).

Pneumothorax—In traumatic cases, since there is usually an associated haemothorax, the principles employed in its management are those outlined for haemothorax. If the main problem is compression of the lung by air, aspiration by means of a pneumothorax apparatus will enable the operator to know whether the air leak from the lung has ceased. If after air aspiration the intrapleural pressures return to a negative value there is no indication that a tension pneumothorax persists (Fig. 11). If, however, the intrapleural pressure remains raised or unaltered, air is still escaping from a major lung air leak. Closed drainage

through a catheter should be instituted. Should the volume of air escaping into the water-sealed bottle be excessive, the rare but important diagnosis of tear of a major bronchus should be remembered. Severe surgical emphysema accompanies such bronchial tears. The commonest tear is seen in the left main bronchus. Bronchoscopy is indicated and the diagnosis is readily made by this method; thoracotomy either early or later can give excellent results after suture of a torn bronchus. The literature contains many accounts of the successful management of this severe injury since the publication of early case histories (Griffith 1949, Paulson 1951).

Open pneumothorax—As a first-aid measure, closure of the sucking wound by application of a firm sealing pad soon relieves the gross physiological disturbance. Later the wound is excised. The extent of the operation performed at this stage calls for careful judgement. A "thoracotomy" enlargement of the wound after examination should be carried out only if there is considerable bleeding; this usually comes from the chest-wall vessels. Lung lacerations are almost invariably self-sealing and this makes their excision and suture unnecessary. In most examples of sucking open pneumothorax apart from excision, closure and temporary closed drainage of the pleura, little is to be gained by wide exploration. The main indications for formal thoracotomy are: 1) continuing bleeding after a well conducted aspiration of the haemothorax; 2) thoraco-abdominal wounds including rupture of the diaphragm; 3) exploration of wounds of the aorta where an acute dissection of that vessel is suspected; 4) some cardiac wounds; 5) decortication operation for clotted or infected haemothoraces; 6) traumatic chylothorax.

Operative measures for continued bleeding—Continuing bleeding from chest wounds, be they the result of penetrating or perforating wounds or of crushing trauma, is not often severe in patients who have reached a hospital service. Probably the commonest call for surgery in civilian practice is rupture of the spleen or liver in crush injuries.

Stab wounds of the heart and lung require open surgery in the minority, not the majority, of patients. The principles underlying the management of bleeding within the pleural cavity and in the pericardium have become very similar. More and more attention has been devoted to restoration of the function of underlying organs, the heart and lung. Pressure on either of the structures is easy to detect, producing tamponade in both instances. If blood is effectively aspirated from the pleural cavity, lung re-expansion usually follows unless the bronchial tree itself is blocked by blood or muco-pus. If blood is aspirated from the pericardium in cardiac tamponade (as indicated by pallor, a falling arterial pressure, a rising venous pressure and a "quiet" often impalpable heart beat) relief is usually dramatic. This initial line of treatment, perhaps first advocated by Blalock and Ravitch (1943) has been established further by the published work from de Bakey's department in Houston (Beall, Ochsner, Morris, Codey and de Bakey 1961). Beall concluded a fine paper with the words "but pericardicentesis remains our primary approach to penetrating wounds of the heart": 139 patients with stab wounds of the heart reached the hospital with signs of life; of these 25·2 per cent died. If those who died before treatment was instituted are excluded, the mortality rate was only 14·4 per cent. Seventy-eight patients were treated primarily by aspiration with a mortality rate of 5·5 per cent. Open surgery was used when aspiration was proving ineffective. The Houston experience supports the wisdom of the directive issued to American medical officers during the second world war for the treatment of cardiac tamponade: 1) aspirate blood from the pericardium; 2) repeat if there is a recurrence; 3) if it again recurs perform an open operation (quoted from Blades 1961).

The indications for surgical exploration for intrapleural bleeding have been discussed. It remains to be said that in the unusual situation today when floating rib segments are fixed by direct surgery by intramedullary pegging or wire fixation, the opportunity to remove blood and blood clots and to tie off damaged intercostal blood vessels should be seized. The pleural cavity should be drained to water-sealed bottles.

FIG. 12

Radiograph of the chest taken in the intensive therapy room. Patient has returned from the theatre. To treat respiratory failure from a flail chest tracheostomy has been performed and the floating anterior segment of the chest stabilised by means of Abrams's pin. (See text.)

FIG. 13

Radiograph of the same patient seventeen days later. Note the clearing of the lung fields.

Traumatic rupture of the diaphragm—Stab and bullet wounds and compression injuries may cause tears of the diaphragm which sometimes escape recognition for months or years. This is because the radiological appearances may be deceptive; we are all used to seeing a raised diaphragm in cases of haemothorax or pleural effusion. The presence of the stomach in the left pleural cavity may be mistakenly regarded as being due to the presence of the round gastric bubble below a raised diaphragmatic leaf. Occasionally the patient with herniation of the stomach into the chest may be in desperate straits as the stomach, filled with gas, may cause severe compressive effects on the lungs and mediastinum. There is a grave danger too of aspiration of vomit into the lungs from sudden emptying of the overloaded stomach in a sedated patient. When the diagnosis is suspected in acute traumatic cases a stomach tube must be passed; the diagnosis can be established by gastro-graphin radiological examination. Wherever possible the diaphragmatic hernia should be repaired as soon as possible by a thoracic approach. This prevents the ever-present risk of gastric or intestinal strangulation or obstruction and allows rapid re-expansion of the lung. As diaphragmatic wounds have a great tendency to disrupt, the tear should be repaired with great care, preferably in two layers using non-absorbable sutures.

Operative measures for "flail" chest and for transverse fractures of the sternum—A few years ago many surgeons advocated a more aggressive attitude towards the operative fixation of floating segments of the chest wall by intramedullary pegs, wiring of broken cartilages and plate fixation of transverse fractures of the sternum. At the same time tracheostomy was being used more and more as a weapon to treat or prevent respiratory failure in patients with "stove-in" or "flail" chest. At the moment the pendulum has swung away from major surgery. The reasons are that more lives are being saved by the well managed tracheostomy employing patient-triggered respiratory machines in many instances, and because the operative fixation of major rib fractures is a difficult and long operation in patients seriously embarrassed by other injuries. At present, surgery tends to be confined to the fixation of transverse fractures of the sternum, usually seen at the junction of the body and the manubrium.

The use of the slightly curved pin advocated by Abrams (1961*a*) for stabilising the sternum after operations for pectus excavatum, when large segments of costal cartilages have been excised, is of great value when a flail chest exists after fractures of the costochondral junctions (Figs. 12 and 13). The pin is inserted obliquely beneath the sternum; it is impacted into the marrow cavity of a rib on one side and firmly fixed to a rib on the opposite side by stout unabsorbable sutures. The pin is removed after four to six weeks.

The main indications for the fixation of multiple fractures of the ribs is to prevent subsequent deformity after the patient's condition has been relieved by tracheostomy. The operation follows the usual principles of orthopaedic surgery—reduction, adequate fixation and early physiotherapy. The operation is often an extensive one, and attention must be paid to adequate muscle repair as well as to the correction of bone deformity.

Attempts to "fix" the disrupted rib cage by heavy strapping or sandbags can only be condemned. Not only is the method totally ineffective; it also causes pain and prevents adequate ventilation of the underlying lung or lungs. The need has been filled by the use of tracheostomy and by the use of skeletal traction to appropriate areas of the floating segment of the chest wall. Small surgical towel clips can be placed to encircle the ribs; these provide good anchors for the attachment of light weights, heavy enough to stop the paradoxical movement of the unstable area of the chest wall.

THE PRESENT PICTURE

Great improvement in correcting oligaemia, and the recognition that in the resuscitation programme physiological dysfunction of the respiratory system adds greatly to circulatory disturbances, is saving many lives. Resuscitation aims to allow adequate amounts of

circulating blood to pass through a physiologically functioning respiratory system. Gravely ill patients restored to a near normal physiology by tracheostomy, good bronchial toilet, adequate supplies of oxygen, satisfactory abstraction of carbon dioxide, correction of abnormal intrathoracic pressures and maintenance of chest wall function by physiotherapy, minor or major interventions to stabilise a flail chest or the provision of artificial respiration via a tracheostomy, are able to survive to become suitable for definitive procedures as in other branches of traumatic surgery. At various stages more and more use is being made of the advances in renal dialysis and cardiac and thoracic surgery. It is possible and practicable today to save the life of a patient who has suffered a traumatic dissecting aneurysm of the aorta and has developed anuria, by the employment of the techniques available to us in the form of renal dialysis and the use of heart-lung machines. Once the acute emergency of bleeding, asphyxia and drowning has been overcome, the diagnostic and therapeutic advances employed for the usual thoracic patient are available to the patient who has survived a severe chest injury.

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