PENETRATING WOUNDS OF THE CHEST.

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Infection is the surgical bugbear of all penetrating injuries, and this is especially true of wounds of the chest, for, in addition to the infection carried by the missile, the damaged pulmonary and pleural tissues are peculiarly liable to secondary infections from the respiratory tract. Any form of penetrating chest wound has therefore to be considered under two headings:—

1. *Immediate effects*; shock, hæmorrhage, physiological disturbances, etc.
2. *Late effects*; largely dependent on infection.

The **immediate effects** depend on the size, shape, type, velocity and track of the missile. A high velocity rifle or machine-gun bullet entering the chest through an intercostal space and making its way out through a posterior space may occasion, apart from the initial shock, little disability and with luck no complications. A small more slowly moving vulnerant may produce a punctured wound such as seen with a knife-thrust or driving in of a rod in a car accident. The severity of such a wound will depend on its site and depth and the amount of visceral injury. When a high velocity bullet strikes a rib on entry, the fragments of bone are driven in and cause extensive laceration of lung; the exit wound is large, torn and ragged. Impact of the missile on to rib may produce considerable deflection of its course with the result that the bullet may make its exit or be lodged in most unexpected places. Shrapnel or high explosive fragments which have a lower velocity on impact often remain lodged in lung or other tissue. The most dangerous type of wound is one produced by a relatively slow moving, ragged shell or bomb fragment which, assuming that the wound is not immediately fatal may lay the train for serious pulmonary and pleural infections. The gravity of this form of injury can be emphasised by the statement of Duval who found that the mortality of shell wounds in the last war was eight times that of rifle wounds. Unfortunately, too, wounds are not always single, nor are they restricted to the thorax alone; abdomino-thoracic injuries are frequent and necessarily include injury to the diaphragm.

The position of the patient in relation to the course of the missile plays an important part in the degree of injury inflicted. In the erect posture a bullet hitting the sternum will probably be immediately fatal; if to either side lung alone may suffer, but if from side to side damage to the heart or great vessels is likely to prove fatal. When stooping forwards or lying prone the bullet may travel through the chest and abdomen with results obviously varying with the amount of damage done to the viscera.

Certain immediate effects of a penetrating wound of the chest demand individual consideration, viz., shock, hæmorrhage, pneumothorax, collapse of lung and subcutaneous emphysema.

The degree of **shock** depends on the constitution of the individual, on the extent of the wound and on its location. Pleural shock can occur, though its importance in civil practice is probably minimised by preliminary anæsthetisation or the pathological condition of the pleura when an exploring needle is introduced. Small punctures which reach but do not pierce the membrane can produce a degree of shock.

Pneumothorax may be produced in two ways:—

1. By entry of air from without through the external wound.
2. By leakage of air from the injured lung.
3. Formation of gas within the pleural cavity.

In the first instance the behaviour of the soft tissues over the parietal pleura determines the extent of the pneumothorax; if air can enter and leave freely the lung collapses and mediastinal displacement may add to the respiratory and circulatory distress. Frequently skin and muscle become sealed with blood clot and limit the extent of the pneumothorax, but occasionally a flap-valve is formed allowing air to be sucked in but not blown out with each respiration. A "sucking wound" produced in this way rapidly gives rise to a *tension pneumothorax* which collapses the lung and pushes the mediastinum over to the opposite side. Intense dyspnoea, cyanosis and extreme distress, with rapid pulse and displacement of the heart and trachea demonstrate the extent of this dangerous complication.

Under the *second heading* the presence of air in the pleura is accounted for by a tear in the visceral pleura over the lung wound. As the lung collapses the size of the opening is reduced by shrinking of lung surface, and this with clotting of the oozing blood usually helps to seal the wound. On the other hand exaggerated respiratory efforts and violent coughing tend to displace the clot and keep the wound patent. Some pneumothoraces tend to be valvular, easily understood when it is realised that inspiration sucks air into the pleura, confirming the collapse, while its return through the lung opening is prevented during expiration. Thus it is seen that a tension pneumothorax can be produced by a flap valve in either the lung or chest wall.

Yet one other form of pneumothorax must be mentioned—the type that arises rapidly from gas formation when anaerobic organisms enter the pleural cavity and become active. It is possible for a tension pneumothorax to develop in this way in a surprisingly short space of time, and the possibility of this virulent infection becoming established must not be lost sight of. The type of case most liable to this formidable complication is one in which the anaerobe spores gain access to the chest from heavily manured soil.

Hæmorrhage into the pleural sac may not be entirely controlled by clotting and, as the lung is collapsed or can retract in response to blood pouring into the pleura, there is no confined space to exert pressure on the bleeding point until the whole sac is filled with blood and air. The main sources of hæmorrhage are:—

1. Chest wall vessels—intercostal and internal mammary.
2. Pulmonary vessels in the lung.
3. Vessels in the mediastinum and nearby (subclavian).

The mural vessels are well protected by bone, and fracture is an invariable cause or accompaniment of a divided intercostal. Spontaneous arrest cannot be expected and the chief danger of bleeding from this source is that the artery may go on silently pumping blood into the pleura. The respiratory factor and general distress somewhat confuse the clinical picture and it is said that vagal irritation sometimes prevents a rise of pulse rate to that which would be expected. Emphasis on hæmorrhage from these parietal vessels is necessary since it is often overlooked.

The extent of hæmorrhage from the lung depends on the size and situation of the injury. Peripheral damage is not nearly so important and dangerous as a

lesion in the region of the lung root. A hæmatoma forms in the lung giving rise to a firm, tense, elastic, purple swelling and the affected lobe may resemble an india-rubber ball. Blood wells or oozes from the torn lung into the pleura, but, coincidentally, the lung collapses, aided by the pressure of the pneumothorax. This reduces the size of the opening and helps in the arrest of bleeding. The value of using air and extruded blood as a pad to control hæmorrhage from lung has been utilised in some instances by inducing or raising the pressure of a pneumothorax with an artificial pneumothorax apparatus. When air tubes of any size are punctured the blood may take another course and *hæmoptysis* of any degree from a slight streak to drowning may result. Clots which are not coughed clear from the bronchial tree may obstruct air tubes to such an extent that atelectasis occurs and the production of this form of collapse with surprising rapidity may affect either lung. It is possible that many cases of *massive collapse* have their origin in this way.

Subcutaneous emphysema can be produced by any open wound, but in the case of chest injuries the invariable cause is the presence of a pneumothorax with a torn pleura which has no free exit to the surface. Air is driven out of the chest by successive bouts of coughing through the pleural rent into the subcutaneous tissues. The extent of the emphysema in a marked case may be considerable and render the patient quite unrecognisable in a few minutes. Nor is it likely that the condition will be controlled as long as air continues to enter the pleura and coughing is unchecked. The solution of the problem lies either in relieving the pleural air pressure by needle or allowing free exit through the surface wound during coughing.

Consideration of complicated or additional injury must be brief. In abdomino-thoracic injuries, the vulnerant having entered in either direction, the abdominal injury must, for obvious reasons, be dealt with and the diaphragmatic rent must be closed at the same time; the chest condition will be treated subsequently or as soon as the patient's condition permits if an abdominal approach was made. In a number of cases the abdominal injury can be treated through the diaphragm with much greater ease than might be expected. Abdominal injuries are dealt with by this transdiaphragmatic laparotomy and when the diaphragm has been sutured the thoracic damage can be considered. Fractures of the arm or any part of the shoulder-girdle, with or without damage to the brachial plexus and large vessels are not infrequent concomitants of a penetrating chest wound. Direct injury of the heart hardly comes within the province of surgery as it is almost invariably fatal, as is also division of the great vessels in the mediastinum. Hæmopericardium was quite common in the last war and demanded aspiration when the "tamponade" of accumulated and accumulating blood threatened a fatal issue.

The management of penetrating chest wounds.

Shock is the instant effect of the wound, no matter how slight or how severe. The patient is distressed and anxious, partly from the pain of the external wound, partly from immediate and distressing dyspnoea, partly from incessant coughing up of bloody mucus or blood. Often the wound is immediately or rapidly fatal and nothing can be done, but if the patient survives and surgical help is available the first step is to prevent further entry of air into the pleura. A sucking or whistling sound from the external wound demands a firm pad, as air-tight as possible; this with morphia is probably all that is possible. When facilities for more thorough treatment are reached clinical examination will reveal a pneumothorax and perhaps

a fluid level suggesting hæmothorax, but as a rule the patient is too ill to be disturbed and the amount of hæmorrhage must be judged from his appearance. In every case the pain of the parietal wound causes catchy, irregular breathing, apart from any pulmonary complication, and morphia or one of its derivatives should be given in full dosage to relieve shock and distress. The fear of the depressing respiratory effects of this drug are groundless; any slight ill-effect is more than compensated for by the rest which counteracts pain, shock and hæmorrhage.

Increasing dyspnœa with cardiac and tracheal displacement suggest a tension pneumothorax, which must be relieved by thrusting a hypodermic needle into the chest where it is left covered by sterile gauze as a safety valve. Leaving a large bore needle or cannula in situ is not advised, in case with coughing the lung re-expands and bleeding recurs.

External bleeding is usually slight except when gravity and intra-pleural pressure expel pleural blood from the wound. As has already been said the pulse and respiration rate are influenced by other factors than that of hæmorrhage, so that clinical signs of internal bleeding are erratic. The degree of pallor is the chief guide, but a rising pulse rate in a patient quietened with morphia is suggestive of active bleeding, most probably from a severed intercostal—a condition that demands immediate treatment.

The value of oxygen therapy in chest injuries is considerable but the question of its accessibility is not always solved. Dyspnœic or distressed patients will derive great benefit from oxygen so long as the concentration can be maintained at a sufficiently high level and the patient will tolerate the apparatus.

In short, emergency treatment consists of a firm pad of dressing, with warmth, rest and morphia and possibly oxygen to combat shock, relieve respiratory distress and reduce or arrest bleeding. A constant watch must be made for tension pneumothorax and persisting hæmorrhage.

Assuming that the patient survives the initial stages, the **problem of infection** has then to be considered in relation to possible lines of treatment. The pleura is open to infection from the external wound, even though infected fragments of cloth or missile have not been lodged in the chest. The damaged lung is liable to invasion by organisms normally resident in the respiratory tract as well as those from foreign parts and these organisms also have access to the pleural cavity.

The most common result of infection is *empyema*. The patient has as a rule a healthy pleura free from adhesions so that an infective inflammation can spread rapidly over the whole face of that membrane. A total pyothorax rather than a localised empyema is to be feared. Blood is a favourable medium for the growth of bacteria and hæmothorax therefore especially encourages infection. The lung itself is variously affected. A clean punctured wound may show little actual lung destruction, but there will be some extravasation of blood into alveolar and interstitial tissues, a condition favourable for bacterial invasion. In consequence some degree of what may be called traumatic pneumonitis is inevitable. Irregularly lacerated lung looks like a torn sponge, stained deep purple, with shreds and strands of pulmonary tissue attached to the main mass. Such fragments are doomed to necrosis and secondary sepsis unless removed.

The nature of the infecting organisms has an important bearing on the course of any wound. A mild pyococcal invasion giving rise to an empyema of relatively low infectivity is of no great significance when adequately drained, but in the last war there

was only too often the extraordinarily virulent behaviour of anaerobes in the pleural cavity. Even in civil empyemata they are very far from rare, but the spores from the heavily manured soil of Northern France are especially virulent and produce fatal results with fearful rapidity. The development of gas-forming organisms in an existing hæmothorax induces an intrapleural pressure that is soon fatal if not relieved.

The later effects of infected chest wounds need only be mentioned here. Chronic empyema with resulting deformity of chest and spine is common. Contracted scars in the lung may ultimately give rise to bronchial stenosis ultimately leading to bronchiectasis. Pulmonary abscess—contrary to what might be expected—is rare, probably because infarcts are rapidly infected and become part and parcel of an empyema. Retained foreign bodies almost always produce some of the above sequelæ with recrudescences of broncho-pneumonia, bronchitis, hæmoptysis, etc., and eventually require removal.

Speaking generally—though every case must be judged on its merits—all penetrating wounds of the chest must be regarded as potentially infected and therefore candidates for surgery. A clean through and through wound or stab without an appreciable hæmothorax may be treated conservatively and it has been suggested that such a wound accompanied by a definite hæmothorax should similarly be left alone. The later progress of these cases shows, however, that intense thickening of the pleura results with diminished lung expansion and restricted movements. It is probably wiser to evacuate a hæmothorax completely a few days after the hæmorrhage has ceased and subsequently to keep the pleural cavity as dry as possible. Effectively performed aspiration will suffice in many instances, but if there is any other factor that gives rise to the slightest suspicion of potential infection it is better to perform deliberate open operation and ensure that the toilet of the pleura is as complete as possible. Gross lacerations or extensive injuries require surgical intervention as soon as the patient is fit enough to undergo the operation. Preliminary blood transfusion is often a wise move if there has been marked loss of blood. Transfusion may render an unfit patient suitable for operation, but giving of blood during and after the operation is advisable in many instances in addition.

X-ray examination of an injured chest should be made, if possible, on all occasions. Fractured ribs can be detected and also fragments of bone that have been driven inwards. The presence of a pneumothorax is also easily detected and the amount of fluid (blood) in the pleural sac can be visualised. Traumatized lung with much extravasation of blood loses its normal markings and becomes homogeneously opaque. Probably one of the most valuable findings in radiology is the presence of foreign bodies which can usually be localised by a combination of antero-posterior and lateral films. A further great asset is some indication of unsuspected injury as may be exemplified by the presence of air under the diaphragm or a pneumothorax on the opposite side.

The nature of the *anæsthetic* is important because the production of a large open pneumothorax is an inevitable part of the operation. The surgeon is dealing with a chest that was probably healthy a day or two previously and the mediastinum is therefore free and unfixed by adhesions; mediastinal flutter is a frequent concomitant of a large thoracotomy and therefore gas and oxygen should be given by way of a close fitting "over-pressure" mask or intratracheal tube. Basal narcotics should also be administered and local anæsthetics added with advantage.

The **plan of the actual operation** must include excision of the parietal lesions, especially the wound of entry, exploration of the chest for removal of foreign bodies, repair to lung, cleansing of the pleura and closure of the wound. The question of

drainage of the pleural cavity will be dealt with separately. The entry wound should be freely and deliberately excised and all fragments of bone and clothing removed. It is important not to overlook any track or burying sinus in the process. The excised wound may sometimes be utilised as a route of access to the pleural cavity by removal of a further length of rib or extension of the incision along the intercostal space, but as a rule it is better to make a planned incision so as to be sure of exposing all parts of the pleural cavity. A U-flap or trap-door does not afford anything like as much working room as a postero-lateral thoracotomy incision through a rib bed or an interspace. This latter exposure is similar to that used in the set operation of lobectomy and requires the use of a suitable rib spreader or automatic retractor to enlarge the opening. An operating light which can be sterilised or a head lamp is a necessary illuminant.

The cavity when freely exposed is cleared of clot, fluid and débris and the lung is carefully inspected. It lies collapsed at the bottom of the opening with the injured parts heavily infiltrated with blood. The wound in the lung will not, of course, correspond to the position of the entry wound, as during collapse the lung will have fallen away for some considerable distance. Obvious foreign bodies are removed and a gentle search made for fragments of rib, missile or cloth, particularly if these have been revealed by X-ray examination.

It is possible that at this stage or at any time when lung is handled that the patient may be upset by coughing or by mediastinal movements. The pulse rises and the general condition deteriorates. The remedy is to close the open wound by placing the hand or a damp swab over it and waiting until the cough and dyspnoea subside with the aid of slight increased pressure in the anæsthetic system and addition of further oxygen. More than one of these pauses during a long operation may be required, but as soon as manipulation has ceased and a suitable interval been given the patient's condition returns to the former level.

The next question is how to deal with the lung. Lung tissue can be safely incised—preferably with a diathermy knife—and if a foreign body is found it is steadied with the fingers and an incision made on to it through the least vascular area. After removal of foreign matter the cut lung edges can be sewn together in one or two layers so as to obtain complete apposition and prevent formation of a hæmatoma. A clean bleeding cut can be secured in most cases without having to identify and ligate individual vessels so long as they are towards the periphery of the lung. Theoretically the wound track should be excised, but in practice this is rarely possible and so long as the track is cleaned and bleeding arrested by suture it can be left alone. A badly torn fringe which appears to be beyond the scope of spontaneous recovery should be removed beyond clamps and the raw edges oversewn by a fine running suture. Wide tears which show active bleeding require a few mattress or underpinning stitches before any attempt is made to unite the visceral pleura over the wound. The pleura over the lung is of course too friable to carry sutures by itself, but when a small edge of pulmonary tissue is included adequate approximation is obtained.

The surgeon is faced with a more serious problem when a large section or whole lobe of lung is damaged. Shall he remove the lobe or lobes or try and patch up the damaged area? The performance of lobectomy is a severe undertaking, not so much because of the actual nature of the operation, but because of the general condition of the patient who has survived a most extensive injury. If lobectomy is decided upon because the lung has been so smashed or torn from its root as to be beyond repair the hilum is temporarily secured by a snare or

tourniquet; the damaged part is excised and the projecting stump transfixed by mattress sutures until all divided vessels are controlled and the bronchial orifices sealed and covered over.

The final stages of any thoracotomy are completed by a final cleansing of the pleura, an assurance that no other lesion is present (e.g. perforation of the diaphragm or puncture of the mediastinum), approximation of the ribs, closure of the wound in layers and provision for drainage.

An opening in the diaphragm must be carefully examined as it implies possible injury to some of the abdominal contents. The wound should be enlarged—bearing in mind that muscle edges bleed freely—and the abdomen explored. Tears in spleen, liver, stomach or colon can be readily repaired through this incision. It is, of course, impossible to deal with the chest from below, but it is surprising how often a belly injury can be repaired by this route. The opening in the diaphragm is carefully sutured often after crushing the phrenic nerve as it lies on the pericardium: it is surprising what improvement in the general condition results when the abdomen and thoracic contents have been separated.

Adequate *drainage* is the last, but by no means the least important part of treatment. Primary closure of the chest after thoracotomy followed by regular and repeated aspiration of any fluid that appears might seem to be sufficient, but, in many cases from technical reasons or delay in aspirating, an empyema develops and the chest has to be reopened and drained. Moreover with an undrained chest and some defect in pleural continuity there is almost bound to be a considerable degree of subcutaneous emphysema which does not add to the comfort of the convalescent patient. If therefore there is any doubt it is advisable to institute closed drainage at the lowest point of the pleural sac through a separate incision. If the possibility of infection is deemed remote an intercostal tube will suffice, but when infection is anticipated a wide tube inserted through a rib resection opening is preferable. Every drainage tube in the chest must be kept as a closed system by some form of water-seal in the early stages: the normal subatmospheric condition of the pleural cavity is imitated and the lung encouraged to expand at the same time as fluid drains away. If and when empyema develops drainage is established at the very onset. It has been suggested that drainage tubes with their attendant connections cause discomfort to the patient, but the experience of thoracic clinics shows that this is quite unnecessary and unfounded if due attention is paid to detail. The drainage tube must be kept in place and free from obstruction until the pleural cavity is reduced by re-expansion of lung to a track of only a few c.c.'s. At times the original drainage becomes shut off by lung re-expansion from other infected parts of the pleura: in these cases careful localisation is necessary to determine where further drainage must be instituted. Breathing exercises of the MacMahon type are invaluable adjuncts in obliterating the pleural cavity.

Bronchoscopy will probably be more and more used in the prevention or relief of massive collapse. The possible explanation that clot or mucus occludes bronchi and produces atelectasis will account for many cases, particularly when it is realised that the initial injury or operation makes the expulsive act of coughing difficult. But it will require further experience to determine whether or not this is the only potent factor. Thoracic surgeons are well acquainted with the extreme value of urgent bronchoscopy during the course of a chest operation and it need only be pointed out that the temporary discomfort of the procedure is a small matter compared with the lasting disability of a collapsed lung, let alone the immediate severe effects.

Severe cardiac injury is beyond surgical help, but on very rare occasions excision of an entry wound reveals a small tear in the heart muscle which can be sutured.

Pericardial injuries are not always immediately fatal, but if the accumulating blood is retained within the confines of the sac a tamponade is established which by its pressure prevents the heart from beating. If the blood can escape into the pleural cavity the chances of survival are improved and if the patient survives until the condition is recognised aspiration should be performed.

Injury of the mediastinum is a dangerous complication. The pleural sac is invariably opened by the same injury and rapidly spreading emphysema immediately embarrasses the heart's action and even if this is relieved a widespread infection is almost bound to follow. Incision over the suprasternal notch and freeing of the tissues in the superior mediastinum may allow sufficient escape of air to relieve the internal pressure.

Illustrative case.

Young man with bullet wound entering the chest above the left clavicle. A pneumo-hæmothorax was diagnosed and the question of abdominal injury discussed on account of pain and resistance of the left upper abdomen. This symptom was subsequently attributed to a referred irritation from blood in the pleura.

Detailed examination shewed a small entry wound in the supraclavicular fossa; the clavicle and first rib were shattered but the great vessels and brachial plexus had escaped injury. It was discovered later that the sympathetic supply to the left arm had been severed, sweating of the face and neck was also affected but Horner's syndrome was not present.

X-ray shewed collapsed lung, and fluid in the pleura; the bullet was seen in the antero-posterior view lying over the 4th and 5th dorsal vertebræ, but the clavicular injury precluded the taking of a satisfactory lateral film.

Shock and dyspnoea were of moderate degree and the decision to operate without delay was based on the rising pulse rate after a few hours observation.

A high postero-lateral thoracotomy was performed under gas and oxygen anaesthesia. On opening the chest the lung was seen to be collapsed, the upper lobe resembling a tense, purple coloured tennis-ball, drilled obliquely from above downwards and backwards, while the lower lobe appeared as an ordinary collapse. Between two and three pints of uncoagulated blood were swelling about the chest and were sucked out. Digital exploration showed the entry wound as a small puncture at the true apex with fragments of bone driven into the chest. At the posterior angle of the 7th or 8th rib was a larger exit wound with grossly splintered bone; the bullet was not in the chest, having been deflected into the mass of erector spinæ. The track of the lung was laid open to allow removal of buried rib fragments and the lung edges were brought together. The thoracotomy wound was closed after a large drainage tube had been inserted through a rib resection at the bottom of the chest; the tube was connected to a closed system. The entry wound was superficially excised.

After draining clear fluid for some days the tube became shut off from the pleural cavity by expansion of the lower lobe and being useless was removed. An unsettled temperature gave rise to some difficulty in differentiating between pneumonic changes in the collapsed upper lobe and an apical empyema. Repeated aspiration of air and fluid from the upper part of the chest gave no evidence of pleural infection, but about a fortnight later pus was found and a drainage tube inserted at the most dependent point of the empyema, the 4th rib in the axillary line. This drain was also kept closed. The temperature subsided and aided by strenuous breathing exercises the cavity

gradually obliterated. Careful control of the healing was maintained by contrast filling of the cavity and X-rays at frequent and regular intervals.

In using the above case as an illustration the following comments may be made:

1. Injury was not confined only to the chest, the clavicle and sympathetic chain being damaged.
2. When brought for treatment a hæmo-pneumo-thorax was present.
3. The missile was still embedded, but its actual localisation by X-rays was impracticable in the absence of satisfactory lateral or oblique films; these were prevented by injury to the shoulder girdle.
4. Active bleeding was suggested, therefore thoracotomy was performed. Splinters of bone were removed from lung and the damaged upper lobe was sutured.
5. Closed drainage was instituted and maintained until expansion of the lower lobe blocked the tube.
6. Fluid in the apical pleural space remained sterile for some time and then became infected, presumably from the underlying damaged lung.
7. This empyema was drained in the axilla and slowly obliterated.

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