It seems certain that the pulmonary capillaries are not passive tubes. They undergo active changes in calibre, as observed by Krogh (1929). I have already referred to these as actually seen by Wearn and his collaborators. It was at first supposed that these variations were due to the contractile cells in the capillary walls described by Rouget in 1873. Changes in surface tension in the capillary walls have also been regarded as responsible. These explanations must be considered as doubtful, and there is accumulating evidence that the changes are due to nervous and chemical control.

Little is known of vasomotor supply to veins, but there seems some reason to believe that they have a vasomotor supply and that they may be influenced by the reflex mechanism of the carotid sinus.

Chemical Factors in Regulation

The suggestion that the action of the vasomotor nerves might be due to an adrenaline-like substance liberated at the nerve endings was made by T. R. Elliott in 1904. Cannon subsequently called the substance "sympathin." Loewi in 1921–6 revived and greatly extended this conception of humoral transmission, and it has been studied in this country by Dale and his collaborators with very interesting results.

It would seem in general that the sympathetic endings are activated by an adrenaline-like substance, and are therefore called "adrenergic," while the parasympathetic endings and the motor nerve endings in voluntary muscle are susceptible to acetylcholine, and are therefore called "cholinergic." It is difficult to determine the effects of adrenaline and acetylcholine on the pulmonary vessels because of their coincident effects on the heart and the systemic and coronary vessels. Adrenaline can constrict the pulmonary arterioles and raise the pressure in the pulmonary artery, but it can sometimes produce dilatation, though this effect is apparently more marked in the capillaries. The action of acetylcholine varies with the dose, a dilatation of the vessels occurring with small and a constriction with large doses.

Histamine is normally present in the lung. Its effect is different upon the pulmonary vessels, which it constricts, from that on the systemic, which it dilates. The part played by Sir Henry Dale in the investigation of the problems of humoral transmission it would be difficult to overestimate. It was recognized by the award of the Nobel Prize in 1936. These researches illustrate the paramount importance biochemistry is taking on in the elucidation of physiological and pathological problems.

Adjustments of the Two Circulations

Although the two circulations are so closely dependent on each other there is a remarkable independence in regard to the respective arterial pressures in health. Considerable rises can take place in the systemic arterial pressure with little or no effect upon the pulmonary pressure levels, and the lungs can undoubtedly protect the left side of the heart from overdistension by shunting large quantities of blood into the pulmonary veins and capillaries. It is only when the left ventricle fails that the "back-working" effects become serious, increasing the pulmonary pressures, and decreasing the velocity of flow while increasing the right ventricle contractions and engorging the lung.

I have endeavoured to give a very brief description of the imposing edifice which has been built by Harvey's successors on one part of the foundation he laid so successfully. There is still much to be done, and no doubt some parts to pull down and rebuild. We must always keep open minds and be prepared to modify and adapt as new facts come to light.

REFERENCES (*continued*)

Barcroft, J. (1934). *Features in the Architecture of Physiological Function*, Cambridge,.
Berry, J. L., Brailsford, J. F., and Daly, I. de B. (1931). *Proc. roy. Soc.*, B, **109**, 319.
Blumgart, H. L. (1931). *Medicine*, **10**, 1, Baltimore.
Hall, H. L. (1925). *Amer. J. Physiol.*, **72**, 446.
Howell, W. H., and Donahue, D. D. (1937). *J. exp. Med.*, **65**, 177.
Krogh, A. (1929). *Anatomy and Physiology of Capillaries*, Newhaven.
Miller, W. Snow (1937). *The Lung*, Baltimore.
Wearn, J. T., *et al.* (1934). *Amer. J. Physiol.*, **109**, 236.
Wiggers, C. J. (1921). *Physiol. Rev.*, **1**, 264. Also *Physiology in Health and Disease*, 2nd ed., 1937, Philadelphia.

NOTES ON PENETRATING CHEST WOUNDS

BY

F. G. THOMSON, M.A., M.D., F.R.C.P.

Consulting Physician, Royal United Hospital, Bath; late Temporary Captain, R.A.M.C.

The following notes are based on over six hundred cases treated at base hospitals in France and England in 1917 and 1918. They may prove of some value to a new generation of medical officers who will presumably be called upon to treat large numbers of similar cases in the immediate future.

The following table shows the relative frequency of the various complications occurring either singly or in combination in a consecutive series of 250 cases seen at an advanced base hospital in France. Of these 75 per cent. were admitted during the first week and 90 per cent. within fourteen days of being wounded.

	No.	Per cent.
Haemothorax and pneumo-haemothorax:		
Simple 143 (57.2%)		
Infected 39 (15.6%)	182	72.8
Empyema (without obvious haemothorax) ..	9	3.6
Pneumothorax (without obvious haemothorax) ..	3	1.2
Pleural effusion (simple)	3	1.2
Homolateral collapse (deflated lung)	24	9.6
Contralateral collapse	16	6.4
Bronchopneumonia and capillary bronchitis ..	10	4.0
Lobar pneumonia	7	2.8
Pericarditis (purulent)	2	0.8
Septicaemia	2	0.8
Mediastinal abscess	1	0.4
Tetanus	1	0.4
Deaths from all causes while under treatment	12	(4.8%)
Transferred to England	238	(95.2%)

Twenty-four cases of non-penetrating wounds or wounds in which penetration was doubtful are included in this series because in all such cases injury involved either the lungs or pleura, as shown by haemoptysis, pleurisy, or pulmonary collapse. Cases seen at a later stage (over 350) at a base hospital in England are not included in the above list, as certain temporary complications—for example, collapse of lung—would have disappeared before the patients came under observation.

The after-history of cases which survive to reach the base emphasizes the great difference in outlook between wounds caused by bullets and those produced by fragments of shell. A simple "e. and e." wound from a machine-gun or rifle bullet which drills a clean hole through clothing, chest wall, and lung substance but fails to penetrate the heart or a big vessel causes remarkably few symptoms after the initial shock and rarely produces sepsis. Apart from temporary haemoptysis and haemothorax—which, unless large, is better left alone—the patient suffers relatively little inconvenience and rapidly

becomes convalescent. In the case of shell wounds the outlook is much more serious. Apart from the greater injury to the lung by laceration and the more frequent presence of a fragment of shell-casing in the chest, grave secondary infection of the pleura almost invariably results from the introduction of portions of dirty clothing, etc., into the wound.

Simple Haemothorax

The physical signs of a simple haemothorax are similar to those of an ordinary pleural effusion, except that, owing probably to the greater density of the fluid, loud bronchial or tubular breath sounds are frequently heard. The diagnosis is usually self-evident, but in case of doubt can be confirmed by exploratory puncture. As the contents of the haemothorax form an excellent medium for the growth of organisms exploration should be avoided if possible, and only be carried out with meticulous care. Repeated exploration is neither necessary nor advisable. Unless the effusion of blood is large enough to cause respiratory embarrassment aspiration is better avoided.

Prognosis.—In the case of perforating lung wounds with simple haemothorax the prognosis is eminently good, and complete functional efficiency appears to result in the great majority of cases. A remarkable example of this was provided by a man who had four Turkish machine-gun bullets through his chest—two through the upper lobe of each lung—in 1916, and was admitted to a base hospital in France just over a year later with a wound of the arm incurred in trench warfare.

Infected Haemothorax

Streptococci and anaerobic gas-producing organisms are mainly responsible for infection. *B. coli* infections occurred in several cases. The physical signs are the same as in a simple haemothorax, except that in the presence of gas-producing organisms the area of hyperresonance, absence of breath sounds, and presence of coin sound may indicate a pyopneumothorax. The symptoms are those of an ordinary empyema—pyrexia, sweating, dirty tongue, malaise, etc. Pain is a doubtful guide, as it will probably be present in any case from the wound in the chest wall. In anaerobic infection the symptoms are very severe. The patient becomes extremely ill, and unless operation is immediately performed the outlook is hopeless. In the case of a single wound in the chest wall the diagnosis of infected haemothorax is simple. The physical signs, together with smears from aspirated blood, settle the matter at once. In the case of multiple wounds, especially if they make it difficult to examine the base of the lungs, the symptoms may be attributed to other areas of infection and the haemothorax be entirely overlooked. It must always be remembered that often the chest is penetrated by missiles entering either at the root of the neck or in the upper abdomen or lumbar region. I have seen a number of such cases in which dullness and tubular breathing at the base accompanied by pyrexia have been wrongly attributed to a secondary pneumonia following on wounds in other areas. When heavy fighting is in progress and streams of wounded are coming through such mistakes are easily made.

Empyema.—Empyema in which the amount of blood effused into the thorax was negligible occurred in only nine cases (3.6 per cent.) of the above series. Large collections of pus lying free in the pleural cavity call for no particular comment and do not present any special difficulty in diagnosis. Other cases in which a small localized empyema is formed from the breaking down of lacerated lung, especially if interlobar, may cause great uncertainty. If there are one or more other infected wounds which might account for pyrexia and other symptoms the equivocal physical signs in the chest may make it almost impossible to be sure whether an empyema exists or not. The sudden onset of peculiarly offensive breath, if unaccompanied by any notable amount of sputum to suggest abscess or gangrene of the lung, may indicate that a small empyema is threatening to burst into a bronchial tube. This occurred in more than one case in the present series, in which, strangely enough, no case of pulmonary abscess or gangrene was seen. Each case of empyema must be taken on its merits and the site of the pus determined by careful examination and intelligent exploration. *X*-ray examination if available may help, but does not necessarily afford conclusive evidence.

Treatment of Infected Haemothorax and Empyema

In cases in which a bullet or shell fragment is shown by *x*-ray film to be lying free in the pleural cavity or near the surface of the lung, resection of rib, removal of the foreign body, and evacuation and drainage of the pleural cavity are obviously indicated. In cases in which it is not proposed to remove a foreign body resection of rib was the accepted treatment in the last war; but I feel strongly that some less drastic method is advisable in the majority of cases, at any rate in the early stages. As the result of haemorrhage, shock, exposure, exhaustion, and subsequent infection many of these cases arrive at the base in a critical condition and are ill fitted to stand the ordeal of a general anaesthetic and resection of rib, and if possible it should be avoided. Any form of treatment must not only ensure efficient drainage but should promote the rapid expansion of lung by preventing air suction through the wound during inspiration. In order to effect this many cases were treated in the last war by closing the resection wound firmly round a large thick-walled long drainage tube which was itself firmly stitched to the skin and allowed to hang over the side of the bed into a vessel containing an antiseptic fluid. This method has nothing to recommend it, for the simple reason that the constant dragging of the heavy tube on the inflamed skin stitch-holes produces continuous and intolerable pain. It is mentioned here only to be condemned.

An ideal method of drainage would be to introduce through a small stab wound in the intercostal space a large flexible self-retaining catheter, using a local or very brief general anaesthetic and attaching the catheter to a continuous suction apparatus—a method of treatment that has proved eminently successful in the empyemas of civil life. As the necessary suction apparatus is not likely to be available in sufficient quantity to deal with the large number of cases inevitable in warfare, a simple method which was found very effective in the war of 1914–18 seems to be indicated. The finger of a rubber glove with the end cut off is tied round the end of a thick-walled drainage tube, which is then passed through a hole in the centre of a six-inch square of jaconet or thin rubber sheeting. The edge of the aperture in the jaconet is firmly bound round the end of the drainage tube over the rubber finger. This simple apparatus can be used in conjunction with resection or be inserted through a stab incision in an intercostal space. While it allows free drainage during expiration, air is prevented from entering through the tube during inspiration by collapse of the rubber finger and from entering round the tube by the close apposition of the sheet of jaconet to the chest wall. Drainage by this method will prove effective

in the majority of cases without resection, and in the few in which this is ultimately required the patient is in far better condition to stand the operation later. Daily irrigation with warm Dakin's solution keeps the cavity clean and appears to hasten the disintegration of fibrin.

Fresh-air Treatment of Infected Haemothorax

During the early summer of 1917 certain desperately ill patients suffering from infected haemothorax in process of drainage were treated experimentally in the open air under awnings. The improvement was so remarkable that whenever circumstances allowed all such cases were subsequently treated in the same way, with equally satisfactory results. The value of fresh-air treatment was shown in another way at a Red Cross hospital devoted entirely to chest wounds, in the autumn of 1918 during the epidemic of influenza. One patient developed the disease and promptly died, whereupon as a preventive measure all windows were either kept permanently open or were removed entirely from their frames; the wards were stripped of all but bare essentials in the way of furniture and sprayed daily with a solution of chloride of lime. This regime was kept up during the whole of the ensuing winter, and though influenza was rampant at the time no further case occurred. The first case was the last.

Prognosis in Infected Haemothorax

Of thirty-three cases ten (30 per cent.) were fatal—six out of twenty cases of streptococcal or mixed streptococcal and anaerobic infection, and four cases out of thirteen due to anaerobes only. I feel that if some effective form of closed drainage on the lines indicated above could be universally employed to replace open resection when it is not proposed to remove a foreign body the results would be much better. In cases that survive the early stages convalescence should be shorter and the final result better owing to earlier and more complete expansion of the lung on the affected side. The early routine use of polyvalent anti-gas-gangrene serum in cases due to anaerobes should also be helpful.

Pneumothorax

Pneumothorax as demonstrated by hyperresonance, absence of breath sounds, and presence of coin sound may be due to perforation of lung, to gas formation by anaerobic infection of a haemothorax, or to the presence of a valvular flap wound of the chest wall allowing air to enter during inspiration but blocking its exit during expiration. Haemothorax due to either of the first two was never very large in the above series of cases. In one very extensive pneumothorax due to a flap wound the amount of air expelled through an aspirating needle and drainage tube was measured and found to displace over two litres of water from inverted bottles. The obvious treatment in such a case is resection and repair of the flap wound in the chest wall.

Homolateral Collapse: Deflated Lung

Following certain wounds of the chest wall, notably contused shell wounds over the base, examination of the underlying lung reveals dullness on percussion with loss of breath sounds and absence of vocal fremitus and vocal resonance, signs taken together strongly suggestive of fluid. Aspiration, however, is negative, and *x*-ray examination shows slightly increased density of lung shadow, a high diaphragm moving on respiration, but no sign of fluid. The lung appears to be stunned by the concussion and temporarily thrown out of action. The condition clears up in a few days and requires no treatment. Though more common in non-penetrating wounds, it occurs occasionally in wounds which actually expose the pleural cavity without producing a haemothorax. Non-penetrating wounds with deflated lung are often mistaken temporarily for penetrating wounds with haemothorax.

Contralateral Collapse

In this condition the physical signs are in strong contrast to those of homolateral deflation. At the end of a few days or a week after injury the base of the lung on the opposite side becomes dull on percussion, with loud tubular breathing, pectoriloquy, and increase of vocal resonance and fremitus. Fine crepitations occur in a few cases, but are more commonly absent. The physical signs are strongly suggestive of pneumonic consolidation, but symptoms of pneumonia are entirely absent. There is no pain, fever, increase of dyspnoea, or subjective symptoms of severe illness, apart from those incidental to the wound on the opposite side. On *x*-ray examination the dome of the diaphragm is seen to be much raised, up to about the level of the fourth rib, but still moves on respiration, indicating that contralateral collapse is a condition arising in the lung itself and not the result of diaphragmatic paralysis. The abnormal physical signs disappear within about a week, and the condition requires no special treatment.

Early Closure of Penetrating Chest Wounds

In 1917, when investigations were being made into the early closure of wounds, many cases of penetrating chest wounds were treated in this way immediately on arrival at a casualty clearing station, the wound in the chest wall being widely resected, a portion of the rib removed, the contents of the pleura swabbed out, and the chest wound firmly closed. While a certain number were extremely successful, others which afterwards developed infection of the pleura broke down, with deplorable results. A large open sucking wound was produced which either proved fatal or took many weeks to heal. Of a series of sixteen cases which arrived at the base after early closure eleven were quite successful, five broke down as described above, and two were fatal. Thus 31 per cent. of early-closure cases became infected, as opposed to 21 per cent. in cases not so treated, and the death rate of infected cases was 40 per cent. as opposed to 30 per cent. So far as it goes this small number of cases suggests that the early closure of penetrating chest wounds is a very doubtful procedure.

Morphine in the Treatment of Chest Wounds

In the first-aid treatment of chest wounds morphine in adequate doses is of vital importance. In reply to a question on this point my friend Mr. J. S. Levis, *M.C.*, speaking with the authority of four years' experience in front-line areas, summarizes the position as follows. "If they don't get enough morphine to stop restlessness and haemorrhage they won't live to get down to the base. If the first half-grain doesn't knock them out give them the other half." Later on, at the base hospital, morphine or one of its derivatives, though not in such heroic doses, is no less valuable to ensure a reasonable amount of sleep in spite of the pain and general mental and physical distress associated with a severe penetrating chest wound, and may be given without the slightest fear of any harmful effects. Omnopon (allopon) appears to be more satisfactory than plain morphine in that it produces less unpleasant after-effects. Though I must have prescribed many hundreds of doses of morphine and omnopon to these cases I have never yet seen it do anything but good.