JOINT DISCUSSION No. 2

Sections of Surgery and Pathology

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[*January* 6, 1941]

DISCUSSION ON THE PROBLEM OF BLAST INJURIES

Professor S. Zuckerman, Department of Human Anatomy, Oxford. (*Work carried out for Research and Experiments Department, Ministry of Home Security*): Aerial attacks on civilian populations raise problems, both in the field of passive defence and in that of medicine, that are new in warfare. They are new not because of any novel quality of bombs or high explosive, but because circumstances make them new. More tons of bombs are dropped on this country almost every night than were dropped in the whole of the 1914-1918 war. They are dropped not in any one place, but far and wide. To-day everybody is exposed not only to the health risks of peacetime, in many cases intensified by changed living conditions, but also to the casualty hazards of air raids. Neither partial and isolated observations, nor preconceived conceptions of what happens in warfare, can show what these hazards are. The medical problems so acutely raised by air raids form a new sphere of research which demands in its attack more than simple clinical observation in hospitals. It was in the realization of this fact that the Research and Experiments Department of the Ministry of Home Security initiated, as part of its programme, a two-sided investigation of the physiological effects of high explosive and of the actual circumstances under which different types of casualties occur.

A bomb is a charge of high explosive encased in metal. Its primary effects (as distinct from any secondary effects due to secondary missiles and falling debris) are clearly defined. In a remote possibility a man may be directly hit by the bomb itself; more frequently he will receive wounds from splinters of the metal casing, or be affected by the blast wave set up by the explosion; in certain special circumstances he may be burnt by the flame of the explosion or poisoned by the gases it generates. However remote they may be from the accidents of civil life, and even though each of them to-day presents special problems for investigation, splinter wounds, burns and carbon monoxide poisoning can be fairly readily understood on the basis of existing knowledge. The effects of blast, however, do not come into any experience of civil life—except when a disaster occurs in an explosives factory.

To a Medical Officer of the 1914-1918 World War, blast was something that blew a man to pieces, or threw him violently. The clinical literature of that period contains practically no reference to the possibility that blast, other than injuring the ear-drums, can directly cause injuries in the thorax and abdomen without surface wounds. The Spanish war gave a different meaning to the term, for numerous observers reported that the blast from bomb explosions could kill at long distances, even when the casualty had not been struck by splinters or secondary missiles. People so killed were picked up dead in the area of an explosion, without any external injury and usually showing blood-stained froth in the mouth and nose. It is realized to-day that these reports exaggerated the danger of blast and the distances at which it can cause casualties; but recent experiences in this country have confirmed the fact that blast can hurt without either blowing a man to pieces or just throwing him to the ground.

Stories of men dead in battle without external injury were also current in the 1914-1918 war. Mott (1919), for example, describes a few such cases in some of whom nervous lesions were found. In general, however, as is clearly indicated in the Report of the War Office Committee of Enquiry into "Shell-shock" (1922), there is little or no evidence about the cause of death in any of these cases, either from the point of view of the circumstances in which it occurred or from that of post-mortem examination. Reconsideration of observations made in 1914-1918 suggests, however, that lung injuries unassociated with open chest wounds did occur during the First World War. Thus Thompson (1940), in a discussion of 250 cases of penetrating chest wounds includes "24 cases of non-penetrating wounds or cases in which penetration was doubtful, because in all such cases injury involved either the lungs or pleura as shown by hæmoptysis, pleurisy or pulmonary collapse". Lockwood (1940), again, writes of men who died as a result of a near-by shell or bomb explosion, without apparent wounds, or from a wound so slight or in such a position that it could not in itself have been the cause of death. According to him, such men manifested "rupture of the visceral pleura of the lungs or a complete collapse of the lungs, through the suction of air incidental to the blast, or due to reflex or bends".

Experimental

Some experimental observations on the effects of blast were also available at the start of the present war. In 1918 Marinesco reported the results of experiments in which dogs were exposed to the blast of small charges of "fulmicoton". Blood was observed in the nose and mouth of one animal, and others exposed in "shelters" suffered afterwards from dyspnœa, depression, and difficulty in walking. Microscopic, and occasionally larger, hæmorrhages were observed in various parts of the central nervous system, and more obvious hæmorrhages in the lungs. Hæmorrhagic lesions occurred less frequently in the liver, spleen, kidney, and adrenal. Similar pulmonary and nervous lesions were observed by Mairet and Durante (1917, 1919), while Hooker (1924), in the course of an experimental study of the shock produced by charges of T.N.T. and gun-blast, found that bruising and occasionally rupture of the lungs was "the single gross lesion found post-mortem in cats, dogs, and rabbits after exposure to air concussion due to gun-blast or high explosive". Hooker also found that disturbances of respiration were frequent and set in at variable times after the explosion. Some animals died as a result of being exposed; others recovered immediately; while rabbits and cats died when exposed to blast which failed to affect dogs seriously. More recently, in physiological studies carried out in this country under the supervision of Sir Joseph Barcroft, F.R.S., in connection with official tests of sectional steel shelters, similar lesions were observed in the lungs of goats and rabbits exposed to the blast of a 500 lb. medium case bomb. (Sectional Steel Shelters: Report upon Investigations of the Standard of Protection Afforded. H.M. Stationery Office, 1939.)

Our first experiments were designed to discover how blast produces lesions in the lungs and in other organs.[1] In the course of this study, in which numerous animals have been exposed in successive experiments to the blast from surface charges of H.E., observations relating to lesions in other organs of the body have also been made. The charge of H.E. used in our studies varied in different experiments, the maximum being 70 lb.; in all cases the explosive was detonated in paper containers so as to avoid any effects of flying missiles.

The Nature of Blast

When a bomb detonates, the solid explosive is converted into gases which initially are confined in the casing at a pressure that has been variously estimated as between 100 and 650 tons per sq. in. As a result of this pressure, the casing is blown to pieces, and the gases escape, and by their expansion produce a blast wave in the surrounding air. The blast wave is a single pulse of increased pressure followed by a phase of suction, and

[1] Detailed reports of these studies will be published later. Dr. P. L. Krohn, Dr. R. B. Fisher, Dr. D. Whitteridge, Dr. E. H. Leach, Dr. F. H. Kemp, Dr. C. W. M. Whitty, Dr. D. L. M. Doran and Dr. T. McKeown have collaborated in different parts of the research.

in general form is similar to a single pulse of a large amplitude sound wave (fig. 1). The wave moves extremely rapidly, much more rapidly than sound close to the explosion, and, in the case of a medium-sized bomb, falling to the velocity of sound (1,120 ft. per sec.) at about 200 ft. The total duration of the whole wave at any given point within 200 ft. of an explosion is very brief. Thus at 30 ft. from a 70 lb. charge the pressure component lasts about 5 and the suction component 30 millisecs. The duration of the pressure

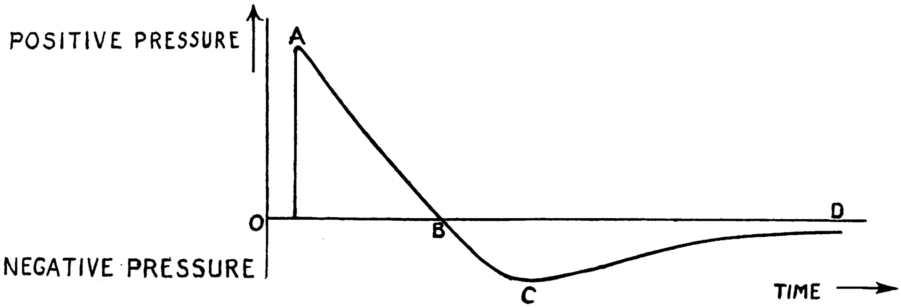

FIG. 1.—Diagrammatic representation of shock-wave. Adapted from A.R.P. Handbook No. 5, " Structural Defence ". Reproduced by permission of the Controller of H.M. Stationery Office.

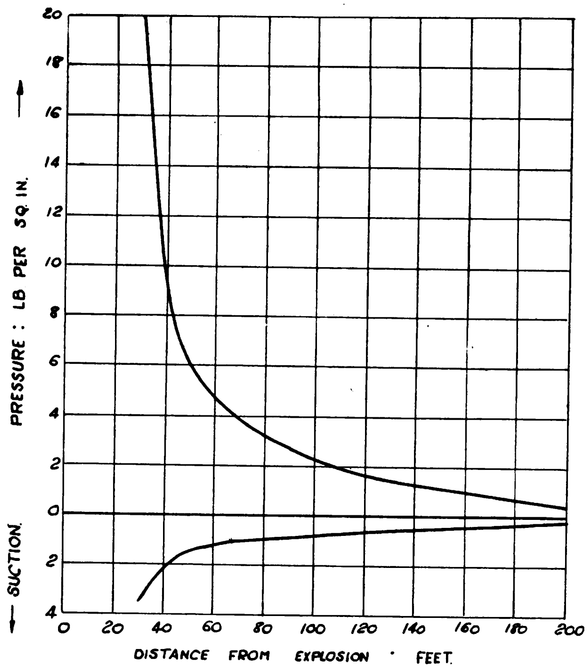

FIG. 2.—Maximum blast pressures and suctions from medium case bombs. From A.R.P. Handbook No. 5. Reproduced by permission of the Controller of H.M. Stationery Office.

component increases progressively with increasing distance from the charge, but the suction component, which generally lasts three to five times as long, remains more or less constant. It should be noted that the velocity and duration of the pressure wave at any given point are such that a body as large as a human being would certainly be completely immersed for an instant in a wave of almost uniformly raised pressure.

The maximum pressure of the wave is highest in the region of the explosion, and the pressure at first falls rapidly the further the wave moves from the source of the explosion (fig. 2). In the case of a 70 lb. charge the pressure falls approximately as follows :—

14 ft. 110 lb. ; 18ft. 60 lb. ; 30 ft. 15 lb. ; 50 ft. 6 lb.

These figures represent hydrostatic pressure in excess of normal atmospheric pressure, which is approximately 15 lb. per sq. in.

Any surface facing an explosion will be subjected not only to this excess hydrostatic pressure but also to pressure due to air-movement immediately behind the shock-front of the blast wave. Close to an explosion this pressure may be as great as, or greater than, the hydrostatic pressure of the shock-front, but further from the bomb the pressure effect of this air-movement is of little importance ; it is negligible for hydrostatic pressures less than 5 lb. per sq. in.

The suction component of the blast wave is always much weaker than the pressure component, and in no case can it ever be greater than 15 lb. per sq. in., since this corresponds to a perfect vacuum.

The magnitudes of the pressure and suction components of a blast wave and the time they last are directly correlated with the amount of explosive, and are much higher for larger than for smaller amounts. On the other hand, if a given positive pressure is caused by a given amount of explosive at a given distance, the same pressure will be experienced at twice that distance only when the amount of explosive is increased eight times.

All things in the immediate neighbourhood of an explosion thus first experience a violent increased pressure, which may tear them to pieces and blow them far from the scene of the explosion, or affect them directly without doing either of these things. Whether or not an object is shattered by, and blown in the direction of the pressure wave, it may later be pulled towards the centre of the explosion by the backward movement of air associated with the weaker suction wave, because of the longer time for which this acts.

It should be noted that close to the point of an explosion the advancing wave's front is uneven, so that objects at equally close distances to the point of detonation may be exposed to different pressures. Further away from the explosion the blast wave becomes more even.

Direct Effects of Blast on Animals

The effects of blast have been studied in mice, rats, guinea-pigs, rabbits, cats, monkeys and pigeons. In general it has been found that different species vary in susceptibility, and that animals exposed close to an explosion (i.e. exposed to a higher blast pressure) suffer more than those further away. No lesions have been observed at pressures of 5 lb. per sq. in., while small mammals such as rabbits may be killed instantaneously at pressures of 50 lb., and are certainly killed at pressures approaching 100 lb. per sq. in.

Field observations.—Animals immediately adjacent to an explosion are blown to pieces. Further away there is a range of pressure, which varies from species to species, in which all animals will be immediately killed, without external injury, but often showing blood-stained froth, or blood, in the nose, mouth, and upper respiratory passages. Still further away, and with considerable variation for different individuals, is a zone of pressure in which animals are found alive immediately after an explosion, but die at intervals varying between a minute and a day. Animals in this group may have blood-stained froth in the upper respiratory passages and often suffer from air-hunger, dyspnœa and tachypnœa. They are usually apathetic and quiet, and disinclined to feed. Such animals are nevertheless capable of considerable physical exertion. Knee-jerks, corneal and pupillary reflexes have been found to be normal immediately after the explosion. Even hearing does not seem (on superficial examination) to be impaired. Observations on immediate changes in blood-pressure are now in progress. Observations on blood-counts, coagulation-time, and cell fragility have not yielded positive results.

Some animals which show blood in the upper respiratory passages, and which exhibit most of the characteristics that have been mentioned, survive the twenty-four-hour period, and recover completely.

Still further from the explosion, in a zone of lower pressure, animals are unaffected externally by the explosion, although internal examination reveals changes in thoracic, and occasionally abdominal, organs. Animals exposed beyond this zone of pressure exhibit neither external nor internal effects of the explosion.

Post-mortem appearances: (1) *The lungs.*—The most outstanding lesion, as was found by Marinesco and by Hooker, is hæmorrhage in the lungs, varying in degree according to the pressures to which the animals have been exposed. The following description has already been given of the pulmonary lesions (Zuckerman, 1940):—

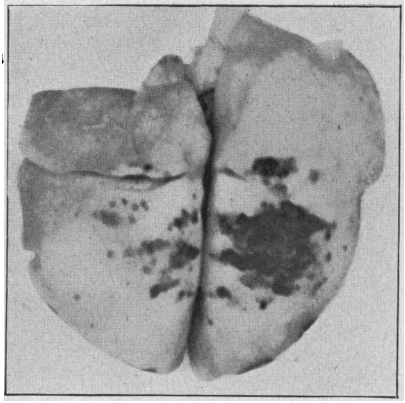

FIG. 3.—Lungs of a rabbit exposed to blast, showing small areas of hæmorrhage, following the lines of the ribs.

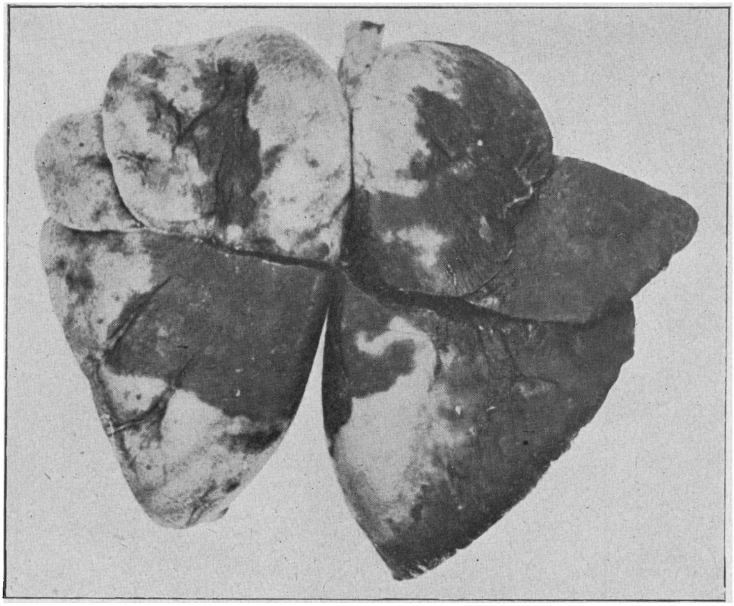

FIG. 4.—Lungs of a monkey exposed to blast, showing more extensive areas of hæmorrhage.

" To direct inspection the lesions, in cases of very slight damage, appear as spots of hæmorrhage on the surface of the lungs (fig. 3). In severer cases, patches of hæmorrhage, of varying size, are present (fig. 4), and in very severe cases the entire surface of the lungs is hæmorrhagic (fig. 5). The hæmorrhages often follow the line of the ribs

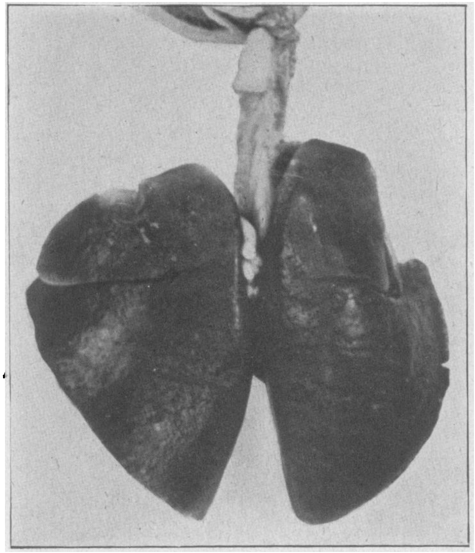

FIG. 5.—Very severe hæmorrhages throughout the lungs of a rabbit exposed to blast.

FIG. 6.—Section through lung of a cat exposed to blast, showing extent of a zone of hæmorrhage.

(fig. 3), and even when the hæmorrhage in the lungs is sufficiently extensive to affect almost the entire surface, darker lines of hæmorrhage following the lines of the ribs can sometimes be recognized against a background of lighter hæmorrhage. In most severe cases there may be superficial laceration along the lines of the ribs, which have presumably been driven into the lungs (*see below*). In such cases a hæmothorax and pneumothorax occur.

"When the lungs are sectioned, confluent zones of hæmorrhage, in very severe cases, are seen to extend almost through their entire substance (fig. 6). In some very severe cases the lungs were completely 'hepatized' by hæmorrhage. In less severe cases localized and scattered hæmorrhages occur, sometimes in relation to a large bronchial tube. In slight cases points of hæmorrhage are present and are mainly subpleural in their disposition. As a general rule areas of internal hæmorrhage are related to zones of hæmorrhage visible on the surface.

"The most vulnerable regions of the lungs are the anterior borders, which become pressed (*see below*) between the front of the chest-wall and the mediastinum, and the inferior borders, which become compressed in the costophrenic sinus. The costal surfaces are also a site of election, and another very common site of injury is the mediastinal surface of the lungs, and in particular the azygos lobe, which passes from the root of the right lung across the mid-line behind the heart towards the left side.

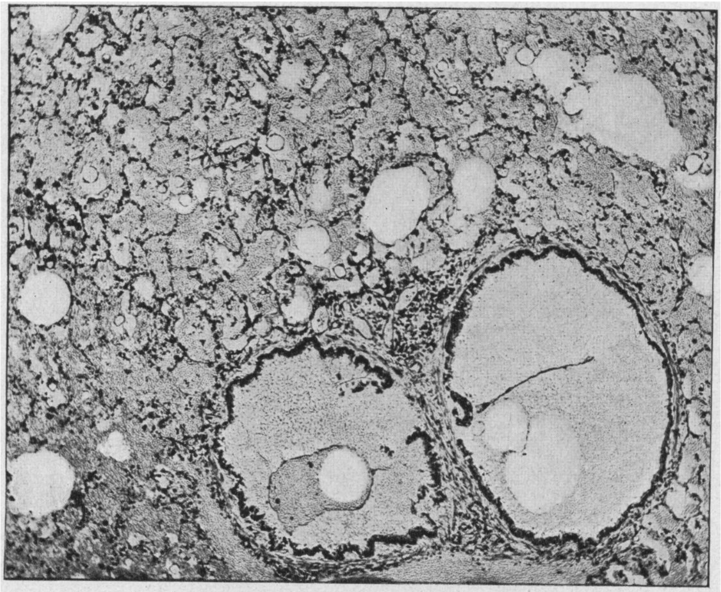

FIG. 7.—Section of a rabbit lung after exposure to blast. The alveoli and bronchioles are filled with blood. × 71.

"In all cases where the degree of lung injury has been sufficient to kill the animal, blood was found in the bronchial tubes, the trachea, and usually the mouth and nose. Blood is not found in the trachea or nasopharynx of animals which have been only moderately injured by blast, and it is occasionally absent when there has been extensive damage."

The following observations can be added to this description. Lacerations occasionally occur on the borders of the lungs, which may show a disproportionate amount of internal as compared with external hæmorrhage which, however, is always present; lesions often appear more pronounced on macroscopic examination in animals that die some hours after an explosion than in animals killed by the explosion; and finally no lungs, in a series of several hundred, have been observed in which the lesions took the form of small uniformly-scattered foci of hæmorrhage.

Microscopically the areas of damage appear as zones in which the alveoli and the smallest bronchial tubes are filled with blood (fig. 7). The alveolar walls can often be seen to be disrupted, hæmorrhage originating in the torn alveolar capillaries. Interstitial hæmorrhage also occurs. In severe grades of damage large areas of the lung are disrupted and hæmorrhagic, and the larger bronchial tubes become filled with blood. Collapse unassociated with hæmorrhage has not been observed except during the process of healing.

Observations on cats show that all but the lesser degrees of lung bruising are detectable radiologically, the lesions appearing as areas of mottling and shadow.

It is difficult to make any definite statement about the rate of healing of the lesions, owing to the impossibility of determining the initial amount of damage in a given lung. X-rays of cats that had been exposed to blast suggest that the process is rapid, but mice and rabbits examined up to forty-five days after exposure have still shown superficial, though not deep, signs of previous damage. Pleural adhesions are not uncommon, and

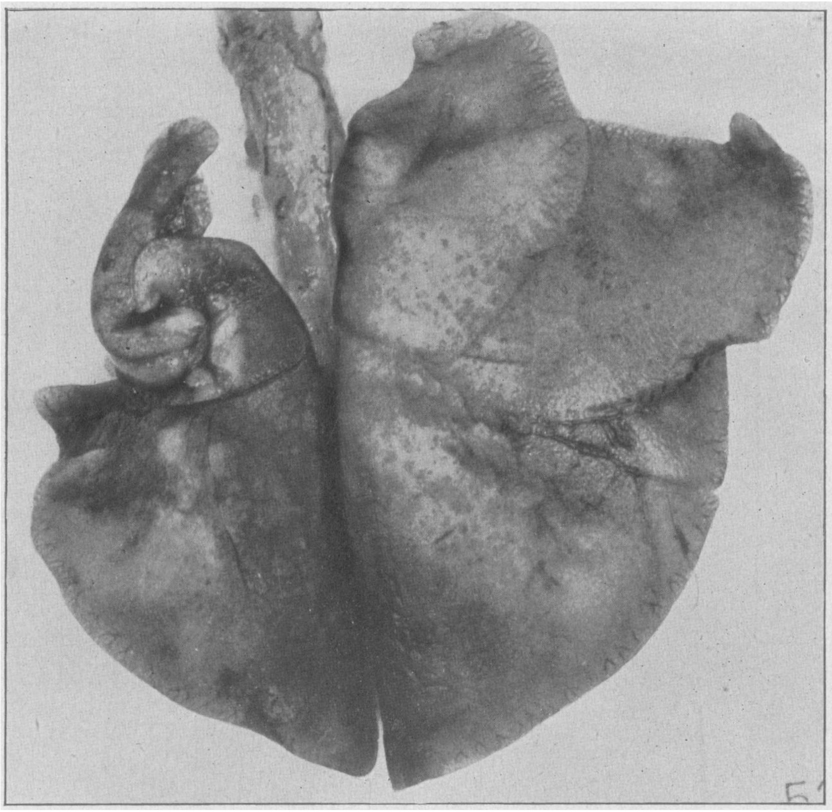

FIG. 8.—Lungs of a rabbit 20 days after exposure to blast. The upper lobe of the left lung is completely collapsed.

in a few cases total collapse of a single lobe has been observed up to twenty days (fig. 8). Pneumonic consolidation, with heavy monocytic and polymorphic infiltration, also occurs.

(2) *Factor responsible for pulmonary hæmorrhages.*—Although they have not investigated the problem experimentally, previous observers have speculated about the manner in which the pulmonary lesions are caused. Three possibilities have been suggested.

The first is that the lesions are due to the lowering of alveolar pressure by the suction wave, acting through the respiratory passages, with the consequent rupture of the alveolar capillaries. This possibility is suggested by Logan (1939), by Shirlaw (1940, p. 41), and in reports of French shelter tests. It is also the view which is often stated in discussions of the casualties that occurred in Spain. The second possibility is that the lesions are caused by the "sudden distension of the lungs with air" rather than by "external pressure on the ribs" (Report on Sectional Steel Shelters. Physiological Section. H.M. Stationery Office, 1939). The third possibility is that the lung lesions are due to the impact of the pressure wave on the chest wall. This view is advocated by Hooker who writes with reference to experiments on frogs: "It is wholly improbable that lowered pressure could distend these organs sufficiently to cause their rupture. On the other hand a sudden elevation of pressure retarding the expulsion of air through the trachea and forcibly compressing the body walls could readily rupture these delicate organs." The same belief about the cause of the injury is stated by Kretzschmar (1940) in his recent clinical description of blast casualties in Spain.

Our own experiments suggest that the last of these possibilities is the correct one, and that internal injuries due to blast are mainly caused by the impact of the blast wave on the body wall.

Thus experiments in which animals were exposed to blast from the explosion of charges of hydrogen and oxygen in balloons showed that lesions are bilateral when the animals are placed some distance from the explosion, and mainly, if not entirely, unilateral when

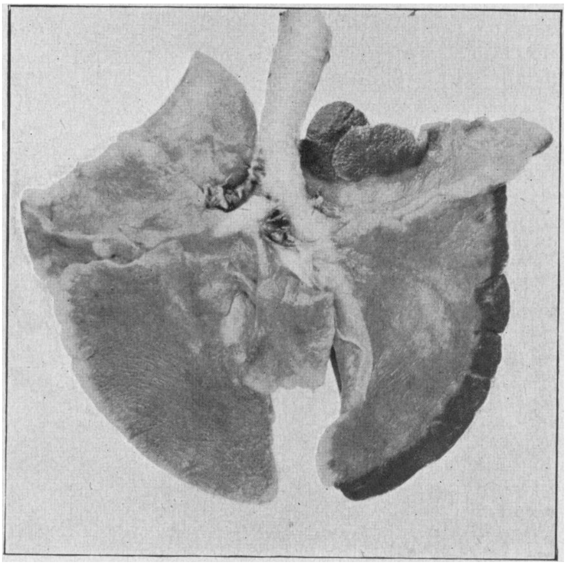

FIG. 9.—Lungs of a rabbit exposed close to the explosion of oxygen and hydrogen in a balloon. The hæmorrhages are confined to the side closest to the explosion.

the animals are placed so close that one side shields the other (fig. 9). In the latter case the lesions are on the side facing the explosion. This fact (as well as the anatomical sites of election of the hæmorrhages) suggested that the lesions are caused by the impact of the wave on the body wall. It could hardly be interpreted in any other way. For if blast affects the lungs through the respiratory passages, either by reducing alveolar pressure or by suddenly distending the alveoli with air, it is impossible to explain why animals placed close to the balloon explosion sustain damage to one lung only, and to the lung on the side facing the explosion. This consideration seems to render untenable views which regard the effect as indirect and not direct. One indirect view which has been tested is that the lesions are due to back pressure in the pulmonary circuit. Experiment showed, however, that while small scattered hæmorrhages do occur in the lungs, following ligation of the aorta, the lesions are bilateral and different in disposition from those seen in animals exposed to blast. A further and important consideration, which suggested that the lesions cannot be due to any pressure changes occurring directly by way of the respiratory passages, is the observation that in some circumstances lesions due to blast may occur in almost every abdominal organ (*see below*).

The hypothesis that the lesions are due to the impact of the blast wave on the body wall was confirmed in a first set of experiments which showed that rabbits that are thickly clothed in sponge rubber jackets receive no pulmonary damage, or very slight damage compared to controls. In a further set of experiments, rabbits were exposed to blast from balloon explosions with only one side of the trunk clothed in this way, the animals being placed as close to the balloon as was possible. Those animals which were exposed with the uncovered side facing the explosion suffered severe damage to the lung on that side, and less severe damage to the lung on the opposite side. Those animals which were exposed with the clothed side facing the explosion suffered no damage, or very slight damage to the lungs. In yet a third series of experiments, rabbits were placed in specially made wooden boxes with only their heads exposed, and arranged at distances from a

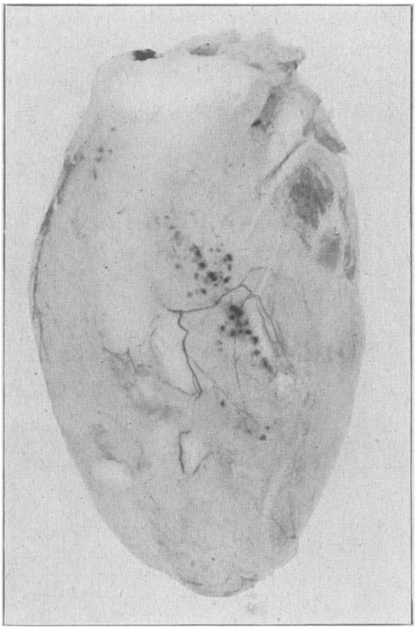

FIG. 10.—Hæmorrhages in the epicardium of the heart of a monkey that had been exposed to blast.

charge which usually proves fatal, and at which severe pulmonary lesions are always found. The boxes did not stand up to the blast, but in those cases in which they were only slightly damaged, pulmonary hæmorrhages were slight or absent.

Although these many considerations show that it is the pressure component of the blast wave which is the factor responsible for internal injuries, it is not impossible that, once the lungs have been bruised by the impact of the pressure wave, the suction wave could add to the damage by pulling the chest wall outwards and thereby stretching the lung tissue (which would follow the movement of the chest wall).

(3) *Other thoracic organs.*—Small hæmorrhages are occasionally observed in the

thymus and pericardium, and more rarely in the epicardium (fig. 10). A fairly constant feature associated with sudden death due to blast is right-sided dilatation, but no changes have as yet been found microscopically in the myocardium or endocardium of animals exposed to blast. A hæmopericardium was observed in one case.

Hæmorrhage is occasionally observed in the intercostal muscles, but none has been seen in the subcutaneous tissues or muscles of the pectoral girdle.

(4) *Abdominal organs.*—About 40% of all animals examined (all of which had pulmonary hæmorrhages) showed hæmorrhagic lesions in various abdominal organs. Two-thirds of the 40% had been killed by the blast to which they had been exposed. The severity of abdominal lesions does not appear to be correlated with survival, and in general abdominal organs are much less sensitive to blast than the lungs.

The most susceptible abdominal organ is the large intestine, where the lesions appear as patches of hæmorrhage varying from small points of bleeding in the subserosa to large annular bands of hæmorrhage, and even rupture (fig. 11). The small intestine and stomach are less frequently affected.

The liver may be bruised, and occasionally torn ; in some animals the surface of the right lobe may be marked by lines corresponding with the ribs. Hæmorrhages are more rarely observed in the spleen, kidney, adrenal, and bladder, which in one case, however, was ruptured. By chance some pregnant guinea-pigs were used in one series of experiments. Hæmorrhages were observed in the uterine wall, and in the upper parts of the fœtuses.

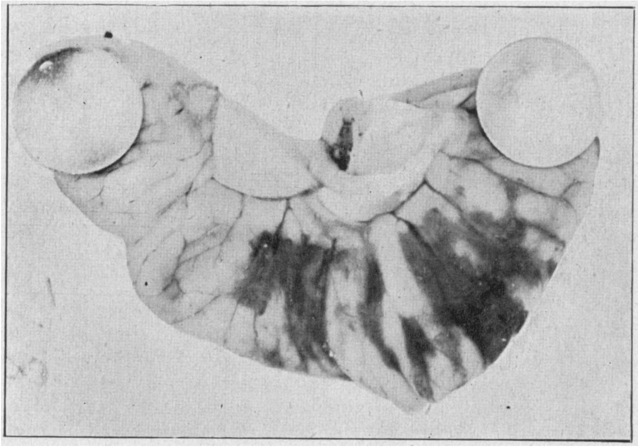

FIG. 11.—Hæmorrhages in the small intestine of a monkey that had been exposed to blast.

Small blood-clots have sometimes been found in the peritoneal cavity, and retroperitoneal hæmorrhage has also been seen. Foci of hæmorrhage are not uncommon in the mesentery.

(5) *Head and neck.*—Hæmorrhages have occasionally been observed in the fascial planes of the orbital cavity, but not in the eyeballs themselves. Rupture of the ear-drums has also been often observed in animals exposed to high pressures. Hæmorrhages have been found in the paratracheal fascia, and more frequently in the trachea itself, where they are mainly localized in the submucosa.

(6) *Nervous system.*—Particular attention has been paid throughout our investigations to the occurrence of nervous lesions. The brains of rabbits exposed in our earliest experiments were examined by Dr. Greenfield ; no changes which could definitely be ascribed to blast were found, a conclusion that was also reached by Professor Le Gros Clark in an independent study of another series of brains. A larger series of animals,

that had been exposed to higher blast pressures, has since been studied, and the following is a brief statement of the more important findings.

No changes were observed in the cortex, mid-brain, pons or medulla of monkeys subjected to pressures as high as 110 lb. per square inch. On the other hand, most monkeys exposed to high pressures show extradural hæmorrhages in the thoracic spinal roots, which are sometimes continuous with hæmorrhage along the intercostal nerves. In two animals that died hæmorrhage had occurred at the central ends of the posterior columns, and in the dorsal commissure. Furthermore, most animals have shown a zone of œdema, absent in controls, around the central canal, especially in the thoracic region but also in the cervical and lumbar cord. This œdema may involve both anterior and posterior commissural fibres.

Changes in nervous tissue are more pronounced in rabbits exposed to high pressures. Pial hæmorrhages occur on the surface of the cortex, and hæmorrhage from the tela choroidea, filling the ventricles, has been observed. Hæmorrhages have not been seen, however, in either the grey or white matter of the brain.

Spinal-cord hæmorrhages are of the same kind as, but more severe than, in the monkey.

It is conceivable that as a result of these lesions the sympathetic outflow may be interrupted, and that sensory defects may occur as a result of œdema and pressure on the commissures.

(7) *The effect of blows on the body wall.*—It has long been known that severe falls, or a blow from a fast-moving vehicle, or a direct blow, may damage thoracic and abdominal organs without causing any penetrating injury. Moreover, traumatic pneumonia has long been recognized as a clinical entity. Thus Morgagni described lung bruising which resulted from a fall off a horse, and Gosselin in 1847 devoted a paper to the subject. More recently the problem has been reviewed by Fischer (1912), and detailed papers describing the condition have recently been published by Fallon (1940) and Osborn (1940). Furthermore, it may be noted that both Courtois in 1873 and Külbs in 1910 showed experimentally that pulmonary hæmorrhages occur when the chest-wall of animals is struck by a mallet.

It follows, therefore, that the pulmonary lesions due to blast are at least partly comparable with those caused by direct blows on the body wall. This fact is important, as is shown below, because air-raid victims are more usually subjected to indirect blast effects such as violent displacement or the impact of flying and falling masonry than they are to the blast wave itself.

Blast as a Factor Causing Casualties

These experimental findings indicate the kind of injuries that are to be expected as a result of the direct action of blast on the body. In air raids, however, the circumstances in which blast acts are very unlike the experimental conditions that have been described. In the first place the explosive is contained in metal, and part of the energy of the explosion-gases is absorbed in shattering the casing. Splinters and secondary missiles are sent flying, buildings are blown up, houses collapse as a result of ground shock-waves; these and many other structural effects all conduce to injuries. In order to see where and how blast of itself can injure it is therefore necessary to define the circumstances under which injuries may occur in air raids. The classification that we have found useful in our casualty survey is as follows:—

Primary

Effects due to.—(1) (*a*) Being hit by splinters; (*b*) being affected by the impact of the blast wave (e.g. effects on the lungs and ears); (*c*) being burnt by the flame of the explosion; (*d*) (possibly) being poisoned by C.O. liberated by the explosion in enclosed spaces; and (*e*) (possibly) in the remote chance, being hit by the bomb itself.

Secondary

Effects due to.—(2) (*a*) being thrown by the blast wave against a hard surface; (*b*) being bowled over as a result of a splinter wound.

Tertiary

Effects due to.—(3) (*a*) Being hit by secondary missiles, e.g. flying masonry, wood, furniture, glass, girders, &c.; (*b*) having walls, floors, ceilings, fall on one, either as an immediate effect of an explosion or as a result of collapse due to an earth shock-wave; burial under debris; in steel shelters, being crushed by the caving-in of the shelter; (*c*) falling, through being knocked, other than directly by blast, from a raised position, or through the collapse of a floor; and (*d*) (possibly) the impact of an underground wall violently accelerated, but not broken, by an earth shock wave.

Quaternary

Effects due to.—(4) (*a*) Asphyxiation; (*b*) carbon monoxide poisoning; (*c*) burns; and (*d*) drowning.

The primary effects of blast will be experienced only very close to an explosion—for example, when a bomb bursts within an inhabited room or shelter. Furthermore, except with large bombs, the primary effects of blast are hardly likely to be experienced further than 20 ft. from the bomb. This danger zone for blast is obviously, too, the most dangerous zone for splinter wounds.

The radius within which primary blast injuries may be expected will be further limited by the circumstances under which the explosion occurs. Thus, when a bomb detonates after it has penetrated into the ground, so that a deep crater is formed, the blast is mainly directed upwards in an expanding cone, and people standing or lying close to the lip of the crater will be protected from the wave of increased atmospheric pressure. Furthermore, when a bomb detonates close to walls, the blast is reflected, and its energy absorbed in odd ways, so that people situated near-by may escape the impact of the wave. Again, as already mentioned, the front of the blast wave close to the bomb is irregular, so that people situated at the same close distances may be subjected to different pressures. This fact helps to explain certain instances in which individuals have escaped injury. For example, in one case that was investigated eight men were together in a single story room 20 ft. by 16 ft. in which a bomb exploded slightly above floor level (having apparently bounced). Of the eight, five were killed and three survived; all three, however, developing symptoms indicative of lung injury.

In general it may be said that, of the total number of people thus far injured in air raids, only a small percentage will have been exposed in circumstances where they would have been affected by the blast wave in such a way as to incur the injuries that have been discussed above.

Fatalities due to blast have, however, already been reported and many more must undoubtedly have occurred. The difficulty arises in their diagnosis. One case has been described by Falla (1940), another by Osborn (1940), and several by Hadfield, Ross, Swain and Drury-White (1940). Falla's case is that of a man who was in a workshop in which a bomb exploded some 45 ft. away from him. This casualty received a large lacerated wound of his right thigh, and died some twelve hours later. Post-mortem examination revealed many small fresh hæmorrhages on the surface of the lungs, and scattered points of hæmorrhage throughout the substance of the lungs—" a miliary condition of fresh hæmorrhages ". Microscopic examination revealed fairly generalized arteriolar dilatation, and intense focal capillary dilatation, with exudation of fluid into many alveoli. In a few places the lung tissue was disrupted and free blood-cells were present in the alveoli, the small bronchial tubes, and the interstitial tissue. In Osborn's case the casualty, a girl of 17, was in a house that was demolished by a high explosive bomb. She showed some external injuries and had a fracture of the skull. A blood-stained effusion was present in both pleural cavities, and the large air passages were filled with blood-stained froth. Both lungs contained multiple small hæmorrhages. A few larger hæmorrhages were also present, and there was a wedge-shaped zone of hæmorrhage 9 cm. long on the inferior border of the left lung, i.e. that part which fits into the phrenico-costal sinus. The spleen was also torn, and there was some intraperitoneal hæmorrhage. The cases described by Hadfield and his collaborators were members of a group of ten air-raid casualties; gross traumatic lesions were either absent or trivial in all but one case. One, a man of 45, was found dead in a public shelter which received a direct hit. There were irregular hæmorrhagic areas throughout both lungs, but no other injuries. A second was a man of 81 who survived ten hours after he was rescued from the debris of a collapsed shelter. Frothy blood-stained mucus was present in the upper respiratory passages, and areas of irregular hæmorrhage were present in the substance of both lungs. There were no other injuries. A third was a woman of 29 who was extricated from a demolished house. Externally she showed a contusion of the scalp and multiple lacerations of both the upper and lower limbs. She had surgical emphysema of the tissues of the neck, the mediastium and pericardium, and a fractured skull. The only other injuries found were ill-defined areas of recent hæmorrhage in both lungs. A fourth was a child aged about 2 years who had numerous external wounds and a penetrating wound of its chest wall. The upper respiratory passages contained frothy blood, and there were areas of hæmorrhage throughout both lungs. A few small hæmorrhages were also present on the posterior part of the liver. The other six cases described by these authors also showed pulmonary hæmorrhages, and in three the blood was heavily saturated with carbon monoxide.

The clinical and experimental literature, as already noted, contain many examples of corresponding lesions produced as a result of the impact of the body either with the ground or with a rapidly moving solid body. The conditions of air raids provide only too many opportunities for such impacts. At pressures slightly lower than those which will cause direct effects upon internal organs, blast may act as a very strong wind, and is able to throw

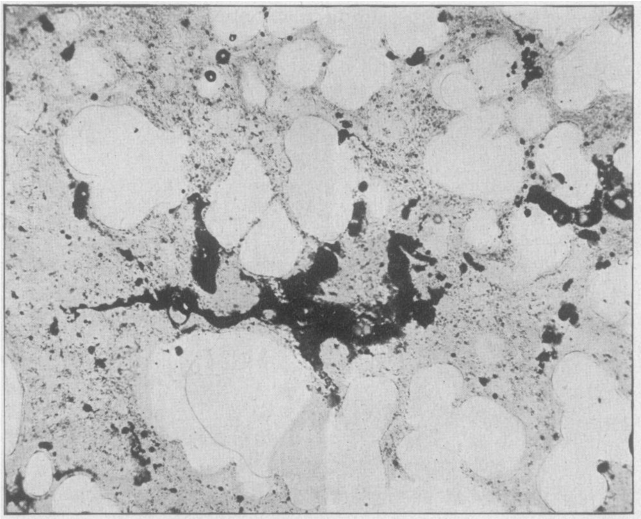

FIG. 12.—Section of the lungs of a woman killed in an air raid. The casualty was extricated from the remains of her house, and autopsy revealed numerous hæmorrhages in both lungs. The specimen has been stained with scharlach R. (black regions) to demonstrate fat. × 58 (H.L.5).

people relatively considerable distances ; when a person is violently thrown against a hard surface, injuries to internal organs may occur. During air raids, again, people are struck by flying or falling masonry, or are compressed by the debris of a house, or fall from an elevated position due to its collapse. All these circumstances may result in internal injuries, and particularly in lung bruising of the sort that has been described in these post-mortem reports. In a recent paper, Robb-Smith (1941) gives a record of 115 fatal accident cases, of whom 20 showed pulmonary hæmorrhages unassociated with penetrating chest wounds. Only one of these 20 was an air-raid casualty, and Robb-Smith states that the pulmonary hæmorrhages that have hitherto been described in air-raid casualties are no different from the hæmorrhages following severe blows and falls. He also suggests that "pulmonary symptoms which arise from exposure to the blast of high explosive may be due to a combination of pulmonary concussion and fat-embolism ". Repeated observation has failed, however, to reveal fat emboli in the lungs of animals exposed to blast, and it must therefore be assumed that fat embolism does not play a part in causing lung lesions in animals exposed to blast alone. It might do so in those clinical cases in which the primary effects of blast are complicated by violent falls and by the impact of falling or flying masonry, or in which lung lesions can be ascribed entirely to the latter circumstances (fig. 12).

The conditions which in air raids predispose to internal injuries without penetrating wounds are so numerous that care should be exercised before it is decided that any instance of lung hæmorrhage is either partly or wholly due to the direct effects of a blast wave. This precaution was amply brought home to us in an analysis of ten autopsies that were made in the course of a casualty survey for the Research and Experiments Department of the Ministry of Home Security where, so far as possible, every circumstance relating to the incidents in which the casualties occurred was known. All ten cases were instances in which people were very close to bomb explosions, and all had either no external or only trivial external injuries.

Of the ten, seven demonstrated hæmorrhages in the lungs, but of these seven only one had apparently been affected by the blast wave of the explosion alone. All the others were either also struck by secondary missiles, injured through being violently thrown, or buried under debris. The following are three typical cases:—

Case 1.—A woman, one of 13 occupants, was sitting in a shelter about 14 ft. from the point of detonation of a bomb outside. The bomb blew in the upper part of the near wall of the shelter, and blew away the whole of the roof. The fatal casualty was picked up dead from the side of her seat. Her only external injuries were some small skin-deep bruises around her right breast. Opposite these bruises were some hæmorrhages in the parietal pleura, and opposed to this parietal hæmorrhage was a patch of hæmorrhage on the costal surface of the right lung. There was also some hæmorrhage along the posterior border of the same lung; the opposite lung was normal. Her only other injury was rupture of an ear-drum.

Case 2.—A woman was killed in a steel shelter that was displaced 30 ft. by a " near miss ". The woman was removed from the remains of the shelter (by which she was not trapped) but died on her way to hospital. She showed no external signs of injury, but a simple fracture was found at the lower end of her right femur. At autopsy the pectoral and intercostal muscles on both sides were found to be much bruised, and about two pints of blood, for which no source was discovered, were found in the right pleural cavity. The right lung was normal. The left pleural cavity also contained some blood, and the base of the lung was almost consolidated with hæmorrhage. Microscopic examination revealed a gradation of hæmorrhagic lesions ranging from small isolated patches to large areas completely consolidated with blood (fig. 13).

Case 3.—This was a man of 48 who died twenty-four hours after he was exposed to the explosion of a bomb. He was 6 ft. from the explosion, and slightly to one side of an open door on the other side of which the bomb exploded. He was neither trapped by debris nor hit by secondary missiles, and his only external injuries were slight abrasions on the fronts of both legs. About a pint of blood was found in each pleural cavity, and extensive subpleural hæmorrhages were found on the mediastinal surfaces of both lungs. The root of the middle lobe of the right lung and the posterior part of the left lung were torn. There were extensive internal hæmorrhages in both lungs. The pericardium and heart muscle were also bruised. Rupture of the spleen and a tear in the liver had led to intraperitoneal hæmorrhage. Parts of the large gut were bruised, and the right adrenal gland was ruptured and hæmorrhagic.

All three casualties were sufficiently close to the explosion for their injuries to be attributed, at first sight, to the direct effects of blast. In only the third, however, could this have been the main cause of injury. In the first the localized character of the pulmonary hæmorrhage in relation to a skin bruise suggests that the lung lesion was due to the impact of masonry—although rupture of an ear-drum suggests that blast may have played a part. If it did it is remarkable, however, that other occupants of the shelter escaped unhurt. In the case of the " near-miss " on the steel shelter, again, there were three other occupants who were not killed. One escaped without any injury, the second received a minor injury, and the third a serious injury. In this incident the bomb exploded after it had penetrated into the earth and left a fairly deep crater. In such circumstances, as has already been pointed out, the blast wave is mainly directed upwards in an expanding cone. The woman who died was subjected to violent displacement when the shelter was blown 30 ft., and her lung injury may have been sustained in that way. On the other hand, the possibility that she may have been directly affected by blast cannot be excluded, for it is conceivable that she was just within, and the other occupants of the shelter just outside, the cone of blast.

It has become increasingly obvious that, to determine the lethal factors in any given incident, it is essential that as detailed information as possible must be available about the ways casualties occur. Hæmorrhages in the lungs, as has been emphasized already, cannot be regarded as an exclusive sign of the direct action of blast. It is useless to speculate how many deaths may have been due to the direct effects of blast alone; on the other hand, it can hardly be doubted, on the basis of available evidence, that lung bruising is at least as frequently a secondary or tertiary as a primary effect of blast, and that it may be a combination of all three.

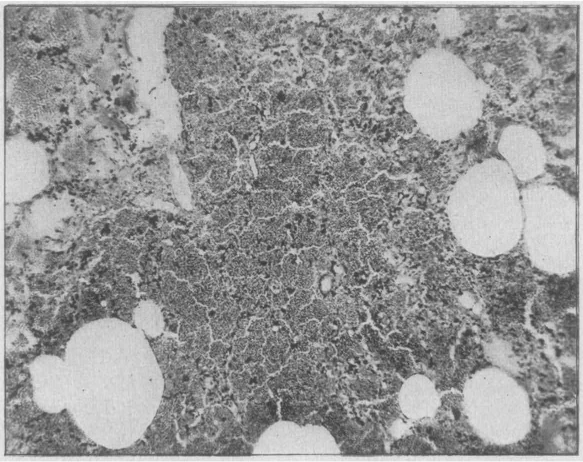

FIG. 13.—Low power view of lung of a woman killed in a steel shelter as the result of a " near miss ". There was massive hæmorrhage throughout the left lung. × 58. (H.L.3.)

In the earlier stages of our experimental work, and before any results had been obtained from casualty surveys, it had been assumed *a priori* that, with widespread bombing, instances of non-fatal lung damage were likely to exceed in number fatal cases " even though neither may prove to be relatively common " (Zuckerman, 1940). Under the special conditions that prevail in ships this forecast may prove correct (Dean, Thomas and Allison, 1940), but it would seem to have been unduly pessimistic so far as civilian casualties are concerned. Up to the present, few cases have been reported of air-raid casualties who have been treated for internal injury due to blast. The following are two clear-cut cases of some that have so far been brought to our attention. The first is that of a man who was in the open when he was bracketed by three heavy calibre bombs. The furthest any bomb was from him was about 25 yards. He was thrown down by the blast, but not rendered unconscious. He noticed a sprinkle of blood on his glasses, but apart from psychogenic shock no other symptoms. He got up on all fours, and was immediately knocked over by the blast of another smaller bomb. He lay on the ground for a few minutes in the lee of a hut, and some wooden slats from the roof fell on him. The blow was slight and (both according to him and his medical officer) would have been regarded as trivial in normal circumstances. It left a slight bruise. The casualty then crawled into an air-raid shelter 5 or 6 yards away, where he started to cough up blood. He remained in the shelter for ten minutes, and then ran to perform the duties which were interrupted by the raid. During the next two hours his condition became worse, and he was then admitted to hospital. No physical signs were present in his chest, but shortly after admission he spat up some blood. X-ray examination revealed some shadows and mottling in the lower part of the right lung, similar to the conditions observed experimentally. The patient remained in hospital for sixteen days, during which repeated radiographs showed that the lung condition was clearing up. Recovery was uneventful.

The second case is that of a man who was sleeping on a divan bed next to a wall, A bomb exploded in a room about 12 ft. away. The wall was blown into the next room, and he and the divan were also blown for a few feet in that direction. He was immediately brought into hospital where perforation of one ear-drum was discovered. There were no external injuries of any kind. The patient suffered from slight hæmoptysis and complained of a sense of " tightness " across the lower chest and shortness of breath, with pain at both bases on deep breathing. Physical signs were absent, but an X-ray revealed congested bronchial markings with patchy consolidation on the right side.

These two histories indicate primary effects of blast, for it would seem that what direct trauma was experienced was too slight to have caused lung changes by itself. They also point to the advisability, in diagnosing injuries directly due to blast, of combining with clinical study and X-ray examination careful analysis of the circumstances under which the injuries occurred.

One point that should not be overlooked in reaching a diagnosis of blast injury is the occurrence of ruptured ear-drums. Though apparently infrequent in air-raid casualties, perforation of the tympanic membrane is to be expected in those who have been exposed sufficiently close to explosions to have suffered internal injuries as a result of the direct action of blast. In reaching a diagnosis particular attention should also be paid to the occurrence of external injuries. By itself blast will not cause external bruises (except, of course, when an individual is close enough to a bomb to be " blown to pieces "), and external bruises associated with chest symptoms may indicate lung bruising at least partly due to indirect effects of blast. Although the present evidence does not suggest that they will be conspicuous, attention should also be paid to signs indicating nervous lesions.

In conclusion two points may be re-emphasized. The first is that fatal casualties with little or no external sign of injury will probably only in rare instances have died from the direct effects of blast alone. Other causes of death in such circumstances are asphyxia following burial under debris, carbon monoxide poisoning, and death from chronic diseases aggravated by sudden shock. Whether blast can cause death as a result of a sudden nervous crisis is a matter which at present is only open to speculation.

The second is that bruising of the lungs may occur not only as a result of the direct action of blast, but also as a result of secondary and tertiary blast effects such as violent displacement, and the impact of flying and falling masonry.

So far our experimental work has given no clear indication of the cause of death in animals which die immediately as a result of the impact of a blast wave. Pulmonary lesions cannot always be regarded as responsible. This problem, amongst others, is now under investigation.

Summary

(1) Without causing external injury, the blast of high explosive may cause hæmorrhagic lesions in various internal organs of experimental animals. The most conspicuous lesions are found in the lungs, where they vary, according to the pressures to which animals are subjected, from small superficial hæmorrhages to hæmorrhage which affects the entire substance of the organs. Hæmorrhagic lesions have also been observed in the pericardium and epicardium, the thymus, the liver, spleen, intestine, kidney, adrenal, bladder, and uterus. Hæmorrhagic lesions are also observed in the submucosa of the upper part of the trachea. Hæmorrhages around spinal roots, especially in the thoracic region, are constant, and pial and ventricular hæmorrhages on and in the brain, occasional, at high pressures. Rupture of the ear-drums has also been observed at high pressures.

(2) Experiment has shown that the thoracic and abdominal lesions are due to the impact on the body wall of the pressure component of the blast wave, and not to any effect of the suction wave acting directly through the upper respiratory passages. The pulmonary lesions directly due to blast are thus comparable to some extent with hæmorrhagic lesions which may occur as a result of severe falls or direct blows on the chest wall.

(3) In air raids people are exposed not only to the direct effects of blast but also to indirect effects such as violent displacement and the impact of falling or flying masonry, both of which may lead to pulmonary hæmorrhages. Observation has shown that the direct effects will be experienced only very close to the explosion. Case histories are analysed, and it is suggested that, before diagnoses of internal injuries directly due to blast are made, attention should be paid to the possibility of internal injury due to indirect blast effects.

We have been greatly helped in the research on which this paper is based by the Chief Adviser and the Officers of the Research and Experiments Department, Ministry of Home Security, and by the Director and Officers of the Road Research Laboratory, D.S.I.R. Our thanks are also due to Professor F. R. Fraser, Director General of the E.M.S., and to Ministry of Health and Hospital Officials for making available to us case histories of people injured in air raids ; and in particular to Drs. C. P. Oliver, E. L. Martyn Lobb, and F. Dudley Hart for particulars about the two non-fatal instances of direct blast injury referred to in this paper, and to Mr. Geoffrey Parker for information about several fatal cases.

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Professor Geoffrey Hadfield: The best way I can contribute to this discussion is to give an account of a series of post-mortem examinations on cases which were considered clinically to have died from blast. All the hard work in connexion with this investigation was carried out by my colleagues, Dr. Joan Ross, Dr. Swain, Dr. Jordan and Dr. Drury-White and I am merely acting as their spokesman.

The number of post-mortem examinations we have carried out is thirty. We know very little about the "incidents" which caused these fatalities so that I cannot be certain that in any of them the effects were due to blast alone, but an account of them may give you some idea of the pathological changes found in people who are discovered dead without any significant external injuries after close exposure to the detonation of high explosive.

Of the thirty cases, seventeen had multiple bilateral pulmonary hæmorrhages with little or no significant injury to the thoracic wall. Of these seventeen cases, four showed between 50% and 75% saturation of the blood by carbon monoxide. Thirteen of the thirty cases in the series considered from circumstantial or clinical evidence to have died from blast showed no clear evidence of this. Two of them died from compression asphyxia and three from asphyxia due to the inhalation of finely-divided chalk, plaster or brick dust, whilst the remaining eight cases had either severe internal trauma or advanced medical diseases sufficient to account for the fatal issue.

As we purposely narrowed down our investigation to cases thought to have died of "blast" alone, this small series of post-mortems gives one no idea of the frequency of pulmonary hæmorrhages in those who sustain gross surgical trauma. With regard to the pulmonary hæmorrhages, I see no essential difference between the human lesions in these cases and the lesions which Professor Zuckerman has described in the experimental animal. We found in the human cases that the hæmorrhages were frequently deep in the lung and occasionally gave relatively little indication on the surface that they were so extensive below. We tried to satisfy ourselves whether the hæmorrhages seen on the outside of the lung were related to the ribs, and sometimes this did appear to be so, but quite often we could not substantiate that idea.

Sections taken through the hæmorrhagic areas show that the blood lies almost exclusively in the alveoli and that its source is the alveolar capillary network. We have been struck by the disproportion between the amount of blood in the alveoli and the relatively slight damage to the alveolar walls themselves. There is always a considerable degree of generalized dilatation and congestion of the capillaries of the alveolar walls and this change is also found in non-hæmorrhagic areas of the lungs. Relatively little blood lies in the airways, but there is always considerable dilatation of the alveolar ducts and respiratory bronchioles. I mention that because a good deal of the clinical picture which these patients present when they survive the incident may possibly be due to widespread capillary dilatation.

The other thing that struck us on reviewing our cases was that the amount of hæmorrhage into the lung in fatal cases varied within very wide limits. I am able to show you some tracings obtained by placing tracing paper over the lung and marking out the areas of hæmorrhage. Quite a large amount of the hæmorrhage is deep in the lung and where the blood approaches the pleura one gets apparent subpleural hæmorrhages. The areas of hæmorrhagic consolidation are quite elastic in their consistence. In one case which died rapidly the hæmorrhages are much smaller than in another in which the patient survived for some hours. I should like particularly to emphasize this finding, because in a moment or two I want to show you the tracing of a lung in which the hæmorrhagic areas are very much larger. This was a case which survived the bombing for about forty-eight hours. We feel that if a case does recover from the initial explosion it is probable that bleeding continues into the lung, so that the cases which survive show very much larger areas of hæmorrhage than do those who are found dead at the site of the incident.

The next tracing is from the lung of a patient who survived exposure to the detonation for fifty-one hours. (Not illustrated.) The lower lobe shows widespread hæmorrhagic consolidation, in which there are many small areas which at post-mortem were ashen grey in colour. These areas present a histological picture which is very suggestive of a pneumonic process. At the periphery of the areas of hæmorrhagic consolidation there were broad irregular zones in which the bleeding was quite fresh. These zones were bright red in colour. Both lungs showed these zones of recent hæmorrhage disposed around the periphery of darker coloured areas of hæmorrhagic consolidation.

The patient surviving exposure to detonation for the longest period also showed the most extensive intra-alveolar hæmorrhages. He survived for fifty-one hours and we believe that during that time he continued to bleed into his lung. This view has an obvious importance from the point of view of treatment, and I will mention his clinical story. The histological picture of the lung in the scattered areas of pseudo-pneumonic consolidation shows all alveoli to be filled with a fibrinous exudate in the meshes of which are large numbers of wandering cells. The general appearance of this part of the consolidated lung is reminiscent of lobar pneumonia, but under higher powers many of the wandering cells are seen to be mononuclear. This rather strange pseudo-pneumonic consolidation lying in big patches of resolving hæmorrhage is a very striking feature and it may affect considerable parts of the lung.

Here is the clinical story of the patient who lived for fifty-one hours. He was aged 23, and was asleep in a wooden hut when it was demolished by a large bomb. He was not buried and he sustained no external injury. He was admitted to hospital about two hours afterwards, suffering from shock and pain in the chest and abdomen, and he vomited some blood-stained fluid. The abdomen was rigid and very tender. Twelve hours later he was still vomiting, the abdomen was still tender and there was now an impaired percussion note over the left base. The respiration rate was 36 and the blood-pressure 126 mm. Hg. He was drinking fluid freely but vomiting large quantities. Tenderness over the abdomen and chest continued, and there were many râles over the lungs. At the end of forty-three hours the hæmoglobin was 125 and the blood urea 85 mgm. Forty-four hours after the incident 600 c.c. of blood was withdrawn by venesection. The patient became quieter, respiration much easier and the râles in the chest were considerably less. This striking improvement was maintained for three hours, when the respiration rate again rose, the pulse failed, and death occurred fifty-one hours after the incident. This patient developed a syndrome which may quite well have been due to generalized capillary congestion of the lesser circuit, and most of his urgent symptoms were relieved by venesection.

We do not wish to insist that the cases investigated have arisen as pure effects of "blast", but all of them showed fairly extensive pulmonary bleeding associated with widespread dilatation and congestion of the alveolar capillaries. We think it worth while considering whether a good deal of this intrapulmonary capillary bleeding may be due to diapedesis. We consider that the bleeding goes on for a considerable time and, on the basis of the case I have described, that it may continue for at least fifty-one hours following the incident. We find it difficult to believe, having in mind the histological picture of these lungs, that the capillary rupture does account for all the capillary bleeding. If the histological picture be combined with the clinical findings in life it is rather more easy to explain the latter on the basis of generalized vasodilatation of the whole lung on both sides than to bleeding itself. It seems to us that the major clinical manifestations are more probably due to capillary dilatation of the lung than to the actual bleeding into the lung, which may be a consequence of capillary dilatation.

There is a specimen of sputum on the table which we thought of interest because the patient in this case was subjected to what appeared to be the effects of blast, and has now almost recovered. He was in a wooden building which sustained a direct hit. He showed no external signs of injury and recovered in the course of a few days from his more urgent respiratory symptoms. That was some seven weeks ago. Since the incident he has had four attacks of hæmoptysis, one as recent as the day before yesterday. Thus it is possible that one result of the detonation of high explosive is that the lung is left in such a condition that it is liable to bleed intermittently for some considerable time after the injury.

My contribution to this discussion, founded as it is on human material, is rather premature. The opportunities for getting suitable material for investigation are few and it is very difficult to reconstruct the incident. I should like to qualify what I have said by pointing out that it is founded on very short experience, but we do feel inclined to express the opinion that following exposure to the detonation of a high explosive, bleeding into the lung may continue for a period of days. If this belief is substantiated it must, of course, have an influence on treatment. It means that these patients should be immobilized as if they had had a recent large hæmoptysis and it may be that disregard of this precaution may explain why some cases, which have been exposed to detonation and have apparently recovered from the initial respiratory embarrassment, have subsequently relapsed.

Dr. J. N. O'Reilly said that he had been able to investigate some cases who were in a wooden building which was demolished by a very heavy bomb. One clinical point emerged from the cases he was able to observe. In two cases within forty-eight hours, and in a third case within five days there were all the clinical appearances of lobar pneumonia. This was rather interesting in view of the histological findings just mentioned. One man had fairly typical "blast" lung, and twenty-four hours after the first X-ray picture was taken—forty-eight hours after the incident—he had a temperature of 103°. He had dyspnœa and pain in the chest, localized in the right lower zone. He also developed tubular breathing. He was treated as an ordinary case of lobar pneumonia with sulphapyridine and made an uninterrupted recovery, and the picture of the lungs showed normal resolution. The second case was a boy aged 19 who was exceedingly ill when admitted—very dyspnœic, very cyanosed, and very shocked, but with no external injury. He appeared from the first examination to have very much impaired air entry at the right base and scattered râles over the rest of the lungs. Twenty-four hours later he, too, had tubular breathing and he appeared clinically to have lobar pneumonia. He was treated with sulphapyridine. Subsequent X-rays taken forty-eight hours later showed collapse of the right lower lobe. He eventually made a complete recovery.

The third case was a little different. This was a man in the same incident who came in complaining only of a little pain in his chest and a certain amount of shock. Within twenty-four hours of the incident he was well except for the chest pain which was centrally placed. On the fifth day he had a temperature (the temperature had never actually settled down but had always been going up to 99° and 100°) of 102°. An X-ray picture was taken and his chest was quite clear. Then forty-eight hours later, he had clinical signs at the right base and a further X-ray showed the usual appearance of lobar pneumonia. He had made a slow recovery but the condition was now almost resolved.

These three men showed as did others what was apparently clinical lobar pneumonia immediately following the incident and apparently caused by pure blast. Professor Zuckerman had rather insisted on pure blast, and it could be said of the three men whose histories he had related that they had no external injuries approaching in any degree those of crush injury. One man did have a lacerated wound on the forehead, apparently the result of tearing by a nail or some such projection ; but he had not been buried.

A second clinical point which he desired to ask about rather than to dogmatize upon arose from the fact that five cases in this same incident were brought in with all the appearances of acute abdominal catastrophe—rigid abdomen, pain, and so on. In two of them the condition was sufficiently serious to require opening up by the surgeon, but when this was done nothing was found, except a few minute subserous hæmorrhages. The abdomen in each case was at once closed up. One of the cases operated on subsequently died. This man in addition to typical blast injuries of the lung, had extrapleural hæmorrhages in his intercostal spaces. When the viscera were removed the inside of the thorax appeared black except for the white bands of the ribs. Whether that had any significance and whether hæmorrhage in that position could cause intercostal nervous irritation and give rise to a rigid abdomen, he did not know.

Dr. J. M. Alston said that a tremendous number of facts on this new subject had been brought forward by Professors Zuckerman and Hadfield and, as might be expected, the experimental approach and the clinico-pathological approach had not quite met so as to form a complete picture. He wondered whether Professor Zuckerman's work had gone far enough in the directions he had indicated to enable him to tell them whether rabbits or other animals which survived the shock experiments did show lesions of pseudo-pneumonia such as those to which Professor Hadfield had referred. That would help to bridge the gap between the two types of work of which they had been hearing.

Dr. Beryl Barsby asked whether Professor Zuckerman had seen any case of blast injury without hæmoptysis. She had had a case unquestionably due to blast which had a spontaneous hæmothorax with X-ray evidence of blast on the other side and ruptured spleen.

Professor Zuckerman said that he had been asked whether there was any evidence of pneumonias occurring in animals after exposure to blast. In this respect Professor Hadfield's clinical observations corresponded closely with the experimental findings. Animals of a group which survived exposure to blast pressure sufficiently high to kill other members of the group sometimes developed pneumonias. The white-cell infiltration associated with the pneumonic process was predominately monocytic.

Experimental findings also coincided with Professor Hadfield's clinical observations in so far as areas of hæmorrhage often appeared more marked in animals killed and autopsied some hours after exposure than in animals that were killed outright by blast. On the other hand, no evidence was available to show that zones of hæmorrhage became more extensive as a result of continued bleeding. In answer to Dr. Barsby it was stated that pulmonary damage due to blast, unassociated with hæmoptysis, was often observed in animals.

Dr. O'Reilly's clinical observation of hæmorrhages in the intercostal space was of interest from the experimental point of view, since similar hæmorrhages were sometimes observed in animals exposed to blast. The hæmorrhages followed the intercostal nerves, and were continuous with hæmorrhages round the spinal roots.

He did not believe that there was any essential difference between the pulmonary lesions that had been described in human air-raid victims and those which had been observed in experimental animals, except in so far as the anatomical distribution of the hæmorrhages appeared to be different. On the other hand, the generalized capillary dilatation which Professor Hadfield regarded as the primary lesion had not been observed in experimental animals. Several hundred lungs had been examined, and the dilatation did not appear to be a primary factor. In the regions where lesions occurred as a result of blast, there was undoubtedly rupture of alveolar walls and disruption of the lung substance. When the lungs were removed at autopsy, areas of hæmorrhage, and occasionally congestion, alternated with areas in which the lung had its normal healthy pink colour.

Without knowing in detail the circumstances under which casualties occurred it was impossible to say that the hæmorrhagic lesions that had been described in air-raid victims were due to blast alone. The question that had to be asked was, how much are they due to the direct action of blast, and how much to the effects of being thrown against a hard object or to the impact of masonry ?

Robb-Smith had suggested in a recent paper that pulmonary fat-embolism is a frequent occurrence in people who die as a result of a violent fall or in a street accident ; and he had demonstrated its occurrence in one victim of an air-raid who died seventeen hours after an explosion. Since fat-embolism was not found in experimental animals exposed to blast, it is conceivable that it is a sign which would allow of differentiation between cases that had been exposed to blast alone and those which had been exposed to blast as well as impact with a hard surface.