0022-5282/83/2311-0955$02.00/0
The Journal of Trauma
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Vol. 23, No. 11
Printed in U.S.A.

Casualties from Terrorist Bombings

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The physical factors responsible for injury following an explosion in a room or building are: direct exposure to overpressure; blast-induced whole body displacement; impact of blast-energized debris; burns from flash and hot gases. The patterns of injury seen in the casualties from four terrorist bombings are described to illustrate the types and severity of particular wounds. The most common fatal injury is brain damage; 'blast lung' is uncommon in civilian terrorist bombings; flash burns, fractures, serious soft-tissue damage, and eardrum injuries are seen in people close to the bomb, who usually require hospital admission; many others taken to hospital can be treated for injury by debris and released. The environment and its internal structure and the position of the occupants of the space can influence the type and severity of injuries.

Terrorism has been responsible for a large number of bomb explosions in Northern Ireland (NI) and the United Kingdom mainland over the last decade. Many of these attacks are designed to inflict economic loss by the destruction of property and the disruption of everyday life. A significant proportion are also designed to produce casualties—this is particularly true of bomb attacks on the UK mainland. Bombings designed to produce casualties are invariably successful if the device detonates. Busy public places such as public houses are obvious targets providing a large number of potential victims and an environment possessing tables, glasses, and bottles which may be fragmented and energized by the overpressure to inflict penetrating and nonpenetrating injuries.

Small explosions within confined spaces such as a public bar produce compound injuries of types that many hospital casualty units may not have experienced in any numbers. They may also stretch the resources of the hospital and its staff. One hundred sixty patients arrived at the St. Bartholomews Hospital, London, less than 1 hour after the explosion of a car bomb outside the Old Bailey, London, on 8 February 1973 (5). This paper attempts to define the types of minor and serious injuries resulting from explosions and also to delineate the major factors responsible for fatalities. This has been accomplished by surveying the major factors responsible for death and serious injury, and by assessing how the particular environment within which a bomb exploded affected the preponderance of particular wounds. The State Pathologist for Northern Ireland has allowed an analysis of bomb blast fatalities within the period 1969 through 1977. With the cooperation of various Police Forces it has also been possible to study in detail four bombing incidents that took place on the UK mainland in 1973 and 1974. The actual position of casualties relative to the exploding device has been determined in three of these incidents. The type and severity of injury have been assessed by the inspection of medical records.

This paper is in two parts. The first is a discussion of the types of injury that may be produced as a result of an explosion. The second part presents a description of four specific incidents.

TYPES OF INJURY

People occupying a room or building within which an explosive device detonates may be injured by a number of phenomena.

a) Direct exposure to air blast. This is a sudden change in environmental pressure propagated from the device and travelling radially at high velocity. (The velocity is dependent upon the overpressure but will be greater than or equal to the speed of sound in air, 330 m/s.)

b) Displacement by the mass movement of air with decelerative tumbling or impact against a rigid object.

c) Penetrating and nonpenetrating impact of blast-energized debris.

d) Burns from the flash and hot gases or the combustion of the surroundings.

e) Inhalation of noxious gaseous products of detonation and/or combustion.

f) Collapse of the building. This is only likely with large quantities of explosive.

The relative significance of each of these factors in

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terms of casualty production is dependent upon the size and the type of explosive and the environment within which the bomb explodes.

a. **Direct Exposure to Overpressure.** This is often described as 'primary' effect of blast. The available literature describes either casualty criteria for nuclear explosions or the primary effects of conventional explosives under 'free field' conditions. The overpressures from nuclear explosions are of much longer duration than those from conventional explosives. The rise time to peak pressure is instantaneous in both cases. The casualty criteria for this type of exposure are of limited application when discussing conventional explosives. For example, the probability of primary blast injury is dependent upon overpressure duration for durations less than 100 ms (i.e., conventional explosives) but becomes independent of duration when this exceeds approximately 100 ms (i.e., nuclear explosions).

The biological response to the shock wave from a conventional explosive is dependent predominantly upon: i) the peak overpressure; ii) the duration of the positive phase of the overpressure. Figure 1a shows these features on an idealized shock front.

Lesions are typically located in the air-containing organs—the lungs and the ears. (The bowel may be affected but this is not common in airblast. It is much more common in underwater blast.) The precise mechanisms involved in lung injury have not been defined but perhaps a reasonably accurate description is that the shock front displaces the chest wall towards the spinal column (for frontal exposure) not unlike the rapid chest wall displacement seen with the impact of a nonpenetrating missile. The shock front, however, produces much more widespread distortion than a localized nonpenetrating missile injury. The chest wall displacement leads to high transient overpressures within the thoracic cage and tearing of the delicate alveolar septae. A small proportion of the shock wave itself will also be propagated through the chest. Experimental animals succumbing to *primary* overpressure damage within 30 minute die commonly as a consequence of air emboli entering the circulation from the blast-damaged lungs. Delayed lethality is due to progressive pulmonary insufficiency caused by intra-alveolar hemorrhage or the production of pulmonary edema due to imbalances in the fluxes of water (with solutes and often protein) across the damaged alveolar-capillary gas exchange membrane. This condition is often given the name 'blast lung.'

The histologic appearance of lung damaged by blast overpressure is dominated by hemorrhage into alveolar spaces (Fig. 2). The origin of this hemorrhage is uncertain. In mild injury, alveoli are seen to contain small amounts of blood and this is likely to have emanated from damaged capillaries in the interalveolar septae. Damage to capillaries is unlikely to be seen on light microscopic examination as the proportion of capillary wall visualized on a single section is very small. In areas

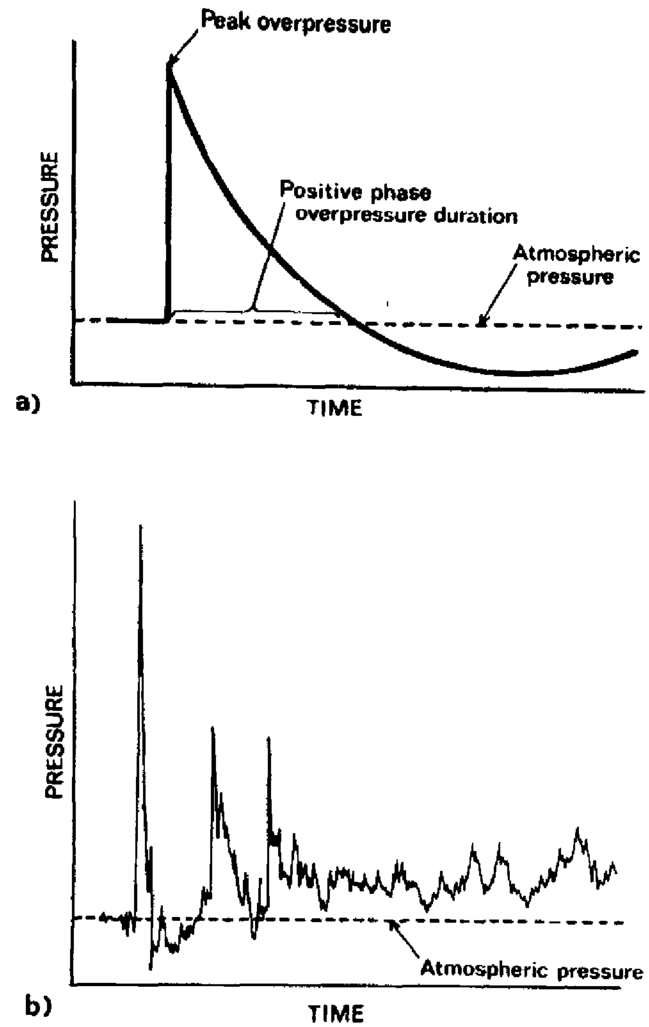

FIG. 1. Blast overpressure in air: a) An idealized shock front resulting from the detonation of an explosive under free-field conditions. b) An example of a pressure/time profile observed following an explosion within a room.

of more severe damage, filling of the alveoli with blood is observed and the blood often spreads into the terminal bronchioles and small bronchioles. Edema may be seen as an eosinophilic deposit filling alveoli and sometimes 'condensing' on the walls of small airways and alveolar ducts as hyaline membranes. The edema seen in sections of experimentally produced 'blast lung' is often patchy in distribution. With severe blast injury, alveolar walls can be disrupted, small airway endothelium may be stripped, and hemorrhage may be seen in the walls of bronchi, large blood vessels, and interlobular septae.

The light microscopic changes seen in blast-damaged lungs closely resemble those seen in the pulmonary contusions produced by nonpenetrating impacts to the chest. This lends support to the theory that the primary biomechanical mechanism of pulmonary damage by blast is the rapid transient inward displacement of the chest wall.

The dependence of the probability of death and the threshold of lung damage upon the peak overpressure

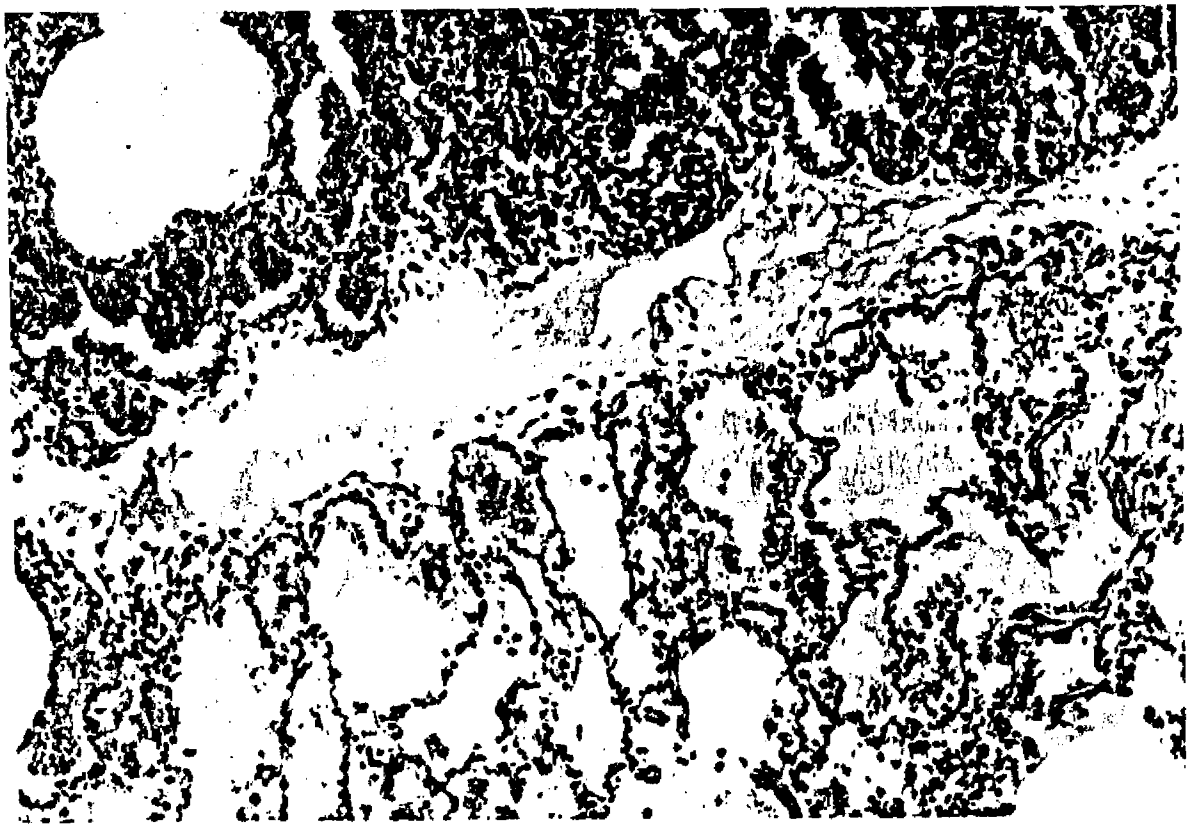

FIG. 2. Blast overpressure injury to pig lung. Interlobular septum and adjacent alveoli showing hemorrhage and edema. (H&E × 160).

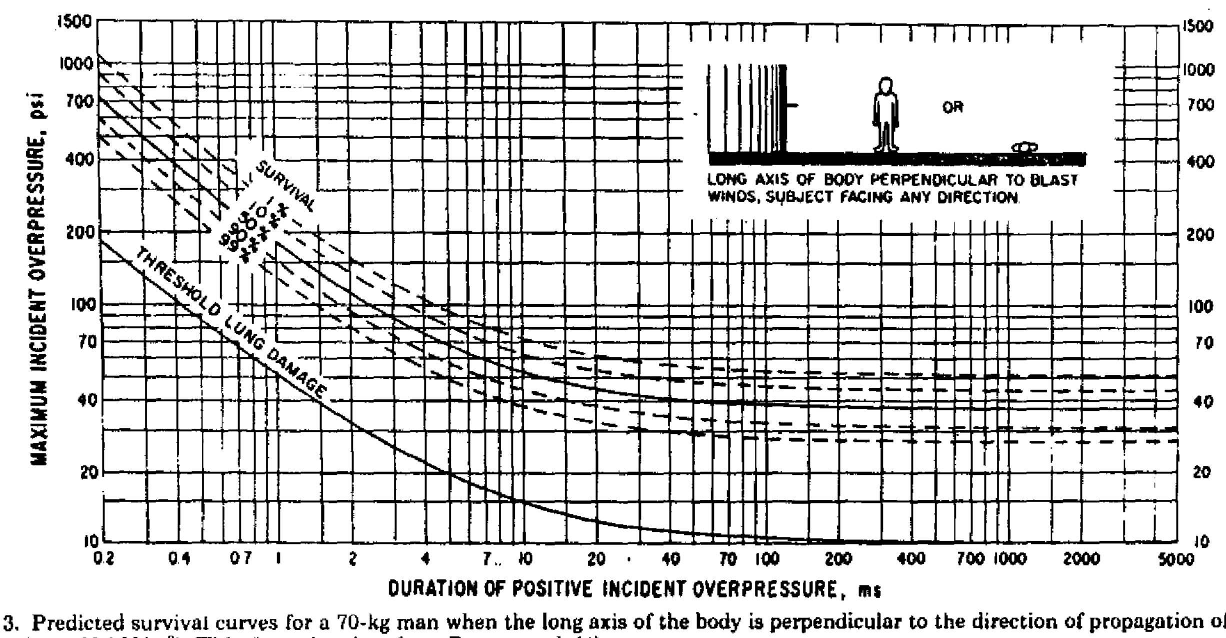

FIG. 3. Predicted survival curves for a 70-kg man when the long axis of the body is perpendicular to the direction of propagation of the blast wave (1 psi = 6.89 kN/m²). This figure is taken from Bowen et al. (4).

and its duration is shown in Figure 3, taken from Bowen et al. 1968 (4).

Many factors can influence these criteria. The orientation of the man and his position relative to a reflecting surface significantly affect his susceptibility to the incident shock front. A man situated close to a wall may be subjected to at least twice the incident overpressure (reflected pressure). Figure 4 shows peak overpressure and its duration related to the probability of lethality for people close to a reflecting surface. The incident overpressures to produce comparable lethality are significantly lower at a reflecting surface than those in free field.

The overpressure seen within an enclosed space such as a room following an explosion has a complex waveform, unlike the 'free field' pressure (Fig. 1b). An initial

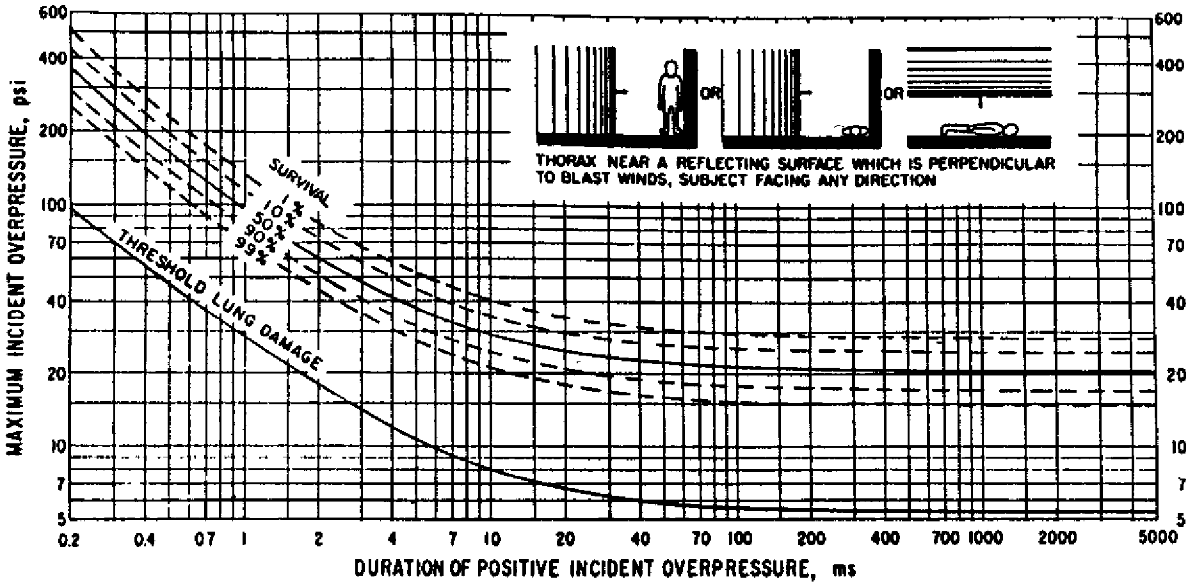

FIG. 4. Predicted survival curves for a 70-kg man when the thorax is near to a reflecting surface at which the blast wave reflects at normal incidence (1 psi = 6.89 kN/m²). This figure is taken from Bowen et al. (4).

peak overpressure is followed by multiple reflection of the shock wave off the walls, around obstacles such as people, pillars, and doors, and is followed by a quasi-static pressure of long duration, the intensity and duration of which are dependent upon the volume of the room and the degree of venting through doors and windows. These factors create therefore not only a complex waveform, but also make predictions of the peak overpressures and durations to which people are subjected at various positions in the room extremely difficult.

Assuming that the initial peak overpressure could be predicted, it would be tempting to use Figures 3 and 4 to predict lethality, but the contribution of the ensuing reflected overpressures and long duration quasi-static pressure cannot easily be determined.

The casualty criteria for complex waveforms are not available in the literature.

Peak overpressure decays rapidly as the shock wave propagates through the air. The magnitude of the overpressure is inversely related to the cube of the distance from the source.* This means therefore that with a small explosion, a person has to be close to the device to suffer traumatic amputation of limbs (this excludes the loss of limbs from flying missiles). Complete disruption of the body will only normally occur if the person is carrying the device or is in very close proximity.

The use of military explosives on a battlefield will result in a significant incidence of primary blast damage in the casualties. However, blast lung is *not* common in terrorist bombings. If a victim is sufficiently close to an improvised device to be subjected to sufficient overpressure from these small quantities of explosive to initiate primary pulmonary insufficiency, then he is far more likely to be killed by blast-energized penetrating and nonpenetrating missiles†. Blast damage to the lung may still occur and be evident at post-mortem (see Table IV) but it will be unlikely to be the primary cause of death. Table I shows the incidence of 'blast lung' in 569 people admitted to the Royal Victoria Hospital, Belfast (1971–1975) following bombing incidents. Sixty-eight people were admitted to the Respiratory Intensive Care Unit. Fifteen developed respiratory failure, of which five were identified as 'blast injury to the lungs.'

The tympanic membrane is particularly susceptible to overpressure. The probability of tympanic rupture is related not only to the peak overpressure, but also to the impulse—the integral of the overpressure/time profile. The no rupture/rupture boundary is a curve asymptotic to the two axes when incident overpressure (psi) is plotted against incident impulse (psi·ms). For positive phase overpressure durations ⩾ about 4 ms, rupture will not occur unless there is a minimum peak incident pressure of about 2 psi (14 kN/m²) arriving normal to the ear. For shorter duration overpressures, the peak pressure at which rupture becomes probable increases progressively as the duration decreases.

The probability of rupture is also dependent upon the orientation of the meatus to the blast wave, the age of the victim, and any existing pathology. Most eardrum ruptures heal spontaneously. Eighty-two per cent of the 60 perforations produced in the Abercorn restaurant

* Overpressure $\alpha(1/r^3)$ where r is the distance from the device is only true close to the explosion. For overpressures within the range approximately 2–200 psi incident (14–1400 kN/m²), overpressure $\alpha(1/r^{2.3})$. The relationship becomes $\alpha(1/r)$ at pressures well below 0.1 psi (0.7 kN/m²).

† A distinction must be made between 'blast lung' pulmonary insufficiency produced by the shock front at the time of detonation, and the insufficiency that may develop from other causes such as missile wounds or head injury ('shock lung') that are not directly attributable as *primary* blast damage.

TABLE I
Patients admitted to the Royal Victoria Hospital, Belfast following bomb explosions, 1971–1975 (from Coppel, 1976, [8])

Total number admitted	569
Number of admitted to Intensive Care Unit	68
Number developing respiratory failure	15
Blast injury to the lungs	5
Fat embolism	4
Aspiration pneumonia	1
Iatrogenic fluid overload	1
Mixed pathology	4

explosion (4 March 1972) healed without any active intervention (11).

It will be demonstrated that prediction of eardrum rupture in people subjected to small explosions in confined space is difficult due to the large number of physical and pathologic factors contributing to the likelihood of rupture.

Tinnitus is common following an explosion. It may persist for some time and is often distressing. Disruption of the ossicular chain is rare—the ear has to be subjected to large overpressures for this lesion to occur. Sensorineural (perceptive) deafness is widespread initially but many victims recover normal hearing within hours. Only 6% of the victims of the Abercorn bombing inspected 1 year later had a hearing loss for speech frequencies in both ears that could be described as 'serious' (11).

b) **Blast-induced Whole Body Displacement.** The displacement of people following an explosion with consequential decelerative tumbling or impact with rigid surfaces is often called the 'tertiary' effect of blast. Mathematical models are available (3, 9) to predict displacement/time profiles of a variety of objects, including human beings. The displacement is predominantly dependent upon the dynamic pressure impulse, and the acceleration coefficient (α) of the object. The dynamic pressure impulse is the dynamic overpressure/time profile where the dynamic pressure is defined mathematically as:

$$\text{Dynamic Pressure (Q)} = \frac{\pi v^2}{2}$$

π = air density
v = air velocity

Dynamic pressure results from the high wind velocity and increased density of the air behind the shock front.

The acceleration coefficient (α) is defined mathematically as:

$$\alpha = \frac{A}{m}\cdot Cd$$

where A = presented area of object
m = mass of object
Cd = drag coefficient of the object

It has not been possible to define the significance of tumbling and whole body impacts against rigid objects in the injury-producing mechanisms of small bombs in confined spaces.

Impact with a rigid surface would produce multiple injuries with bone fractures predominating (13, 14) but of course these injuries may also be produced by the impact of large blast-energized projectiles. Whole body displacement certainly carries a high risk of injury and there is evidence in some bombing incidents such as the Tower of London explosion that a large number of skull and limb fractures can be attributed to impact with walls and other obstacles. It is not easy to acquire definitive details from most incidents.

This lack of information of whole body displacement is undoubtedly due to the general chaos following an explosion. People seem able to remember their position just before the explosion but the conditions following detonation—darkness, dust, blast-induced deafness, dizziness, and disorientation—preclude precise location after the explosion. There are, however, a number of recollections by witnesses of an explosion that present a graphic account of displacements:

". . . . as I started to pull the door open, there was a terrific noise. It was a tremendous whoosh. It was a similar noise made by a pool of petrol being ignited only much magnified. Accompanied by this, I was aware of a great deal of debris and glass flying about. I was thrown up sideways towards the southern wall of the bar. This was as if by a terrific amount of pressure not unlike the forces rendered by a very large sea wave. I was thrown sideways for a distance of about 6 feet . . . ."

". . . I was thrown in the air, I hit the ceiling and came down by the door . . . "

". . . . Everything went dark. I remember a lot of dust, I remember being blasted through a window . . . . "

The tolerance of the human frame to impact has been determined experimentally (13) and from the analysis of free-fall impacts resulting from accidents (14).

c) **Penetrating and Nonpenetrating Impact of Blast-energized Debris.** The criteria outlined in the previous section for the displacement of people by the dynamic pressure wave can of course be used to predict the velocity of blast-energized debris. Debris for blast exposure within confined spaces consists of small and large pieces of glass, splintered wood, plaster, and any other material that is relatively unfixed*. The velocities attained by these projectiles are certainly sufficient to penetrate body cavities, although fragment injuries in people some distance from the device may be superficial but anatomically widespread.

Small fragments may be rapidly accelerated to significant velocities by the dynamic pressure, but because of their irregular shape they tend to experience considerable air resistance and therefore limited effective range for serious injury. Large objects such as chair legs attain relatively lower velocities but because of their high mass

* These are secondary fragments. Primary fragments originate from the casing of the charge, for example, a hand grenade.

they are still capable of inflicting serious injury. Their range may be quite substantial due to the considerable momentum that the objects possess.

Forensic and surgical papers abound with horrific pictures of limbs and trunks transfixed or obliterated by these large objects (10). Falling glass from high office blocks also presents a considerable hazard (5).

The wounding power of a missile is dependent upon two things: i) the *physical* tissue destruction within an organ; ii) the *clinical* consequences of tissue damage within that organ. The anatomic location of the wound is of course a major factor in the overall assessment of injury severity in man.

i) **Physical Destruction within Tissues.** The extent of tissue destruction within any chosen organ or body area in purely *physical* terms (as opposed to a 'life-threatening' or clinical assessment) is predominantly dependent upon the *total* energy transferred and the energy release per unit length of wound tract.

For penetrating missiles, the total energy transfer and its distribution along the permanent wound tract is dependent upon: a) The preimpact velocity and mass of the projectile. This is usually expressed in terms of kinetic energy ($\frac{1}{2}\ m \cdot v^2$). b) The retardation afforded to the projectile by the tissue. The drag on the projectile is related to: (i) the shape, density and mean presented area of the projectile; (ii) propensity of the projectile to break up; (iii) propensity of the projectile to tumble; (iv) the 'properties' of the tissue, i.e., density, presence of bone, the strength of the overlying skin, etc. Some of these factors are interdependent.

Missiles possessing irregular shape or ballistic instability tend to deposit a great proportion of their preimpact kinetic energy rapidly along the wound tract producing tissue destruction. In many instances, they may deposit such a large proportion of their energy that they are unable to emerge from the body.

Blast-energized debris from small explosions can possess considerable penetrating power. Twenty-five per cent of the bomb blast fatalities from Northern Ireland (NI) had single or multiple penetrating wounds of the thorax. Table II shows the incidence of laceration of particular thoracic organs in the fatally wounded.

The abdomen was penetrated in 26% of the fatalities. The most common injury following small explosions in confined spaces is superficial tissue damage produced by blast-energized missiles. Victims show characteristic bruises, lacerations, and small-missile entry holes in the skin. Larger wounds caused by heavy fragments are often superimposed on these wounds, particularly if the victim was close to the device. The skin presents a considerable barrier to a missile and it may absorb all the kinetic energy of a relatively slow projectile. Very small pieces of dust may be embedded within the skin producing a discoloration called 'dust tattooing.' Clothing can offer considerable protection to the missiles at long ranges. The head and neck and the legs in female patients are often involved. One patient had 300 small pieces of wood removed following the Tower of London explosion, 17 July 1974 (16).

TABLE II
Thoracic organ laceration in the fatally wounded, Northern Ireland (8/69–8/77), 305 cases

Organ	Percentage of Total Fatalities Exhibiting Laceration in the Organ
Major vessels	18
Heart	14
Left lung	20
Right lung	21
Upper respiratory tract	11

Of the total number of people taken to hospital following an explosion, only 15% will be admitted (NI data). The majority of those patients admitted will have sustained multiple wounds, but in many cases, their admission can be related to a single cause—fractures, burns, and concussion predominate.

Eighty-five per cent of the total number taken to hospital were either discharged with no treatment, or treated on an outpatient basis. The types of injury seen in the people not admitted to hospital are shown in Table III.

The majority of these injuries were caused by penetrating and nonpenetrating missiles.

There are a considerable number of mathematical models available to predict the penetrative properties of projectiles. Sturdivan (15) describes a predictive model for tissue simulant penetration for a variety of projectiles. Bexon and Sturdivan (2) have developed a mathematical model of the penetration of the human skull by a ballistic projectile.

Nonpenetrating impacts can also be modelled (6, 7). The impact of a nonpenetrating projectile on the chest produces a rapid, transient displacement of the chest wall that can be related to injury severity (7). The degree of chest wall displacement is dependent upon the kinetic energy of the projectile, its effective diameter, and the mass of the target.

ii) **The Clinical Consequences of Tissue Destruction within an Organ.** The likelihood of incapacitation or death following a penetrating or nonpenetrating mis-

TABLE III
Wound type in patients not admitted to hospital (NI data 1972/3)

Type	Percentage Occurrence in Nonadmissions
Bruises	13
Abrasions	18
Laceration	40
Other	29

sile wound is dependent upon the *physiologic* consequences of the tissue destruction. (There are other factors involved in general war such as time delay before medical help is available and quality of medical support.) Injuries to the head and heart carry a more grave prognosis than injuries to the limbs, for example. However, it must be remembered that a single limb wound can prove fatal if by chance the fragment transects a major blood vessel such as the femoral artery. It is not possible to present absolute rules for determining incapacitation or death following a strike on a particular organ; however, probabilities based on clinical experience are available (12).

The susceptibility of the head and neck to injury is demonstrated in Table IV. This table shows the most common serious injury seen in the dead following a bomb explosion. Although the head and neck occupy only 12% of the mean projected area of human beings, serious injuries to this region are seen in 66% of the fatally wounded. This disparity emphasizes the vulnerability of the head and neck to penetrating and nonpenetrating missiles.

d) **Burns from the Flash and Hot Gases.** The flash produced by the detonation of an explosive is capable of inflicting significant skin burns. The severity of a burn is directly related to the temperature rise within the skin and to the duration of this rise. Total heat transfer to the skin is the algebraic sum of transfer by radiation, conduction, and convection. Casualties may suffer flash burns from the radiated heat and by contact with hot, dust-laden air. The rate of transfer of heat (thermal flux) is expressed as the number of calories crossing a surface 1 cm^2 in area every second ($cal/cm^2/s$). The time of delivery of total heat dose is unimportant if the delivery duration is 10 seconds or less. Burn severity can then be related to thermal dose in cal/cm^2.

There is very limited information on the relationship between burn severity and thermal load when the heat is transferred by convection from hot air. Ashe and Roberts (1) related air temperature, duration of exposure, and burn severity in humans using clean air. This may not be directly applicable to explosion in confined spaces due to greater thermal capacity of dust-laden air.

Even superficial burns to particular body sites can cause distress because of their critical location. Burns of the elbows, knees, hands, and feet can produce immobility or limitation of movement as a result of swelling, pain, or scab formation. Superficial burns of the face can be classed as significant. Burns surrounding the eyes cause occluded vision as a result of the swelling of the eyelids. The lips may also swell.

The temperature of a fireball may be high, but its heat content is low, and consequently burns of the upper respiratory tract are not common in small bombings.

Clothing usually provides good protection from flash burns and it is a characteristic of bombings that burns are usually localized to exposed areas of the body—the head, neck, hands, and in female patients the legs. The

TABLE IV
The single most common factors observed in bomb blast fatalities (NI, 8/69–8/77) excluding serious soft-tissue damage

Injury	Percentage of Fatally Injured Exhibiting the Injury
Brain damage	66
Skull fracture	51
Diffuse contusion to lungs	47
Eardrum rupture	45
Liver laceration	34

TABLE V
Total casualties, and the frequency of described wound types in those admitted to hospital

		Tower of London	'Tavern in the Town' and 'Mulberry Bush' public houses, Birmingham	'Horse and Groom' and 'Seven Stars' public houses, Guildford	Old Bailey London	Totals
Date		17 July 1974	21 Nov 1974	5 Oct 1974	6 Feb 1973	
Total fatalities		1	21	5	1	28
Total number of casualties		37	119	69	160	385
Number admitted to hospital		19	42*	24*	19	104
Wound Type	Serious soft-tissue damage or loss	17	22	11	6	56
	Burns	10	23	10	0	43
	Fractures	13	13	7	3	36
	Eye damage	4	6	3	0	13
	'Blast lung'	0	3	2	0	5
	Eardrum rupture	12	17	9	0	38

Total number admitted = 104. Each casualty may exhibit more than one wound type.
The Tower of London and the Old Bailey data were taken from Tucker and Lettin (16) Caro and Irving (5), respectively.
* A total of 172 records for the Birmingham pub bombings and 50 records of the Guildford bombings were examined. Forty-two required admission in the Birmingham records and 24 were admitted in the Guildford records.

FIG. 5. The saloon bar of the Tavern in the Town public house, Birmingham, 21 November 1974.

head and hands occupy about 20% of the total body surface area. Burns occupying substantially greater surface area imply that either the heat was of such intensity that the clothing caught fire (not common with small bombs), that the clothing was blown away, or that the vehicle or building within which the explosion occurred caught fire. This is not common with antipersonnel bombs. Incendiary devices do of course initiate fires.

There is no evidence from the casualty analysis that the gaseous products of detonation of the explosive present a significant hazard.

CASUALTY ANALYSIS OF SPECIFIC INCIDENTS

The relative frequency and severity of the aforementioned types of injury produced by an explosion within a confined space will now be determined by the detailed analysis of four groups of incidents. Three of these groups involved the detonation of devices within rooms, and the fourth was the explosion of a large quantity of explosives within a car parked in a busy London street.

The four groups of incidents are:

a) An explosion in the Tower of London, London, U.K., on 17 July 1974.

b) Explosions in the Tavern in the Town public house and in the Mulberry Bush public house, Birmingham, U.K., on 21 November 1974.

c) Explosions in the Horse and Groom public house and the Seven Stars public house, Guildford, U.K., on 5 October 1974.

d) A car-bomb explosion outside the Old Bailey, London, U.K., on 6 February 1973.

a) **The Tower of London Explosion.** On 17 July 1974 an explosion occurred in a room of the armory of the White Tower, the Tower of London. One person died and 37 were injured, of whom 19 required admission to hospital (16). The device had been placed alongside the wooden gun carriage of a 50-cwt 18th-century bronze cannon. The wooden carriage fragmented and the projectiles were responsible for many of the casualties.

The room was large (21 × 8.5 × 6 m) and the high incidence of bone fractures (13 patients) indicates that significant blast-induced body displacement occurred, resulting in collisions with solid obstacles and the armory walls.

The patient who died suffered severe brain damage. Table V shows the number of patients *admitted* to hospital presenting the characteristic wounds of blast injury.

Seventeen patients had multiple extensive and contaminated wounds (one patient had 300 small pieces of wood removed). Ten patients suffered flash burns to unprotected skin and 12 people had ruptured eardrums. Thirty-five per cent of the total casualties suffered bone

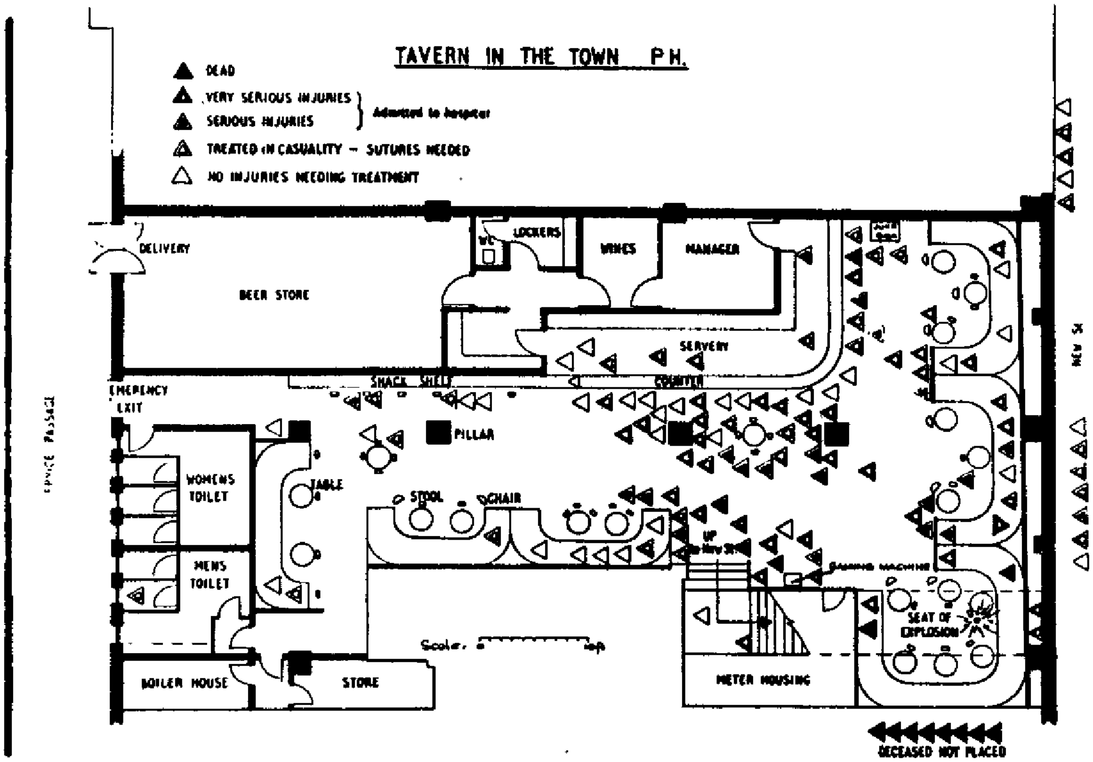

FIG. 6. The Tavern in the Town public house, Birmingham. The position of people immediately before the explosion is shown with an assessment of the severity of injuries received. Eight of the dead could not be placed. The center of the explosion is shown in the bottom right-hand corner of the figure.

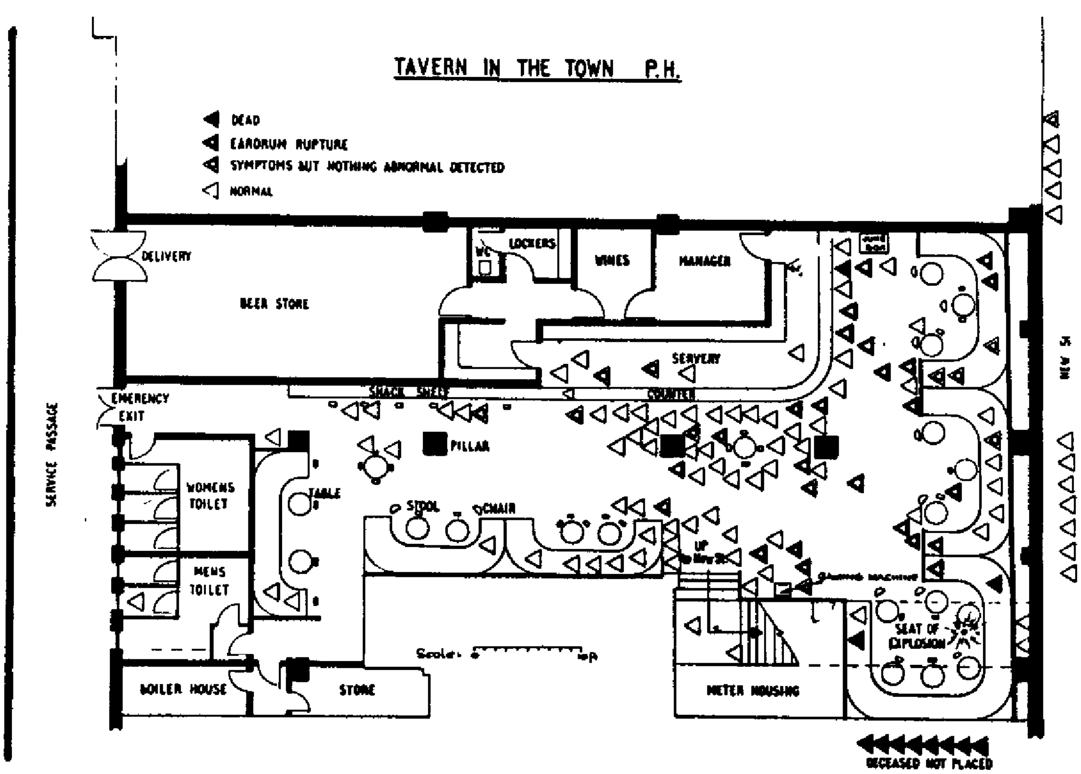

FIG. 7. The Tavern in the Town public house, Birmingham. The incidence of eardrum rupture and of other auditory disturbances in the occupants of the bar following the explosion.

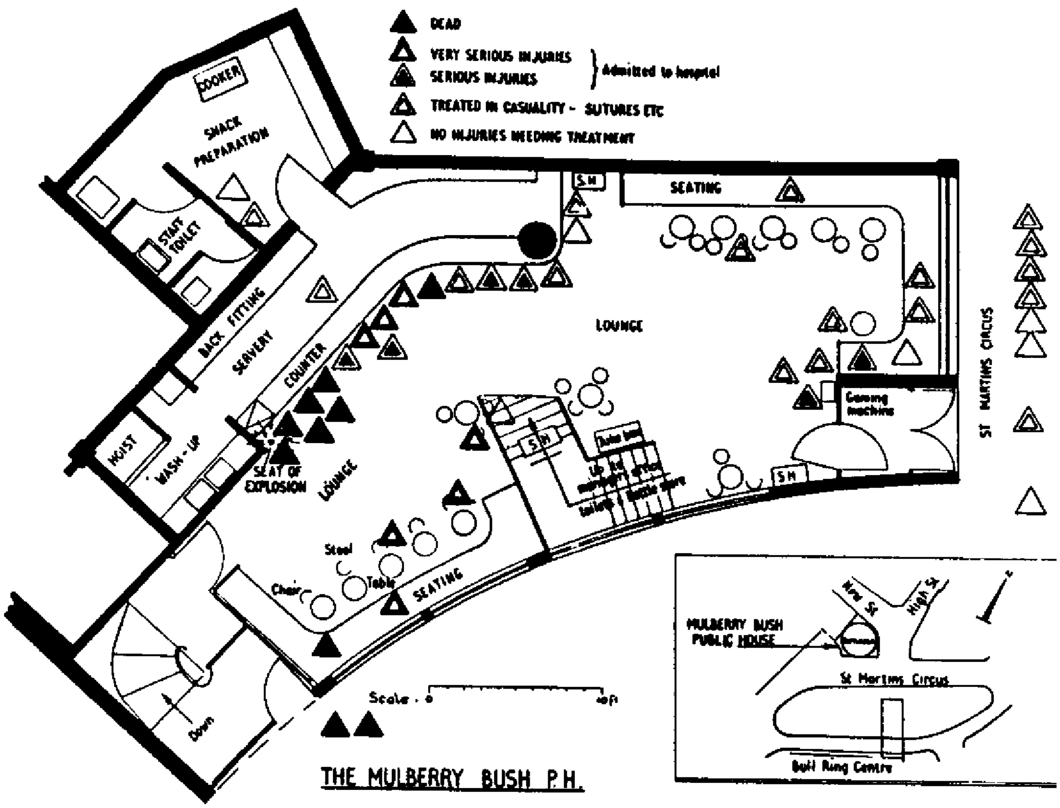

FIG. 8. The Mulberry Bush public house, Birmingham. The position of people immediately before the explosion is shown with an assessment of the severity of injuries received. Two of the dead could not be placed. The center of the explosion is marked center-left.

fractures. This is an unusually high incidence of fractures and, as mentioned earlier, can probably be accounted for by the blast-induced body displacement within the room and by the impact of large pieces of the fragmented gun carriage.

Of those *admitted* to hospital, 90% showed serious soft-tissue damage, 53% were burned, 68% suffered fractures, and 63% had tympanic membrane rupture.

There was no evidence of 'blast lung.' Two children suffered contusions in the lower lobes of the right lung. The localization of these contusions suggests that they were caused by blast-energized nonpenetrating missiles.

Although 46% of the *total* casualties suffered serious soft-tissue wounds, only one patient suffered laceration of an internal organ by a penetrating missile—a 45-cm long sliver of wood lacerated the left kidney of a child. The low incidence of internal organ laceration demonstrates the poor ballistic properties of the wood slivers. Their irregular shape and low density rapidly reduce their velocity in air and tissue, resulting in limited range and penetrating power.

b) **Explosions in the Tavern in the Town and the Mulberry Bush Public Houses, Birmingham.** On the night of 21 November 1974 two bombs exploded in Birmingham. A device exploded in a corner of the underground bar, the Tavern in the Town (Fig. 5). Eleven people died and 89 were injured. A similar device exploded in the Mulberry Bush public house producing ten deaths and injuries to 30 people. Table V shows the overall severity of injuries for the combined incidents for those casualties admitted to hospital. The most common injury was of course superficial tissue damage—bruises, lacerations, and abrasions. Only the more serious injuries are shown. Fifty-two per cent of the *admitted* patients showed serious soft-tissue damage, 55% were burned, 41% suffered ruptured eardrums, and 35% had bone fractures.

With the cooperation of the West Midlands Constabulary and a number of hospitals, it was possible to determine the position of each person within the two bars at the time of explosion and to determine the severity of the injuries received.

Figure 6 shows a plan of the Tavern in the Town public house. This bar is below ground level. The reported positions of people just before the explosion are shown as triangles. This figure shows a generalized classification of severity of injury—'very serious injuries' describes victims who sustained either greater than 15% burns or required more than one major operation. 'Serious injuries' refers to those of people who were admitted to hospital for treatment, but whose injuries were rather less severe than the previous group.

There were eight fatalities whose precise location was not possible to determine. It is assumed that a large proportion of these victims were within the corner alcove, close to the device.

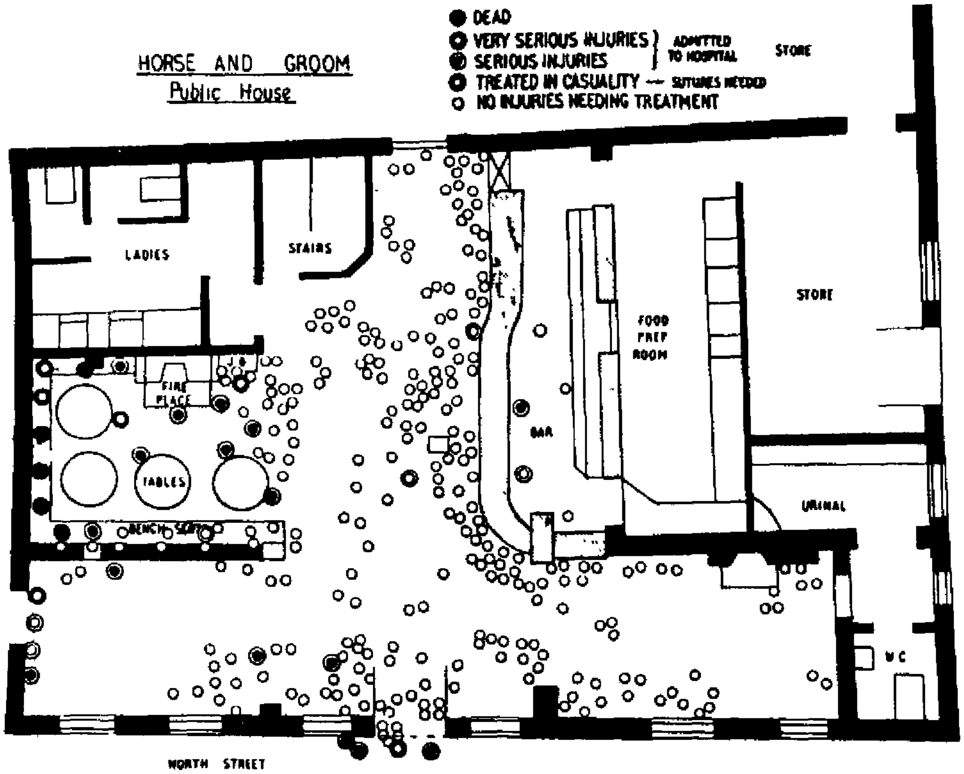

FIG. 9. The Horse and Groom public house, Guildford. The position of people immediately before the explosion is shown with an assessment of the severity of injuries received. A scale is not available for this plan. Some of the tables have been removed for clarity. The center of the explosion was at the far left center of the alcove containing the fireplace. See Fig. 10.

It is evident that a large proportion of the people in the bar required hospital treatment. The furthest confirmed position of a fatality was 11 meters from the device. The furthest 'very serious injury' was also 11 meters away, in a person on the edge of a group of people clustered around the serving counter. The people on the edge of the group in a direct line with the device suffered 'very serious' or 'serious' injuries. The people directly behind them tended to suffer 'minor' outpatient injuries, or no injuries at all even though only 7 or 8 meters from the device. The human body is a good spall suppressor.

The people out of direct sight of the device tended to suffer minor injuries (one exception). This is not solely due to protection by walls, but, because of the design of the room, they also tended to be at some distance from the bomb.

It is also interesting to note the proximity of some survivors to the bomb. Two people escaped death even though only about 2 to 3 meters away. The people seated in the wall alcoves in the direction of the juke box tended on the whole to suffer less serious injuries than those who stood in the bar. The alcove seating may well have provided significant spall suppression to these seated people.

Figure 7 shows the incidence of eardrum rupture and of other hearing defects such as tinnitus and temporary sensorineural deafness. Eardrum rupture did occur up to 11 meters away but it is evident that there were marked inconsistencies in the occurrence of rupture. Some people very close to the device escaped rupture. There is a wide tolerance in the susceptibility of the human tympanic membrane to blast overpressure. There is, however, a relatively high proportion of ruptures in the corner close to the juke box—this may possibly be accounted for by the reflection of the incident shock front from the walls resulting in greater reflected pressures.

Figure 8 shows a plan of the Mulberry Bush public house and the position of people just before the explosion. Unlike the Tavern in the Town, the bar is at ground level. A very large proportion of the occupants of the room required treatment (only two people escaped injury). All the fatalities and 'very serious injuries' were within 4 to 5 meters of the device and although it is thought that this device contained the same quantity of explosive as that in the Tavern in the Town, injury severity seems to be less when related to distance from the explosive.

A number of people stood in front of the device. Their bodies would have taken the full force of the explosion and may therefore have reduced its severity further within the bar.

Two 'serious injuries' occurred 10 meters away in the midst of a group of people that required only outpatient treatment.

The incidence of eardrum rupture again showed considerable variation. The furthest rupture occurred 5 me-

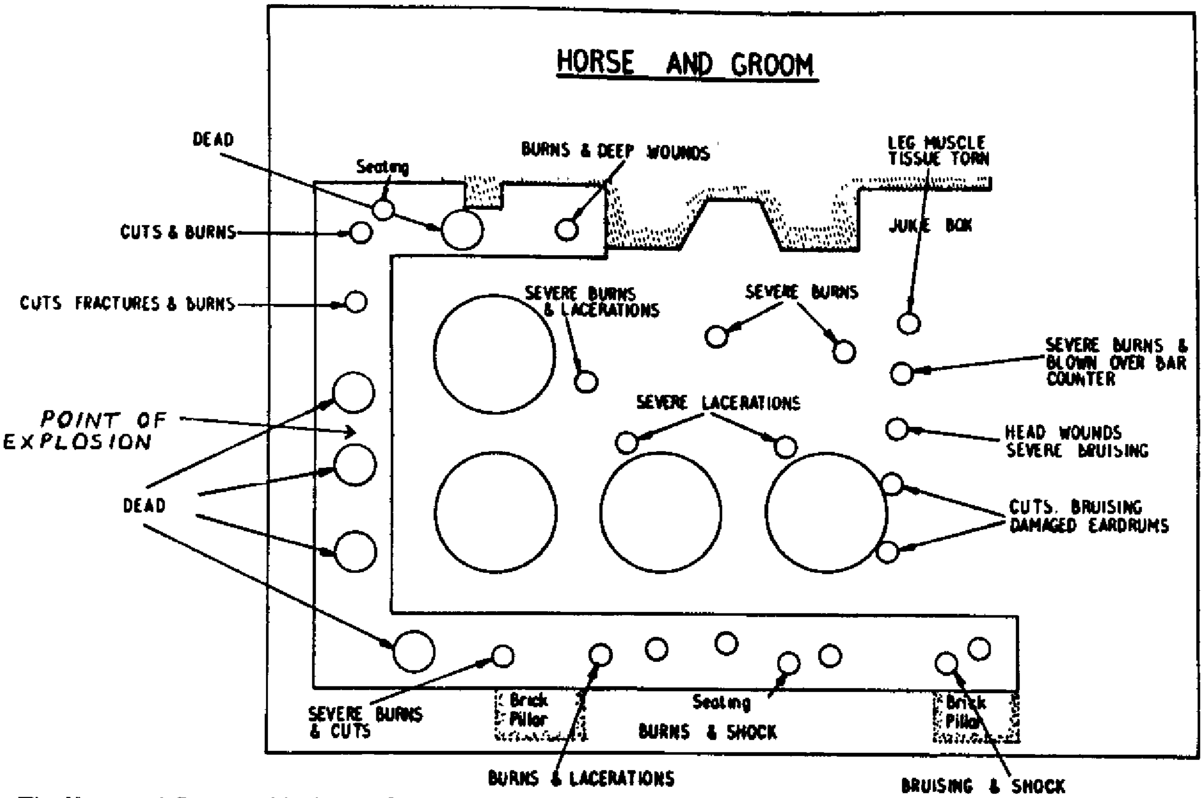

FIG. 10. The Horse and Groom public house, Guildford. A detailed analysis of the severity of injuries received by the people in the alcove within which the device exploded. The assumed center of the explosion is marked on the far left of the figure.

ters away and the nearest nonrupture, 2 to 3 meters from the explosion.

c) **Explosions in the Horse and Groom and the Seven Stars Public Houses, Guildford.** On 5 October 1974, two explosions occurred in Guildford. An explosive device detonated in an alcove at the Horse and Groom public house. The bar was very busy at the time: five people were killed and 62 were injured. A device had also been left at the Seven Stars, but upon hearing of the Horse and Groom explosion, the landlord cleared the bar. Only seven people were injured when the Seven Stars bomb exploded.

A summary of the types and numbers of casualties produced is shown in Table V. The relative frequency of specific injuries within the admitted casualties is not unlike those seen in the Birmingham bombings. Forty-six per cent of the admitted casualties suffered serious soft-tissue damage, 42% were burned, 29% suffered fractures, and 38% had ruptured eardrums.

Figure 9 is a plan of the whole bar of the Horse and Groom and Figure 10 provides details of the casualties within the alcove.

The bomb was a relatively small device and serious casualties tended to occur solely within the alcove. There was, however, a group of people near the entrance to the bar who received serious wounds. The injuries detailed in Figure 10 show the characteristic patterns seen with blast injuries—lacerations, burns,and serious soft-tissue damage with some people very close to the device escaping injury.

There were no burns to the people outside the alcove. Eardrum ruptures were also localized to the alcove with the exception of three ruptures occurring some distance (~8 meters) from the device within the group of people stood near the door, some of whom were also seriously injured.

d) **Explosion at the Old Bailey, London.** On 8 February 1973 at about 3 P.M. a car bomb exploded outside the Old Bailey. One person died (from a subsequent heart attack) and 160 were injured (5).

Of the 160 people taken to hospital, 19 were admitted and of these nine required surgery (Table V). Three patients had fractures (one of these patients received a fractured ilium following a collision with a car), three people had severe lacerations, and a further three had a major vascular injury. The lacerations in the people not admitted to hospital were caused predominantly by glass falling from and shattering in the surrounding office blocks. Fifty-two people required suturing under local anaesthesia, 59 people had minor abrasions and lacerations, and 24 were classed as 'other minor injuries' including emotional shock and minor eye injuries. There were no instances of burns, eardrum rupture or 'blast lung.'

CONCLUSIONS

A number of points emerge from the analysis of the bombing incidents:

1) An explosion in a populated area results in a large number of people being taken to hospital.

2) A substantial majority of those taken to hospital are not admitted, but they may require treatment for superficial soft-tissue damage produced by blast-energized debris.

3) The most common injury seen in the fatally wounded is brain damage.

4) 'Blast lung' is uncommon in civilian terrorist bombings.

5) Flash burns, bone fractures, serious soft-tissue damage, and eardrum ruptures are the predominant injuries in the people close to the device, who usually require admission to hospital.

6) The particular environment within which the device explodes can significantly influence the frequency and the severity of a particular wound type (Table V).

Acknowledgments

We are indebted to the State Pathologist for Northern Ireland, Professor T. K Marshall, for permission to analyze postmortem reports of bomb blast fatalities, the West Midlands Police Constabulary for providing information on the Birmingham pub bombings, the Surrey Policy Constabulary for providing information on the Guildford pub bombings, and to many hospitals for allowing access to casualty records.

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