10 Analysis of Explosive Events

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Abstract

This chapter considers the forensic investigation of explosions with three sections each outlining methods to assist the Court.

In Sect. 10.1, we describe the immediate aftermath and evidence collection indicating how clinical staff caring for victims may help or hinder this process. Thereafter follow two case studies of expert panel review.

Section 10.2 reports on the 2005 '7/7' attacks in London. Individuals had been reported alive after the explosions but died before reaching hospital. Had any of these individuals had died from potentially survivable injury? The absence of post-mortem CT imaging made this a complex task, so weapon effects and blast over pressure for each environment were modelled and correlated to probability of survival.

In Sect. 10.3, we report on the 1974 Birmingham Pub Bombings on behalf of the Coroner for the Inquests into the bombings. This required examination of reports and images that were over 40 years old. Hospitals had closed and relocated several times during the intervening period. Clinical notes other than autopsy reports could not be located. The reports available including scene photographs were used to assess injury mechanisms and correlate individual's distance from the seat of the explosions. Contemporary publications in the open literature were matched to individual patients and used to give clinical detail.

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A. M. J. Bull et al. (eds.), *Blast Injury Science and Engineering*,
https://doi.org/10.1007/978-3-031-10355-1_10

10.1 The Examination of Post-Blast Scenes

Karl Harrison and Mike Harris

10.1.1 Introduction

Post-blast scene examination has traditionally formed a component of the general training and awareness undertaken by Crime Scene Investigators (CSIs). While the environments of operation (potentially widely dispersed fields of disrupted or detonated debris), the nature of the examination (the prospect of large numbers of casualties) and the surrounding investigative concerns of a high-profile investigation with wide-ranging political ramifications all conspire to distance the post-blast scene from the general experience of most CSIs, the application of their core technical disciplines remains as important throughout the scene examination as with more routine examinations. There will undoubtedly be pressure to identify the cause of the blast in order to commence subsequent investigations. It is therefore critical that an early indication is given as to whether the explosion[1] at the scene was caused by an accident, such as a gas leak, or explosives placed with criminal intent. Indeed, for the CSI, the requirement to provide exhaustive photographic and locational documentation is even greater, given the chaotic nature of such scenes and the importance of reconstructing the distribution of debris at a later date for the courtroom, for understanding the relative position of affected individuals, or for modelling the nature and placement of the charge. As a consequence, it is crucial to understand the 'standard' model of training and approach to scenes adopted by CSIs in order to understand how adaptations to post-blast scenes might be managed. For this chapter, the focus will be on crime scenes resulting from the use of explosives that results in a chemical explosion rather than a mechanical, nuclear or electrical explosion.

10.1.2 Coordination of the Post-Blast Scene

CSIs working for UK police forces are now almost entirely a body of civilian specialists operating in a niche role. The shift away from warranted police officers engaging in crime scene investigation began as early as the late 1960s in some police forces, but this small number greatly expanded following the publication of the recommendations of the Touche Ross Report in 1987 [1]. A further expansion of civilian specialists followed as a consequence of the growing importance of DNA evidence, as the required level of technical knowledge increased beyond the general forensic awareness of most warrant-holding police officers. By contrast, Bomb Scene Managers (BSMs) who supersede the role of the Crime Scene Manager (CSM) on post-blast scenes are much more likely to be warranted police officers who do not engage in core CSI activities, but rather gain their training and experience through specialised roles within Counter-Terrorism units.

Of vital importance to the initial management of all major crimes scenes, post-blast scenes included are the first actions undertaken by uniformed police response teams, who in relation to this role are referred to as the First Officers Attending (FOA). The role of the FOA entails not only the confirmation of the suspected major offence but also the initial identification of obvious foci of forensic attention (the presence of a body or weapon, for example), the administering of emergency first aid, the identification of obvious risks to health and safety and the recording of details relating to witnesses still present at the scene. The fulfilment of these duties should ideally be completed in a non-invasive manner that does not jeopardise the forensic potential offered by the scene—the preservation of life is recog-

[1] An explosion is "a violent expansion of gas at high pressure". Akhavean et al. (2009: 4)"Introduction to Explosives"Jan 2009. Cranfield University Page 4.

nised as the one FOA responsibility that takes precedence over scene preservation, but clearly in relation to any wide-ranging disruption such as the aftermath of a blast, this would be an impossible task, and initial disturbance of elements of the scene is an inescapable fact. On occasions, a suspect explosive device may be identified prior to it functioning either due to a warning from the terrorist group or by a vigilant member of the public. In these instances, the FOA, potentially aided by local contingency plans, will commence cordon and evacuation procedures based upon the 4Cs framework (Confirm, Clear, Cordon, Control). Thus, the CSI may attend a scene which is already prepared.

Any intervention a FOA is forced to undertake in the commission of their duties (such as forcing a door to reach the body of a victim thought to still be alive) should be recorded in detail at the earliest opportunity and that record be made available to the incident room (the advent of body-worn cameras and the saturation of CCTV systems have made this process far more comprehensive). In the example of a post-blast scene of magnitude, this is likely to comprise the actions of numerous first responders including the police, ambulance and fire and rescue assets.

Initial attendance at the major scene and ongoing examination would generally be completed by CSIs. Any CSIs deployed to a major scene would be managed directly by a CSM or BSM who has a responsibility to ensure that a forensic strategy is complied with, and that findings from the crime scene are communicated back to the Incident Room (see Fig. 10.1). Whilst the CSM is deployed to the scene with CSIs, the Crime Scene Coordinator (CSC) has overall responsibility for deploying staff to scenes; coordinates the examination strategies of numerous CSMs and ensures integration between the forensic strategy and the overall investigation directed by the Senior Investigating Officer (SIO). The role of CSC might be filled by any suitably trained individual within the Scientific Support Department, from Senior CSI to Head of Scenes of Crime, depending on the size of the police force, the complexity of the forensic investigation and the wider public impact of the offence.

Because of the close relationship between the SIO and CSC, there is an expectation that crime scene coordination should be managed from the incident room. As such, there is generally no requirement for CSCs to deploy to crime scenes, as this would compromise their pivotal management role. Post-blast scenes are somewhat different; the scale of disruption and the level of attention focused at the scene are more likely to result in a permanent coordination team being deployed to the scene.

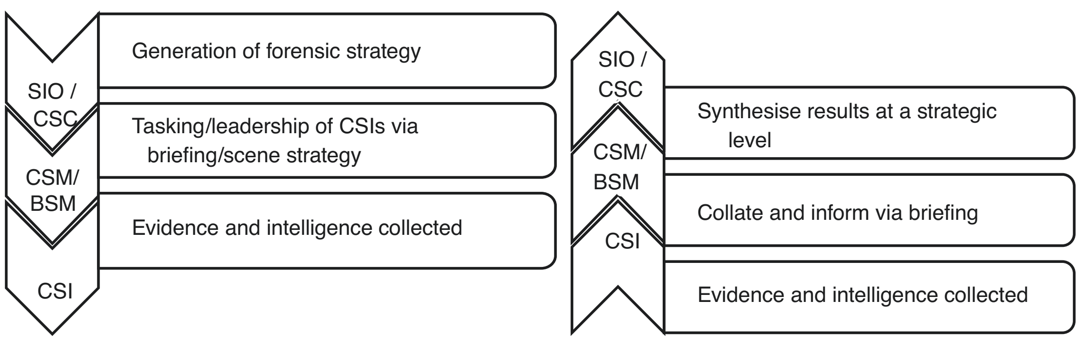

Fig. 10.1 Directions of tasking and information flow

10.1.3 Optimal Capture of Forensic Evidence

While the methods of scene examination can be adapted depending on the requirements of the investigation, the general commanding concept is that of unrepeatability; a crime scene can be revisited, but it can be examined in its entirety only once, hence there is an onus on the role of the CSC and CSM to ensure an optimal capture of potential forensic evidence. The notion of 'optimal' rather than 'total' is crucial; any one scene examined in its entirety might contain hundreds of items suitable for some form of recovery or analysis, which in turn might generate thousands of fragments of forensic data (trace evidence, fingerprints, DNA profiles, for instance). Consequently, while it is important that a forensic examination maintains a degree of independence from the investigation, it must remain driven by an investigative strategy if it is to retain any sort of focus that can bring meaning to the results of the examination.

The concept of unrepeatability of examination and the requirement to optimise evidence gathering puts great emphasis on the sequence of examination. Generally speaking, whatever techniques of examination are required at the scene, they are undertaken in a sequence that begins with the least invasive and disruptive of methods and ends with the most potentially disruptive.

All major scenes are likely to see some adaptations from the generalised approach that will form part of the written forensic strategy; such adaptations might be required by limitations of access to a scene, or environmental variations. Post-blast scenes are more likely than standard large major scenes to see the need to make considerable changes to otherwise standard scene approaches; initial scene and safety assessments must include a consideration of potential threats, such as the presence of secondary hazards, including explosive devices that have yet to function or have been designed to catch first responders, CBRN (Chemical, biological, radiological and nuclear) materials, or other risks associated with extensive structural damage to buildings—all of which can cause considerable delay to the forensic examination commencing.

10.1.4 Access Control and Cordoning

While perimeters need to be established for all crime scenes, control of access through extensive double cordons is frequently required for post-blast scenes together with large numbers of scene guards, and these might be located within highly populated urban areas with residences located within cordoned areas. The inner cordon encompasses the explosion area and has a radius of approximately one and a half times the distance from the seat of the explosion or centre to the furthest identifiable piece of evidence. Only the BSM and their team can enter the inner cordoned area until the examination and evidence retrieval is complete. The outer cordon marks a perimeter which ensures public safety while preventing those who are not associated with the investigation from disturbing the scene, destroying or moving evidence, observing examinations too closely or overhearing conversations pertinent to it. It also provides a safe working area within which members of the police and other emergency services can operate [2].

10.1.5 Explosives, Seat of Explosion, Device Identification

The explosive used will have an effect on the dispersal of debris and evidence surviving at the scene. Factors such as whether a low explosive or high explosive was used, as well as the integrity of the composition, its confinement and placement will need to be considered. Indeed, observation of debris at the scene could provide an initial indication of the type of explosive involved; debris being spread over a wide area will lead to complexes of material preserving multiple instances of forensic opportunities that would require the imposing of a sequence.

Explosive Ordnance Disposal (EOD) or Bomb Disposal Operators should be present to assist when the use of explosives is suspected. In the UK, EOD support (outside of the Metropolitan Police area) is provided by military personnel through Military Aid to the Civil Authorities (MACA) and is requested by the relevant Police Force to the Joint Service EOD Operations Centre (JSEODOC). EOD support for the Metropolitan Police is provided by their own Explosive Officers (EXPOs) department. The role of the EOD Operator is primarily to ensure explosive safety in order to allow the scene investigation to commence. Therefore, the EOD Operator may have undertaken various actions on the scene before the CSI is allowed to enter. This means the EOD Operator can be a source of information as a witness, in addition to providing a set of technical functions. Once satisfied that the immediate scene is explosively safe, the EOD Operator will 'hand over' to the CSI. At this point, it is critical for the CSI to understand what the EOD Operator has done, and more importantly, not done. 'Explosively safe' does not necessarily mean the removal of all explosive material nor does it mean that the entire area has been searched for other explosive devices or hazards. In complex post-blast cases, the BSM may require EOD support to remain on site for safety as well as in an advisory capacity.

Just as 'standard' major investigations require the identification of a range key scenes (a murder investigation might feature an attack site and a body deposition site, in addition to suspect addresses and vehicles), post-blast examination has similar specific challenges. The identification of the focus of the blast is crucial for both the sampling of material that might retain chemical traces of the explosive used [3, 4], but also to facilitate a reconstruction of items that might relate directly to the placement and nature of an explosive device. In terms of reconstructing events around the blast, the BSM must consider a strategy of examination that seeks to identify material traces that assist in building a picture of events prior to the placement of the device, the complex of activity around the blast itself, and the events that immediately followed activation.

In addition, the search of debris directly associated with the centre of the blast may reveal components of the device (timers, switches and batteries) that both assist with understanding the nature of the device's operation (and hence potentially providing intelligence regarding the technical capability of the maker of the device), as well as providing forensic opportunities related directly to the identification of the makers or placers of the device. However, as highlighted above, the spread of debris may be such that device componentry can be found hundreds of metres away from the seat of the explosion.

10.1.6 Zoning and Detailed Recording

The activities that follow a blast are almost certain to include the action of first responders discussed above, and the associated evacuation of casualties or the movement of walking wounded. The disturbance of debris associated with their activities might result in the contamination of items later found to be of forensic importance.

One of the key challenges facing the BSM is that of identifying exhibits that might prove to be of significance, forensic or otherwise, amongst a vast quantity of scattered and disordered debris. The standard means by which this is achieved is by the division of the scene into zones that then defines the aggregation of recovered debris. This enables the rapid clearance of material, while still allowing the tracing of a recovered item back to a generalised location on the scene. While the nature of the zones created depends upon the topography of the scene and the extent of the debris field, this long-standing technique can now be supplemented with three-dimensional scanning capability that assists with the reconstruction of the scene and the more specific location of items within the zones. In the UK, liaison with the Forensic Explosives Laboratory (FEL), and if deemed necessary, attendance by FEL scientists themselves at the scene may also benefit the decision-making process regarding evidence location, retrieval and best practice.

The identification of potential items of evidential importance requires a teamwork approach and, following confirmation of explosive safety, is initiated with a walk-through of the scene, during which (as with other crime scenes), evidence marking, photography and recording are constant tasks. Each evidence item is collected into an appropriate sterile container (e.g. metal cans, glass containers, paper, plastic or nylon bags) on which details describing the item and its location would be recorded. In post-blast examination, clearing a zone requires that all loose debris and material are swept up and either sieved at the scene or placed into bags or containers for further examination. The purpose of such a search is the singling out of component pieces of the device. A combination of coarse and fine sieve meshes can reveal very small items such as pieces of switching mechanisms, circuit boards, power sources and wires [5].

The meticulous examination of the seat of the explosion is usually one of the most painstaking tasks, requiring the swabbing of the area for trace explosive residues, the measurement of crater dimensions, the removal of loose debris (which may be treated as a single evidential exhibit), and further excavation of the crater in order to locate embedded components.

In addition to searches of the ground and crater, the examination of any secondary craters (if present) can also be forensically lucrative. Furthermore, items in the vicinity of the central explosion area which are positioned perpendicular to the ground—such as signposts, building walls or nearby car doors if outside; furniture or walls inside—may harbour pertinent forensic evidence whether they exhibit signs of blast damage or not. Consideration should also be given to the possible route of the blast wave given the surrounding environment as items may have been taken some distance due to pressure channelling. In addition, seeing how structures, vehicles, people and other objects have been affected will assist in the assessment of the explosive quantity and potentially identifying supplementary sources of evidence.

Fragmented remains of a device and associated explosive residues can also become embedded within skin and tissue; intended and unintended victims of the incident are therefore also potential sources of evidence. The BSM must ensure that if casualties are involved, then investigating personnel are dispatched to hospitals to recover any evidence either with emergency room staff or pathologists.

10.1.7 Forensic Intelligence and Evidence

There is an implicit challenge for the BSM and investigating police in the recognition of important intelligence gathered from blast scenes. This recognition touches on the conflation that persists between concepts of forensic intelligence and evidence, and the tendency to regard only specific forensic evidence types as being suitable providers of intelligence (most specifically those derived from DNA profiling [6]). By contrast, the experience of security services and military over many years of gathering weapons intelligence from Improvised Explosive Devices (IEDs) and other weapon systems is that devices, their placement locations and understanding of their 'tactical design' represent rich loci of potential intelligence. Whereas some complex enquiries that might be led in some parts by forensic intelligence in its broadest sense can be hamstrung by a syndrome of tunnel vision that equates the term 'intelligence' directly with 'biometric identification'.

Alongside the role of developing and delivering strategies to conduct a full methodological forensic examination, it is the responsibility of the BSM to ensure the welfare and safety of the forensic team. All must be suitably equipped with appropriate materials to perform their tasks effectively; be provided with sufficient refreshments and breaks during lengthy investigations and the required personal protective equipment, which may include hard hats (to protect from falling debris and head strikes) and face masks to protect from noxious gases and dust which may be present in confined areas. Welfare considerations should also extend to the psychological impacts when potentially dealing with multiple casualties, body parts and other significant hazards in a high profile and therefore pressurised situation. This could also have implications for individuals after the investigation in complete.

It is also the role of the BSM to consider the use of tents and screens which can be used to guard the investigation from prevailing weather conditions or to provide a degree of privacy to the investigators. In addition, the BSM needs to consider the use of lighting to lengthen the period of examination and protect the scene, or to halt the scene examination when lighting levels are especially poor (the use of flood lights can cause deep shadows that can mask potential evidence, and it may not be best to work actively through the nights). A further consideration is the impact of certain devices on the safety of the scene. For example, transmitting devices (including radios, mobile phones and wearable devices) should not be used where there remains the potential for electrical initiation of an explosive device.

One role of particular importance for the BSM is to maintain consultation and liaison with relevant parties throughout the investigation. If there are disruptions to the investigation, zone clearance might take many days, and throughout this time it is the duty of the BSM to regularly update the SIO as well as facilitate contact with the media in order to ensure the community and other interested parties remain suitably informed about progress.

10.1.8 Conclusion

As with any major crime scene, no two bomb scenes are the same as one another, each varying substantially in size, impact and associated scene variables. The roles, responsibilities and considerations outlined above are relevant to all scenes but particular investigative tactics will vary on the unique set of challenges each post-blast scene presents. Moreover, the general examples above are predominantly applicable to civilian scenarios which are only time-gated by the pressure of closure of urban areas. By contrast, post-blast investigation in a military context may have significant limits to available time to complete an examination and potentially a lack of resources. In either care, specialist systems of operation and the associated skillsets of personnel assist in distinguishing post-blast scenes from other major incidents. Despite this, the fundamental reliance on the core skills of scene examination is clearly present throughout the investigation process, as well as in the mindset of those involved.

10.2 Case Study 1: Modelling the Blast Environment and Relating this to Clinical Injury: Experience From the 7/7 Inquest

Alan E. Hepper, Daniel J. Pope, Maria Bishop, Andrew J. Sedman, Robert Russell, Peter F. Mahoney and Jon Clasper

10.2.1 Introduction

On the 2nd August 2010, the United Kingdom Surgeon General was instructed by Her Majesty's Assistant Deputy Coroner for Inner West London (Rt Hon Lady Justice Hallett DBE) to provide Expert Witness Reports relating to the terrorist events of 7 July 2005 on the London Public Transport Network. These Reports were required to review the evidence that had been gathered during the investigations into the event surrounding the bombings. Her Majesty's Coroner asked a series of specific questions relating to the survivability and preventability (with respect to the medical interventions and care) of the deaths of many of the victims, and these had to be answered on an individual basis with a review of all of the relevant information. It was appreciated that the most appropriate and current experience of dealing with personnel injured in this type of event came from the UK Ministry of Defence Surgeon General's Department who are experienced in dealing with combat-related injuries, particularly in the context of the current operations. This was also assisted by the fact that the UK Military Medical community already had a proven technique for the regular review of operational mortality and medical response [7, 8].

There had also been concerns about the nature of the events, criticism about the initial response, and one review in particular was highly critical of the communication systems of the emergency services which led to delays in understanding what was happening during the first few hours of the events of 7 July 2005 [9]. Survivors had also raised concern at the response of the emergency services [10].

10.2.2 Approach

In order to answer all of the questions posed by Her Majesty's Coroner, a multidisciplinary team was essential. This would take expertise from the Royal Centre for Defence Medicine (RCDM), Birmingham and Defence Science and Technology Laboratory (Dstl) Porton Down.

Her Majesty's Coroner was particularly concerned with the victims who were not killed immediately by the explosions, but died prior to reaching hospital. Of interest was what happened to them; what attention and/or treatment they received, whether there were any failings in the way that they were treated, the circumstances of their eventual death, and whether any failings in the emergency response contributed to or were causative of their death.

The decision was made at an early stage that a single report covering all personnel would be inappropriate and unique reports for each of the people in question would be written. There were two reasons for this:

- The victims were all individuals and should be regarded on an individual basis.
- The reports may be released to the families of the deceased and the reports would need to be redacted to ensure what was released was only relevant to their relative. There was a risk that such redaction would leave the feeling that some vital information had been removed, and this would simply amplify any conspiracy theory or any feeling that the Government (or in particular, the Ministry of Defence or Ministry of Justice) wanted to hide something of relevance.

This increased the workload substantially, resulting in multiple unique reports.

10.2.2.1 Work Strands

The broad ranging and complex nature of these questions required a substantial investment of time to address these questions. A three-phase approach was adopted as the only practical way to answer the questions within the challenging timescale (3 months start to delivery). These three phases were conducted in series; however, any hypotheses, assumptions or conclusions from either of the analysis phases were not allowed to affect or influence the other, in order to keep all options open.

The first phase required an engineering expert in blast effects on structures and injury modelling to review photographs of the damaged carriages and bus to give a view on the likely physical effects on people close to the explosions. This was coupled with a review of the forensic evidence relating to the explosions. This provided one strand of opinion on the nature of the injuries (the blast effects and injury mechanism) that was used in the final comparison.

The second phase was a clinical review of the evidence by military clinicians to assess blast injury in the casualties. This used techniques developed both in the deployed environment and at regular morbidity and mortality reviews over a number of years [7, 8] to review mechanisms of blast injury and likely cause of death. This method has shown significant benefit in demonstrating the survivability and preventability of the deaths of personnel and to provide a robust evidence base to guide the changes in medical care and response to the critically injured patient. This was coupled with a review of the nature of injuries from other terrorist incidents to provide a baseline comparison of injury mechanisms, as well as a review in the progression of pre-hospital care to advise the Court of changes in treatment strategies that may assist in survival rates.

In the third phase, the blast environment was modelled by the structural dynamics experts [11] to assess likely blast loading on victims. This loading information was then assessed by physiology experts with access to data from experimental studies that provided a correlation of precisely measured blast data with injury, focusing principally on blast lung [12] since this is one of the most difficult aspects to evaluate from post-mortem reports. Simple modelling was also undertaken in isolation of the complex structural dynamics modelling to provide simple predictions of the risk of blast lung and other injury mechanisms.

The relationship of these phases is shown in Fig. 10.2.

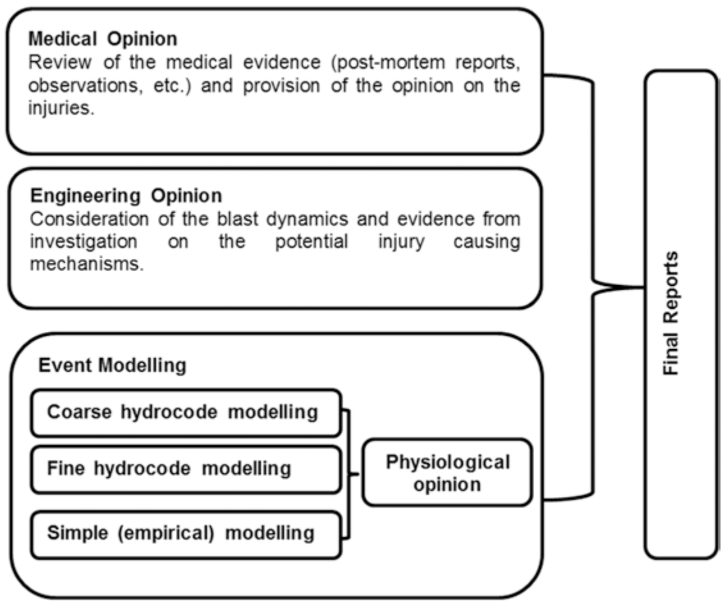

Fig. 10.2 Relationship of three phase work strands

The outputs from these three phases were combined into a joint report and a single opinion on the nature of the injuries and the survivability of personnel as described in the transcripts from the Inquest [13–15]. Each report was formatted to provide a main section written by the principal author and summarising the work that was undertaken.

10.2.2.2 Model Design and Risk Reduction

Substantial risks were inherent in the mathematical models of the blast environment because of the model complexity and the degree of uncertainty (exact charge size, exact charge dynamics, exact charge location, location and orientation of victims, etc). As a result, three different levels of model were run for each of the events in the trains:

- A coarse hydrocode model (see Chap. 5) was used to:
  - Study the mechanisms of blast load development and provide broad levels of peak overpressure and specific impulse.
  - Establish 'zones of blast wave intensity'.
  - Determine the extent to which the fireball extended within the carriage during the event.
- A fine hydrocode model to quantify the probable pressure time history loading sustained by occupants within each carriage. This model also produced images and videos of the effects of the blast that showed the blast propagation (see Fig. 10.3). These images were useful for the team, the Court and families to understand the nature of the blast environment.
- A simple (uniform blast wave model) to give an empirical relationship of blast pressure from idealised explosives and compare the results to simple estimates of lethality from blast lung.

10.2.2.3 Resources

The team had access to a combination of scene photographs, post-mortem photographs, external post-mortem reports and witness statements to form an opinion of the internal and external injuries received by the victims and for how long they showed signs of life after the bombing (if at all).

The team looked particularly at witness statements to understand if the victims were noted to be breathing and have a pulse after the bombing, whether or not they were conscious and the likely time course over which they died from their injuries.

Information provided by the court to support this activity was stored on encrypted memory drives, secured at Dstl and at RCDM, where they could be examined in a secure environment.

The scene reports included seating plans for the underground carriages and the bus indicating positions of individuals pre- and post-explosion (where this information was known) and during recovery of the deceased.

As some deceased and live casualties had to be moved at some of the bombing locations after the attacks to allow access to other casualties, the position of a victim post-explosion does not always indicate where that person was prior to the explosion or if that position was the location where they died. This meant that the team needed to use a number of methods to try and work out how close a victim was to the seat of the explosion and from this offer a view on likely internal injuries, as well as providing a review of relevant related information to inform a final opinion on the probable nature of injuries.

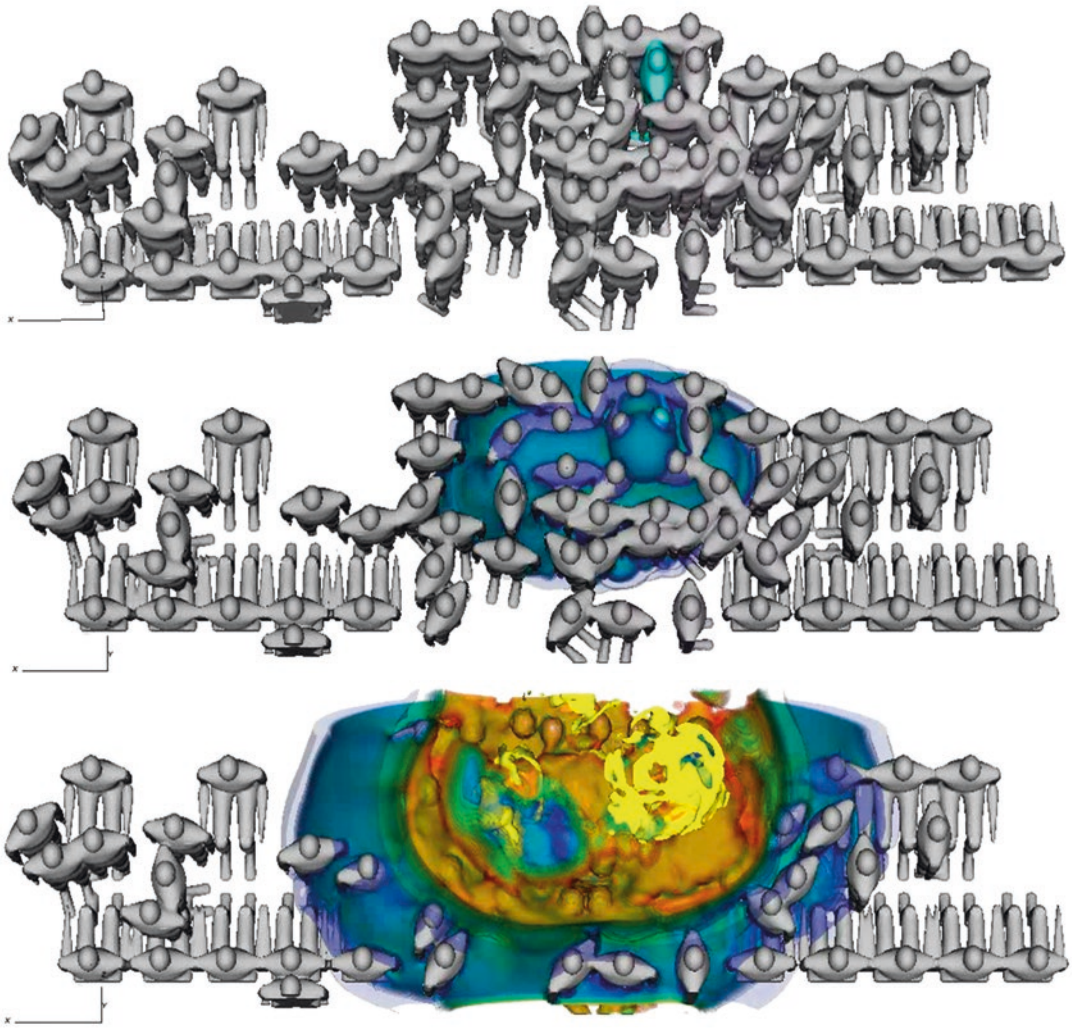

Fig. 10.3 Sample blast propagation from fine hydrocode model

10.2.2.4 Challenges: Quality of Information

Usually when conducting such a review, the clinicians and scientists looking at the information would have a complete list of the victim's injuries derived from a combination of a full post-mortem examination plus X-ray imaging. This in turn would be used to calculate mathematical trauma and injury scores which help in assessing whether or not a particular combination of injuries would or would not be expected to be survivable. On this occasion, the information from internal post-mortem examination was not available and the X-ray imaging information was limited to fluoroscopy. The fluoroscopic examination was used to identify some fractures and foreign materials present in the victims' bodies.

The team, therefore, relied upon a number of sources of information and scientific methods to come to a considered opinion for each of the victims; however, in an ideal world, more structured observations, measurements and opinions would have been available for the team to consider.

The amount of information missing from a simple external post-mortem was a significant challenge in this work. If anything can be stressed from this work, the importance of a detailed post-mortem examination must be one element.

10.2.3 Conclusion

We believe that this detailed understanding of the nature of injury from blast and fragmentation threats, and the modelling and understanding of the physical interaction of combat-related threats can only come from a multidisciplinary grouping such as the group formed to address the events of 7 July 2005 and the applicability of this form of analysis should be considered in the event of other terrorist events.

Acknowledgements
The original version of this material was first published by the Research and Technology Organisation, North Atlantic Treaty Organisation (RTO/NATO) in meeting proceedings RTO-MP-HFM-207 'A survey of blast injury across the full landscape of military science' held in Halifax, Canada, 3–5 October 2011.

A shortened version was published, with permission, in the Journal of the Royal Army Medical Corps as Hepper AE et al., J R Army Med Corps 2014;160:171–174.

This section reproduces the J R Army Med Corps material, with permission.

10.3 Case Study 2: Injury Mechanism and Potential Survivability Following the 1974 Birmingham Pub Bombings

Jon Clasper, Alan E. Hepper, Ruth McGuire, Anthony M. J. Bull and Peter F. Mahoney

10.3.1 Introduction

On the 21st November 1974, two bombs exploded in Birmingham. There were 21 fatalities, and it is reported that 220 people were injured [16].

On the 28th May 1975, Inquest hearings were held and evidence relating to the identification of the fatalities was given. As a criminal investigation was taking place, the Inquest was then formally adjourned. Following an application from some of the families of the victims of the bombings, the Inquest's proceedings were resumed on 1st June 2016.

In view of the complexity of explosive injuries and in particular, the length of time that had passed since the initial Inquest, expert evidence was required in order to explore any issues with causation and time of death. Required expertise included explanations of the consequences of an explosion, understanding of the variables that can impact the blast load, and an analysis of the injuries suffered by the deceased.

Potential survivability of the injuries with current advanced medical treatment was highlighted, as a number of the victims had survived long enough to reach hospital. An approach was made to the Centre for Blast Injury Studies (CBIS) at Imperial College to assemble and co-ordinate a team to provide this, and the authors were formally instructed on 5th May 2017 by His Honour Sir Peter Thornton QC, Coroner for the Birmingham Inquests (1974).

10.3.2 Overview

The two bombs exploded in different Public Houses in Birmingham: the Mulberry Bush and the Tavern in the Town. Both establishments were busy, resulting in multiple casualties. It was reported that of the 21 killed, 18 'were killed outright' and 3 died later in hospital [17].

Although 6 people were convicted of the murder of the 21 casualties, following a Court of Appeal ruling, these convictions were quashed as being 'unsafe and unsatisfactory' on 14th March 1991 [18]. As noted above, the Inquest's proceedings were resumed on 1st June 2016.

Unlike most civilian trauma, victims of explosions are subjected to multiple mechanisms of injury. As described in Chap. 9 blast injuries fall into five main categories Primary, Secondary, Tertiary, Quaternary and Quinary injury.

As a result of the multiple casualties, multiple injuries and multiple mechanisms of injury, the Coroner sought expert evidence to explain the consequences of an explosion and the variables that can impact the blast load, and an analysis of the injuries suffered by the deceased in order to explore any issues with causation and time of death. This analysis required an approach that could understand and articulate the physics of the blast, the injury causing mechanisms and consequences to the victims. This was required to assist Her Majesty's Coroner, the families and any other interested parties of the events of 21st November 1974. As well as a narrative of the blast events and possible injury modes, the potential survivability of the victims needed to be understood, especially for those who were reported as having signs of life at the scene.

10.3.3 Approach

10.3.3.1 Multidisciplinary Team Approach

Three of the authors (JC, AH, PM) had been involved in providing evidence for the 7/7 bombing Inquest, and so a similar multidisciplinary team approach was used. The team comprised personnel from CBIS, the Defence Science and Technology Laboratory (Dstl) and the Royal Centre for Defence Medicine (RCDM). All are authors of this chapter (JC, AH, PM, AB). The academic disciplines and experience of the group are summarised in Table 10.1. The involvement of personnel from a range of organisations and backgrounds also brought independent learning and a range of opinions—this was seen as important in exploring as many eventualities as possible.

Table 10.1 Academic disciplines and experience of the CBIS, Dstl and RCDM team

Clinical management of multiply injured blast and ballistic casualties on military operations
Civilian pre-hospital care
Bioengineering and trauma biomechanics
Forensic investigation
Blast physics
Explosives chemistry
Specialist engineering knowledge of human vulnerability
Injury scoring and wound mapping

The team was provided with contemporaneous witness statements, post-mortem reports and photographs and scene photographs and sketches. Additional information was available in the open literature [17]; this was obtained, reviewed and considered in the context of the other provided information.

The panel members held a series of review meetings at which information provided was analysed and other experts were recruited to provide additional analysis. The witness statements and reports for each victim were reviewed in turn to build up an understanding of where they were at the time of the explosion, the injuries they suffered and any treatment they received. An analysis of the two incidents was conducted; this included consideration of survivability for each of the victims.

Injuries were collated onto external injury mapping software by Dstl [19] and Abbreviated Injury Scale Scores [20] assigned (see Fig. 10.4), which could then be calculated into Injury Severity Scores [21] (ISS) and New Injury Severity Scores [22] (NISS). The NISS is implied to provide a better calculation of overall injury severity than ISS [23], yet there are known caveats in the use of ISS and NISS with blast (see Chap. 11 and [24]).

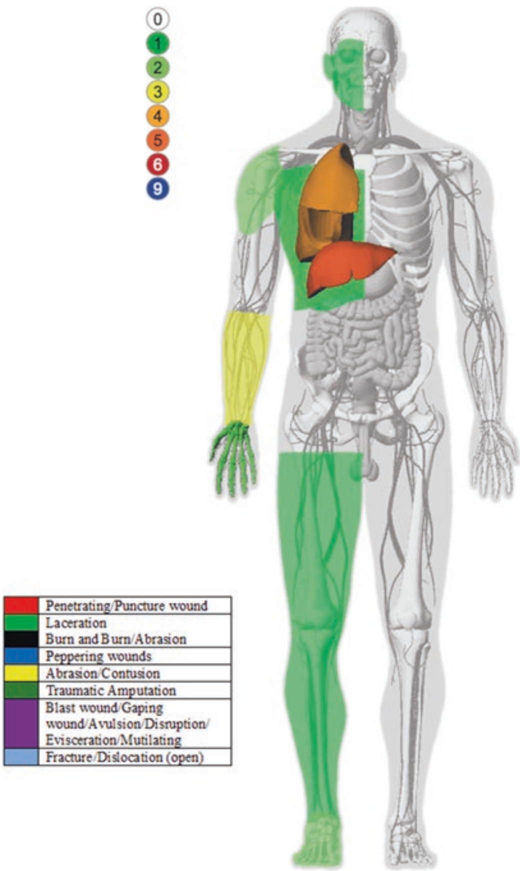

Fig. 10.4 Example of injury map and wound scoring for a fictitious casualty

In each case evidence of primary, secondary, tertiary and quaternary blast injuries was sought, together with the injury (or injuries) most likely to have caused death. Following detailed discussion, a consensus on potential survivability was given.

10.3.3.2 Challenges: Missing Clinical Information

Due to the length of time, a series of hospital closures and reorganisations in Birmingham since the bombings, contemporaneous clinical records were not available for the casualties admitted to hospital. There were, however, several peer reviewed clinical publications in relation to the bombings [17, 25]. In conjunction with witness statements and the post-mortem reports, a forensic analysis was possible. One particular publication allowed a sufficiently detailed analysis of the in-hospital deaths to be made [26].

All the collated data was reviewed and re-reviewed iteratively to ensure that any lessons identified during the first stages of the review were applied consistently to all cases.

10.3.4 Findings

Of the 21 fatalities, 17 were found to be dead at the scene, 2 were declared dead soon after admission to hospital, 1 died 6 days, and 1 died 18 days after the explosion. The age range was 17–56, and of the 21, 14 (66.7%) were male.

All 21 fatalities had multiple injuries, and died as a result of significant head injury, severe blast lung, or major haemorrhage. Fourteen of the 21 (66.7%) had more than 1 of these 3 modes of death.

Based on the analysis, of the 21 deaths, 13 people (71.4%) had evidence of all 4 blast injury mechanisms. Six people (19.0%) had evidence of three blast injury mechanisms. One person had evidence of two (4.8%) mechanisms, and one (4.8%) had evidence of only one mechanism of injury; both these casualties had a significant secondary blast (penetrating) injury to a vital structure and died rapidly after the explosion.

Despite initial reservations, it was possible, based on a knowledge of the injuries at post-mortem together with a relevant publication [26], to state with confidence that the four deaths that occurred after arrival at hospital were not preventable. We were therefore able to confirm at the inquest that, on balance, all 21 casualties sustained non-survivable injuries.

Although we were not tasked to provide an opinion on the location of individuals in relation to the seat of the explosion, we were able to confirm that the injuries were consistent with the location proposed in the witness statements. For the three fatalities who could not be placed accurately, it was possible to give an opinion that they were close to the seat of the explosion. Two individuals could be placed outside a building when the bomb detonated.

The absence of detailed records presented a challenge but, as noted above, this was mitigated by the availability of additional sources of expert information. The variability in the quality of available information also presented a challenge and there needed to be an understanding that the standards of 1974 are not the same as today, and much of the information was recorded without any belief that this would need to be critically reviewed in legal proceedings more than 40 years later. The methods and techniques used in this work had been previously used, and the use of injury scoring was found valuable in determining a common way of describing the injury types and severities. Despite all this, some of the scoring methods, notably ISS, were seen as under-predicting the total burden of injury. NISS, in this limited set, was better, but still not ideal and clinical expertise, experience and judgement were seen key ways in which injury mechanisms and the overall survivability could be provided.

10.3.5 Conclusions

As with our previous Inquest work [7/7], the value of a multidisciplinary team approach was confirmed. All conclusions were based on evidence or expert opinion, and all team members confined their comments to their area of expertise. The multidisciplinary and multiorganisational approach also provided internal group review that ensured that narratives were widely understandable.

The lack of contemporaneous hospital records was a potential problem but managed by cross-referencing an open access peer reviewed publication with the witness statements and post-mortem reports. This was declared to the Coroner and caveated.

There was considerable variety in the narrative description and detail of injuries in the post-mortem reports but the images provided allowed us to interpret blast mechanism where written detail was lacking.

In this analysis, ISS did not appear particularly helpful, as it appeared to under-score some injuries and injury complexes. This may be due to the fact that blast injury can result from different mechanisms (primary to quaternary), and some injuries, notably lung trauma, may occur from several mechanisms occurring at the same time, when the explosion occurs. The effect of this may be cumulative, even though the individual components may appear less severe. In addition, severe head injuries and blast lung evolve over time, due to the physiological response. Thus, significant injuries, such as diffuse brain injury may appear less severe at post-mortem if death is rapid.

The effect on different mechanisms of injury has been reported previously [27], but to our knowledge no scoring system has considered blast detail, particularly in relation to lung injury from the different blast mechanisms, which occurred in most of the casualties we reviewed in this work. Whilst NISS appeared in this limited cohort to be better than ISS, there was no replacement for training, experience and judgement of the medical experts in the group.

Based on this Inquest work, a number of recommendations were made to the Coroner. These are included at Annex 1.

Annex 1

The panel's recommendations to the Coroner, Sir Peter Thornton QC were as follows. The Coroner and the families of those killed have approved the inclusion of these recommendations in this chapter.

1. The case review approach taken by the expert panel has resulted in a detailed understanding of the 1974 Birmingham bombings. This would not have been possible if the approach had been to produce separate reports without meeting in person and conducting a joint review.

   We recommend that similar inquests follow the suitably formed expert panel approach.

   Recommendation owners: HM Coroners.
2. The lessons learned by the expert panel are important and should be captured for the

benefit of others and to inform future inquisitions.

We recommend that the lessons learned by the expert panel are written up as a report to be published in the open literature.

Recommendation owners: Expert Panel.

Birmingham Bombings—1974 inquest Coroner.

3. We acknowledge the complexity of the review we undertook in the context of the elapsed time since 1974 as well as lack of detailed record keeping in a form which facilitates such an understanding. This lack of detail made the panel's work difficult and hampered the total progress that could be made. Detailed record keeping of all key facts would facilitate timely analysis of any future incidents.

   We recommend that detailed record keeping of the following facts is made following any explosive event by the Coroners/Police and separate digitised copies of these be held, ensuring that these are future-proofed to any technological changes:

   1.1 location of all individuals involved (fatalities, survivors and uninjured);
   1.2 detailed and consistent injury recording of fatalities and survivors, post-mortem records, photographs;
   1.3 medical notes of all individuals involved;
   1.4 detailed plans of the location;
   1.5 details of explosives, device construction, detonation method, fragmentation;
   1.6 structural damage records; and
   1.7 building records and construction techniques.

4. In particular, we would highlight the necessity to obtain information not only on fatalities, but also on injured survivors, as the ability to learn from other incidents in order to effect changes that could increase survivorship requires knowledge of current survivors, not only fatalities.

   We recommend the keeping of detailed records for all those injured in a blast event.

   Recommendation owners: HM Coroners/Police.

5. The injury 'scoring' systems currently may not adequately capture the complex injuries associated with blast. Such systems need to be consistent and improved. A key point in this is that the pathologist reports did not have a standard form and, as such, the articulation of injuries were affected by individual pathologist reports.

   We recommend that research is conducted to ensure a consistent method for injury recording that is appropriate for the review and analysis of blast injuries.

   Recommendation owners: Academic community. Research funders.

6. We were unable to conduct a detailed computer model analysis of the blast in the 1974 Birmingham bombings. Validated computer models could be used pre-emptively to design new facilitates to mitigate the effects of potential explosions. Whilst we are aware these are being developed, validation is limited. Detailed analyses of incidents such as the 1974 Birmingham bombings could be used retrospectively to improve computer model analysis.

   We recommend that the information collated as part of this inquest be released to conduct a detailed computer analysis of the blasts in the 1974 Birmingham bombings.

   Recommendation owners: Birmingham Bombings – 1974 inquest Coroner.

   Competent computer modellers.

   We recommend that such computer analysis be considered and commissioned for any future incidents.

   Recommendation owners: HM Coroners.

DSTL/PUB120062.

References

1. Tilley N, Ford A. Forensic science and crime investigation. London: Home Office Police Research Group; 1995.
2. Technical Working Group for Bombing Scene Investigation. 2000.
3. Abdul-Karim N, Morgan R, Temple T, Harrison K. The spatial distribution of post-blast RDX residue: forensic implications. J Forensic Sci. 2013;58:365–71.
4. Abdul-Karim N, Blackman CS, Gill PP, Wingstedt EM, Reif BAP. Post-blast explosives residue–a review

of formation and dispersion theories and experimental research. RSC Adv. 2014;4:54354–71.
5. Thurman JT. Practical bomb scene investigation. Boca Raton: CRC Press, Taylor and Francis Group; 2006.
6. Ribaux O, Gorid A, Walsh SJ, Margot P, Mizrahi S, Clivaz V. Forensic intelligence and crime analysis. Law Prob Risk. 2003;2:47.
7. Russell RJ, Hodgetts TJ, McLeod J, Starkey K, Mahoney P, Harrison K, Bell E. The role of trauma scoring in developing trauma clinical governance in the Defence Medical Services. Phil Trans R Soc B. 2011;366:171–91.
8. Hodgetts TJ, Davies S, Midwinter M, Russell R, Smith J, Clasper J, et al. Operational mortality of UK service personnel in Iraq and Afghanistan: a one year analysis 2006-7. J R Army Med Corps. 2007;153:252–4.
9. London Assembly. Report of the 7 July Review Committee, June 2006, http://legacy.london.gov.uk/assembly/reports/7july/report.pdf, ISBN 1 85261 878 7.
10. Alexandra Topping, The Guardian., http://www.guardian.co.uk/uk/2011/may/06/london-bombings-victims-relatives-call-for-overhaul, 6 May 2011.
11. Pope DJ. The development of a quick-running prediction tool for the assessment of human injury owing to terrorist attack within crowded metropolitan environments. Phil Trans R Soc B. 2011;366:127–43.
12. Kirkman E, Watts S, Cooper G. Blast injury research models. Phil Trans R Soc B. 2011;366:144–59.
13. http://7julyinquests.independent.gov.uk/hearing_transcripts/31012011am.htm
14. http://7julyinquests.independent.gov.uk/hearing_transcripts/31012011pm.htm
15. http://7julyinquests.independent.gov.uk/hearing_transcripts/01022011am.htm
16. https://www.bbc.co.uk/news/uk-england-birmingham-47377548. Accessed 22nd April 2020.
17. Waterworth TA, Carr MJ. An analysis of the post-mortem findings in the 21 victims of the Birmingham pub bombings. Injury. 1975;7:89–95.
18. Regina v. McIlkenny, Hunter, Walker, Callaghan, Hill and Power. The Birmingham Six *(*1991*)* 93 Crim. App R 287.
19. Breeze J, Allanson-Bailey LC, Hunt NC, Delaney R, Hepper AE, Lewis J. Using computerised surface wound mapping to compare the potential medical effectiveness of enhanced protection under body armour combat shirt collar designs. R Army Med Corps. 2015;161:22–6.
20. Gennarelli TA, Wodzin E. Abbreviated Injury Scale 2005 (Update 2008). Association for the Advancement of Automotive Medicine. P.O. Box 4176–Barrington, IL 60011–4176. 2008.
21. Baker SP, O'Neill B, Haddon W, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974;14:187–96.
22. Osler T, Baker SP, Long W. A modification of the injury severity score that both improves accuracy and simplifies scoring. J Trauma. 1997;43:922–5.
23. Samin OA, Civil ID. The new injury severity score versus the injury severity score in predicting patient outcome: a comparative evaluation on trauma service patients of the Auckland Hospital. Annu Proc Assoc Adv Automot Med. 1999;43:1–15.
24. Hazell GA, Pearce AP, Hepper AE, Bull AMJ. A critique of injury scoring systems when used for blast injuries: a narrative review with recommendations for future work. Brit J Anaesth. 2022;128:e27–34.
25. Waterworth TA, Carr MJ. Report on injuries sustained by patients treated at the Birmingham general hospital following the recent bomb explosions. Br Med J. 1975;2:25–7.
26. Caseby NG, Porter MF. Blast injuries to the lungs: clinical presentation, management and course. Injury. 1976;8:1–12.
27. Santaniello JM, Luchette FA, Esposito TJ, Gunawan H, Reed RL, Davis KA, et al. Ten year experience of burn, trauma, and combined burn/trauma injuries comparing outcomes. J Trauma. 2004;57:696–700.