

Chapter 2

Toxic Trauma: A Historical Perspective

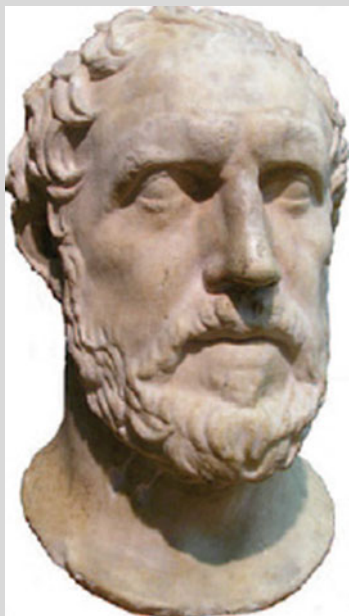
Abstract Exposure to toxic chemicals goes back at least 2000 years with the first use of irritating agents such as smokes and burning sulphur in warfare, a practice which continued until the Middle Ages. The industrial revolution and the development of large-scale chemical industries in Europe laid the basis for the large-scale chemical warfare seen in the First World War. Throughout the remainder of the twentieth century and beyond there were continuing occurrences of mass exposure to chemicals, not only from deliberate release in chemical warfare but also from accidental release by an ever-expanding chemical industry. These had particularly severe consequences in developing countries with limited emergency responses. This chapter presents a brief historical perspective of the toxic trauma produced from exposure to chemical substances in both the military and civil settings.

2.1 Exposure to Chemicals From Early Times to the Nineteenth Century

Man has learned the dangers of poisonous substances in the wild since his days as a hunter-gatherer in pre-history. Exposure to toxic agents in warfare and in peace also dates back many thousands of years. As long ago as 2000 BC, toxic smokes were being used in battle in China and India. They are also recorded by Thucydides in around 500 BC. The Athenian general described the first use of chemicals in

Western warfare in his history of the Peloponnesian War, which took place between 431 and 404 BC. (Box 2.1) The Romans also, around 80 BC, used a toxic smoke in battles which caused blindness and choking pulmonary symptoms.

Box 2.1 Thucydides and the First Use of Chemical Warfare



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The Athenian general and historian Thucydides (c. 460–c. 395 BC) described the first use of chemical warfare in Western civilisation, by Sparta against Athens, in his *History of the Peloponnesian War* (431–404 BC). Wood was saturated with pitch and sulphur and then burned under the walls of the city during the siege of Plataea in 428 BC to produce poisonous choking fumes (as well as fear and panic). The use of fire and poisonous fumes continued to be a weapon of siege warfare until well beyond the Middle Ages.

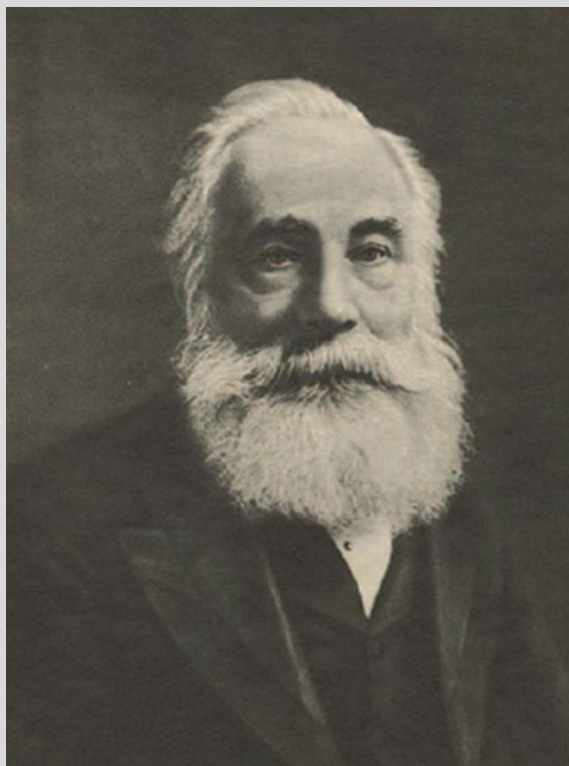
The concept of an incendiary chemical device was developed by Callinus in Constantinople around 670 AD with the development and use of Greek Fire. This was an autocombustive mixture of resin, pitch sulphur, naphtha, quicklime and saltpetre (later to be a main constituent of gunpowder). The mixture ignited on

contact with water and burned on the surface of the sea, causing immense damage to enemy vessels. Incendiary devices which produced toxic fumes continued to be used through the Middle Ages and Renaissance.

Agents that caused pulmonary toxic trauma (see Chap. 6) were being used and considered in the Middle Ages following the use of fire and smoke in earlier sieges. Leonardo da Vinci himself proposed the use of a mixture of sulphur, arsenic and copper acetate as a lung-damaging warfare agent. In 1672, Christoph Bernhard von Galen, the Bishop of Munster, used a number of incendiary devices designed to produce toxic fumes. This led to the 1675 Strasbourg agreement which represented the first attempt to control the use of toxic substances in warfare, a process which has continued to the present day.

2.2 The Industrial Revolution and the Development of Mass Chemical Warfare

The foundations of modern chemical warfare (CW) agents in the twentieth century were made possible by the creation of large industrial chemical facilities in Europe in the nineteenth century. The astonishing range of chemicals that were tested and used as CW agents during World War I was made possible by the industrial revolution and particularly by the chance discovery of aniline dyes by the British chemist William Perkin (Box 2.2) in the mid-nineteenth century. Perkin built up a major British synthetic dye industry which was then overtaken by a number of German companies. This opened the pathway to the creation of industrial chemical giants such as IG Farben which allowed the mass production and stockpiling of chemical agents at the beginning of World War I and the development of new chemical agents between the wars.

Box 2.2 William Perkin: The Father of Modern Synthetic Dyes

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William Perkin was born in the East End of London, the youngest of the seven children of George Perkin, a successful carpenter. In 1853, at the age of only 15, Perkin entered the Royal College of Chemistry in London (now part of Imperial College London), where he began his studies under the distinguished German chemist August Wilhelm von Hofmann. Although he was working on the chemistry of quinine, Perkin performed his own experiments in the crude laboratory in his apartment on the top floor of his home in East London. It was here that he made the discovery that aniline could be partly transformed to produce a substance with an intense purple colour which he called Mauveine. Perkin's discovery came at a time when the industrial revolution had created major improvements in the production of textiles. Chemistry now had a major impact on industrial processes, and coal tar, the major source of Perkin's raw material, was an abundant by-product of the process for making coal gas and coke. Perkin set up a successful factory that was to become the basis of the synthetic dye industry in the UK. The technology spread to Germany, a country that was to become dominant in the

field by the end of the nineteenth century, leading to the establishment of a chemical industry that would provide the basis for the production of chemical warfare agents.

2.3 First Suggested Uses of Chemical Weapons in the Nineteenth Century

The first suggested military use of chemicals as weapons took place in the middle of the nineteenth century when the British chemist Lyon Playfair proposed in 1854, the use of a cyanide shell to break the siege at Sevastopol in the Crimea. Nearly a decade later, in the American Civil War, John Doughty suggested the use of a chlorine shell against an entrenched enemy. Neither of these suggestions was adopted, but full-scale CW was to become a stark reality 50 years later in the First World War when extensive use of toxic agents was made by both sides, starting with the use of chlorine by the German in April 1915. There was growing awareness of the threat of CW towards the end of the century, and the 1899 Hague Convention banned the use of chemical agents in warfare, but only if delivered by shell or other projectiles.

2.4 The First World War

The First World War saw the beginning of mass use of toxic chemical agents in battle. This has been exhaustively analysed by military historians and is the subject of a number of detailed texts, some of which are listed at the end of this chapter. At the time of writing, the first gas attack occurred 100 years ago and the detailed experience of the emergency medical and nursing personnel who had to deal with casualties of this new form of warfare has been largely forgotten. However, the war provides many valuable lessons for modern emergency responders in the management of toxic trauma which are still relevant.

The chemical attacks of the first war could not have taken place without the backing of the German chemical industry and the scientists working within it. The original use of the chlorine and phosgene in 1915 was coordinated by the chemist Fritz Haber who is best known for his chemical synthesis of ammonia to produce explosives, for which he received the Nobel Prize for chemistry in 1919. Haber directed the enormous resources of the German chemical industry, originally based on the production of dyestuffs into mass production of CW agents (Box 2.3). Use of chemical weapons, although banned by the Hague Convention, was rapidly adopted by both sides and caused many millions of casualties.

Box 2.3 Fritz Haber

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Fritz Haber (1868–1934) was a German chemist and professor at the Kaiser Wilhelm Institute in Berlin who received the Nobel Prize in 1919 for his innovative work on the production of synthetic nitrates from ammonia. This was in fact driven by the need for their requirements in the production of explosives in the First World War after the blockade of raw materials from Chile. Haber worked in the IG Farben group of companies, initially set up as the name suggests for the production of dyes but whose chemical engineering expertise was diverted to the production of chemical warfare agents. IG Farben (*Interessen Gemeinschaft Farben*, literally, community of interests, of dye-making corporation) was a union of six German chemical companies who dominated the synthetic dye industry before the First World War. In 1913, Germany produced over 85 % of the world's dyes (the UK by this stage only produced 2.5 % and the USA 2 %). Haber was closely associated with the planning of the first major gas attack at Ypres in 1915 where chlorine was released from cylinders (thus not violating the Hague Convention of

1899 which only prohibited the use of toxic gases in artillery shells) but was said to be frustrated by the failure of the military to follow through the successful attack and end the war. Chlorine was selected by Haber because it was lethal, had a short latency of action and was non-persistent. It could form a dense toxic cloud able to resist dilution in a moderate wind but with no prolonged effect on the terrain. Haber was also associated with the development of phosgene and sulphur mustard gas, first used in July 1917, again at Ypres. Haber was Jewish and was forced out of Germany in 1934 after the rise of the Nazis. He died in Switzerland shortly afterwards.

Early experimental attacks by both sides using irritant (tear gas) agents had taken place in late 1914 and early 1915 on both the western and eastern fronts with mixed results. However, this signalled the way to disregard the Hague Convention and to launch attacks with potentially lethal CW agents.

The first major chemical attack took place at Ypres in Belgium on 22 April 1915. The German Army released 168 tons of chlorine gas from nearly 6000 cylinders (which were not covered by the Hague Convention) on to the French lines with devastating results. Although the accurate figure is not known, the number of French and North African troops killed in the attack is thought to have been around 10,000. The attack produced a gap of nearly 9 miles on the western front, but the German commander, von Falkenhayn, did not believe the reports he had heard about this; he had no reserves available to exploit the advantage, complete the German assault on to Paris and thus end the war. Within 2 days, British and Canadian troops had secured the line and the military advantage had been lost. Only one subsequent attack, at Bolimov on the eastern front where the Germans attacked Russian troops, was to have such a devastating effect. This time, 262 tons of chlorine was released from 12,000 cylinders along a line of 7.5 miles producing 25,000 casualties and 6000 dead. This was a lesson about CW the Russians never forgot up to and beyond the Second World War.

Countermeasures to the initial attacks were quickly introduced, including primitive gas masks and better training, and the catastrophic effects of the first gas attacks were never repeated. Nevertheless, in combination with other arms, toxic chemicals proved to be a continuing and influential factor in the largely static warfare of the first war.

Chlorine was quickly replaced by the Germans with diphosgene and phosgene (first used in December 1915). Phosgene, with its early upper respiratory irritant effects and late onset pulmonary oedema (see Chap. 6), proved to be one of the most dangerous agents of the war.

Inhaled gas warfare continued to be a major factor in the trench warfare of 1916, but in 1917, a new agent, sulphur mustard gas, was used by the Germans with continuing success. Mustard gas was designed to disable combatants rather than to kill, and it proved to be one of the most insidious of CW agents. It still remains a major military and terrorist threat up to the present day.

More than 60 chemical compounds were tested during World War I, but only a few found extensive use as chemical weapons. The most notable were chlorine, phosgene, hydrogen cyanide, arsines and mustard gas. The vesicant Lewisite which had quicker actions than mustard gas was produced in 1919 and not used during the war. Of these compounds, it is noteworthy that three of them are toxic industrial chemicals (TIC) and are still being produced in large quantities by the chemical industry today.

Despite the ban on the use of chemical projectiles which was in force in 1914, by the end of the war, chemical shells were widely used. Had the war continued into 1919, it was predicted that more than half of the shell fills would have been chemical.

Despite their mass disabling actions, CW agents produced the lowest dead-to-wounded ratio of all the weapons used in World War I (4 % as opposed to over 12 % from artillery). The high proportion of the latter reflects the limited responses to major physical trauma at the time. By the end of the twentieth century and after the application of advanced life-support measures in battle for physical and toxic trauma, both ratios have steadily decreased.

2.5 Between the World Wars

The Geneva chemical weapons convention of 1925 banned the first use but not the stockpiling of chemical weapons. Most countries ratified the treaty quickly but the USA did not do so until 1975. There are still three countries, North Korea, Syria and Israel, who still have not ratified the treaty at the time of writing.

Despite the indignant reaction against chemical weapons during and after the First World War, most combatant countries had learned lessons from the new warfare and proceeded with development and training. The Russians in particular who had suffered over 400,000 wounded and 56,000 dead were quick to build up their chemical capability, ironically under the guidance of ex-officers of the former Imperial German Army. Russian chemical capability continued with the formation of special chemical battalions in the Second World War that were not involved in general fighting duties, even during the battle of Stalingrad. The lessons of the first war were not forgotten.

2.5.1 The 1930s: First Systematic Use of Chemical Warfare Agents Against Civil Populations

Despite the 1925 treaty, the following decade saw the continued production and use of CW agents against civil populations.

In 1936, the Italian Army used mustard gas against a poorly trained and equipped army and civilians in Abyssinia as part of a systematic campaign of CW. Waves of aircraft drenched combatants and civilians and polluted rivers, lakes and

pastures. The devastating effects of this campaign, which caused tens of thousands of victims, were a major contribution to the Italian victory and the occupation of Abyssinia until the British liberation during World War II.

The wider effect of this campaign was to alert nations that were about to fight World War II of the effects of aerial gas attacks against a civilian population. As a result, by 1939, there was mass production of gas masks in the UK and Germany. In the event, gas was not used by either side in Europe during World War I, but the threat was always regarded as high.

Elsewhere, during the Manchurian War between Japan and China which started in 1937 and which some historians regard as effectively the beginning of World War II in the Far East, chemical weapons, notably mustard gas, were used against civilian populations in a number of attacks. At that time, Japan had not ratified the 1925 Geneva CW treaty. By 1941, there were reports that there had been over 800 attacks against the Chinese Nationalists of Chiang Kai-shek using mainly mustard gas. There were continuing fears in the USA that the Japanese would use gas weapons against them, but in the event, the Japanese wound down their CW training and production ability as the war progressed against them, possibly for fear of reprisals.

2.6 The Second World War

Despite the growing fears in the 1930s, chemical weapons were not used in Europe during the Second World War either in battle or against civilians. Historians debate the reasons for this, but one major factor affecting German use was their diminishing air capability as the war progressed and the fear of aerial reprisals by the Allies with their overwhelming air superiority by 1945.

The nonuse of CW agents, however, did not stop the production and stockpiling of chemical weapons. In one of the worst mustard gas releases recorded, more than a thousand sailors and civilians were killed on 2 December 1943 in Bari harbour in Italy. In one of the heaviest raids of the war, more than 100 German JU88 bombers attacked packed Allied shipping in the harbour, producing the most devastating attack of its type since Pearl Harbour. Seventeen ships carrying over 90,000 tons of supplies were sunk. One of the ships moored in the harbour, the John Harvey, was carrying a cargo of mustard gas bombs. As the ship sank, liquid mustard gas was released onto the surface of the water where it combined with floating oil. Hundreds of sailors in the water who had abandoned the ship suffered heavy contamination. The result of the attack was a mass influx of mustard casualties into hospitals who had no idea of the cause of the wounds, which because of the very heavy contamination were severe and lead to early deaths.

The Bari disaster influenced opinion anew about the disastrous consequences of mass CW and possibly was the first event to lead to CW agents being considered as weapons of ‘mass destruction’.

2.6.1 The Secret Development of Nerve Agents

In 1936, Gerhard Schrader (Box 2.4) who also worked for IG Farben in Germany discovered the first nerve gas (tabun) as an offshoot of research into organophosphate pesticide compounds. The nerve gases (considered in detail in subsequent chapters) were the most toxic substances discovered. Schrader's work was reported to the German High Command and was immediately given the highest security classification. As a result, the Allies were unaware of the research and production that had taken place even by the time of victory in 1945. Schrader and his colleagues Ambros, Rudiger and van der Linde went on to synthesise the other nerve agents, sarin and soman. Sarin derives its name from an acronym of the researchers. By 1945, the Germans have produced about 12,000 tons of tabun and about 1000 tons of sarin. The capture of the production plant at Dyhernfurth in Poland by the Russians and its subsequent shipping to Volgograd where it was reconstructed saw the beginning of the Cold War chemical arms race that was to last for more than 40 years.

Box 2.4 Gerhard Schrader

Gerhard Schrader (25 February 1903–1990) was a German chemist specialising in the discovery of new insecticides, Schrader is best known for his accidental discovery of nerve agents such as sarin and tabun. In 1936, while employed by the large German conglomerate IG Farben (who later supplied Zyklon B, a hydrogen cyanide compound for use in the Nazi extermination camps), he was experimenting with organophosphate compounds (known at that time for nearly 80 years) as insecticides. Schrader discovered several very effective insecticides, including bladon (the first fully synthetic contact insecticide) and parathion. While searching for a new insecticide, he accidentally discovered tabun, the first chemical warfare nerve agent and later sarin (a name formed from the initials of Schrader and his collaborators). Schrader's discovery was placed under the tightest secrecy by the Nazis, and he continued to work on the development of further nerve agents during the Second World War. Nerve agents were not used in that war and their development was not detected by Allied intelligence services until the defeat of Germany in 1945. The plant producing sarin was captured by the Red Army and transported to Volgograd in the USSR where it continued production and started the chemical arms race of the Cold War.

2.7 The Cold War Period

Following the end of the Second World War, the Allied powers established secret research and production facilities based on the German work on nerve agents. Academic research into the effects of these and new compounds was supported by special contracts in the USA and by the creation of special state research institutes in the Union of Soviet Socialist Republics (USSR). Open publications during the period reported toxicological studies on both animals and human volunteers. Training for protection against CW agents became a feature of all sides during the Cold War with the development of new treatment measures and antidotes.

A large number of publications indicated that there was considerable interest in toxins (see Chap. 11) and the development of new chemical compounds such as short-chain neuropeptides which could affect thinking and consciousness and severely affect fighting ability. Toxins, although chemical in nature, are produced by biological organisms and are not classed as CW agents. Their use would not therefore violate the 1925 Geneva treaty.

2.8 Continued Military Use of Chemical Warfare Agents

Despite the treaty obligations, CW agents were used in a number of wars after 1945 although the facts in many cases are often hard to establish due to the intense secrecy that surrounded and still surrounds the subject.

There was alleged use of chemical agents including nerve agents and mustard gas in Yemen between 1963 and 1967 and also of trichothecene toxins in Cambodia during the Vietnam War. However, the most extensive use of both nerve and mustard agents took place during the Iran–Iraq war in the 1980s where the Iranians suffered over 20,000 casualties from the use of nerve agents and mustard gas. This was the first war where chemical casualties were assessed and managed using modern medical techniques with a consequent reduction in the number of fatalities from that seen in the First World War.

In 1995, there was the first documented use of a CW agent by terrorists in a civil setting with the release of sarin in the Japanese cities of Matsumoto and Tokyo. These incidents again raised public awareness of the vulnerability of unprotected civil populations to toxic agents. These incidents are discussed in more detail in Chap. 10.

2.9 Mass Accidental Release of Toxic Industrial Chemicals

The increasing use and transportation of toxic industrial chemicals around the world following the Second World War has been accompanied by a rise in the number of small- and large-scale accidental releases causing toxic trauma in the civil setting. The most devastating of this was in Bhopal in India in 1984 where the accidental release of 40 tons of methyl isocyanate, a chemical intermediary in the production of pesticide and other compounds in a densely populated urban area, led to more than 5000 fatalities. The important medical lessons from this incident are considered in Chap. 10.

2.10 Conclusions

The deliberate release of toxic chemicals has been a feature of warfare for more than 2000 years. Up to the age of enlightenment, it was conducted on only a small scale, but the arrival of the industrial revolution saw the creation of a civil chemical industry that could support the mass production and use of chemical agents in warfare. The First World War caused mass casualties and fatalities from this form of warfare, which had been described as the most significant development in arms since the invention of gunpowder. Since that time, CW agents have been used on a regular basis and have proved to be particularly effective against unprotected civilian populations. In addition, deliberate release of chemical agents has now been proven to be within the capability of terrorist organisations. Accidental release of toxic industrial chemicals has been an increasing feature of the twentieth century and beyond. An understanding of the basic history of the development and use of chemical agents and lessons from accidental release is more than valuable for a structured approach towards effective management of toxic trauma, considered in the following chapters. Box 2.5 gives a timeline of the history of chemical releases, both deliberate and accidental over the past 100 years.

Box 2.5 One hundred years of toxic trauma: a timeline of events

1915 January: First use of tear gas shells on the Russian front in Poland

April: First recorded chemical warfare attack at Ypres, Belgium, using chlorine gas released from cylinders. Over 10,000 dead from inhalation of high concentrations of gas

May: Chlorine used at the Battle of Bolimov on the eastern front. Six thousand Russian soldiers killed with 25,000 further casualties

December: Phosgene used against the British at Ypres

1916: Continued effective use of phosgene and also attacks using hydrogen cyanide

1917 July: First use of mustard gas at Ypres. Four thousand British casualties of whom 500 died within 3 weeks

1919: Development of the rapid-acting vesicant Lewisite (never used in battle)

1936: Use of mustard gas in the Italian Ethiopian campaign

1936–1945: Discovery and production of nerve gases in Germany

1938–1941: Probable use of mustard gas and other chemical agents in the Sino–Japanese Manchurian war

1943: Explosion of US liberty ship carrying mustard gas shells in Bari harbour, Italy

1945: Beginning of the Cold War chemical arms race

1968: Probable use of mycotoxin agents in the Vietnam War

1963–1967: Use of nerve and mustard agents in the Yemen

1984: Bhopal, India. Release of 40 tons of methyl isocyanate into an urban residential area. More than 5000 deaths and more than 50,000 injured, many with long-term lung problems

1984–1988: Use of nerve agents and mustard gas in the Iran–Iraq War. Substantial casualties but a reduced mortality due to overall improvements in medical care

1988: Use of nerve and mustard agents on a civil population in Halabja, Kurdistan. More than 5000 fatalities

1975–1992: Development of a new generation of powerful nerve agents (Novichoks) by the USSR

1994–1995: First substantiated use of a chemical weapon (sarin nerve gas) by a terrorist organisation in a civil setting. Matsumoto and Tokyo, Japan

2002: Use of a calmative ‘knockdown’ agent by Russian special forces during the Moscow theatre siege. More than 160 fatalities

2006: Chlorine improvised explosive device used in Iraq

2013–2015: Use of CW agents (sarin, sulphur mustard and chlorine) against civilians during the Syrian Civil War

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Toxic Trauma

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