PART A Human Remains: Decay, DNA, Tissues and Fluids

1 The decay, discovery and recovery of human bodies

Chapter outline

Objectives

Compare the chemical and physical characteristics of the different stages of decomposition.

Explain how a body's rate of decomposition is affected by the way in which death occurred and the environment in which it is placed.

Compare the conditions that promote the formation of adipocere and of mummification and how these processes preserve body tissues.

Compare and contrast the various techniques by which a dead body may be located and retrieved.

Evaluate the potential and limitations of radiocarbon dating and stable isotope analysis as means of determining the age and geographical origin of human remains.

The dead body

The time before a person dies is known as the ante mortem period whilst that after death is called the post mortem period. The moment of death is called the 'agonal

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period' – the word being derived from 'agony' because it used to be believed that death was always a painful experience. Either side of the moment of death is the peri mortem period although there is no consensus about how many hours this should encompass. It is important to know in which of these time periods events took place in order to determine their sequence, the cause of death and whether or not a crime might have been committed. Similarly, it is important to know the length of the post mortem period, referred to as the post mortem interval (PMI) because by knowing exactly when death occurred it is possible, amongst other things, to either include or exclude the involvement of a suspect. The study of what happens to remains after death is known as 'taphonomy' and the factors that affect the remains are called 'taphonomic processes'. Thus, burning, maggot feeding, and cannibalism are all examples of taphonomic processes.

When investigating any death it is essential to keep an open mind as to the possible causes. For example, if the partially clothed body of a woman is found on an isolated moor, there are many possible explanations other than she was murdered following a sexual assault. First of all, she may have lost some of her clothes after death through them decaying and blowing away or from them being ripped off by scavengers (Chapter 8). Secondly, she may have been a keen rambler who liked the open countryside. Most people die of natural causes and she may have suffered from a medical condition that predisposed her to a heart attack, stroke, or similar potentially fatal condition whilst out on one of her walks. Another possibility is that she may have committed suicide: persons with suicidal intent will sometimes choose an isolated spot in which to die. Another explanation for the woman's death would be that she had suffered an accident, such as tripping over a stone, landing badly and receiving a fatal blow to her head. And, finally, it is possible that she was murdered. All of these scenarios must be considered in the light of the evidence provided by the scene and the body.

The stages of decomposition

After we die our body undergoes dramatic changes in its chemical and physical composition and these changes can provide an indication of the PMI. The changes also influence the body's attractiveness to detritivores – organisms that consume dead organic matter – and their species composition and abundance can also be used as indicators of the PMI. Furthermore, the post mortem events may preserve or destroy forensic evidence as well as bring about the formation of artefacts that need to be recognized for what they are. An understanding of the decay process and the factors that influence it is therefore essential for the interpretation of dead human and animal remains.

The stages of decomposition in terrestrial environments can be loosely divided into four stages: fresh, bloat, putrefaction, and putrid dry remains. However, these stages merge into one another and it is impossible to separate them into discrete entities. In addition, a body seldom decays in a uniform manner. Consequently, part of the body may become reduced to a skeleton whilst another part continues to retain fleshy tissue.

Figure 1.1 Mummified fingertip. The drying and retraction of the surrounding skin makes the fingernail appear longer and hence the common perception that after death nails continue to grow. The drying of the skin can make taking fingerprints impossible. (Reproduced from Dolinak, D. *et al.*, (2005) *Forensic Pathology Theory and Practice*. Copyright © 2005, Elsevier Academic Press.)

Fresh

Owing to the blood circulation ceasing and the settling of blood to dependent regions (see later), the skin and mucous membranes appear pale immediately after death. Because the circulation has ceased, the tissues and cells are deprived of oxygen and begin to die. Different cells die at different rates, so, for example, brain cells die within 3–7 minutes while skin cells can be taken from a dead body for up to 24 hours after death and still grow in a laboratory culture. Contrary to folklore, human hair and fingernails do not continue to grow after death, although shrinkage of the surrounding skin can make it seem as though they do (Fig. 1.1).

Temperature changes

Because normal metabolism ceases after death our body starts to cool – this cooling is referred to as *algor mortis*: literally, the coldness of death. For many years measurements of body temperature were used as the principal means of determining the PMI but it is now recognized that the technique suffers from a variety of shortcomings. To begin with, the skin surface usually cools rapidly after death and the mouth often remains open so measurements recorded from the mouth or under the armpits would not accurately reflect the core body temperature. The core body temperature must therefore be measured using a long rectal thermometer. However, inserting a rectal thermometer often involves moving the body and removing the clothing and it could also interfere with evidence collection in cases where anal intercourse before or after death might have occurred. It has therefore been suggested that it might be

Table 1.1 Factors affecting the rate at which a body cools after death

Factors that enhance the rate of cooling
Small body size
Low fat content
Body stretched out
Body dismembered
Serious blood loss
Lack of clothes
Wet clothes
Strong air currents
Low ambient temperature
Rain, hail
Cold, damp substrate that conducts heat readily (e.g. damp clay soil)
Body in cold water
Dry atmosphere
Factors that delay the rate of cooling
Large body size
High fat content
Foetal position (reduces the exposed surface area)
Clothing – the nature of clothing is important because a thin, highly insulative layer can provide more protection than a thick poorly insulative material.
Insulative covering (e.g. blanket, dustbin bags, paper etc)
Protection from draughts
Warm ambient temperature
Warm microclimate (e.g. body next to a hot radiator)
Exposed to the sun
Insulative substrate (e.g. mattress)
High humidity

feasible to measure temperature changes in the external auditory canal (Rutty, 2005). A second major problem with using temperature as a measure of the PMI is that the rate of cooling depends upon a host of complicating factors starting with the assumption that the body temperature at the time of death was 37 °C. In reality the body temperature may be higher (e.g. owing to infection, exercise or heat stroke) or lower (e.g. hypothermia or severe blood loss). In addition, the rate of temperature loss depends upon numerous factors (Table 1.1). For example, the body of a fat man who dies inside a car on a hot sunny day may not lose heat to any appreciable extent; indeed, his body temperature may even increase.

Various formulae have been developed to relate body temperature to time since death but these are mostly too simplistic to be reliable. Clauss Henßge has designed a sophisticated nomogram (Fig. 1.2) that accounts for body weight and environmental temperature and allows for corrective factors to be applied according to the individual circumstances of the case (Henßge & Madea, 2004; Henßge *et al*., 2002). A nomogram is a graphical calculator that usually has three scales. Two of these scales record known values (rectal and environmental temperature) and the third scale is the one from which the result is read off (time since death). Unfortunately, even this approach has limitations – for example, it is not reliable if the body was

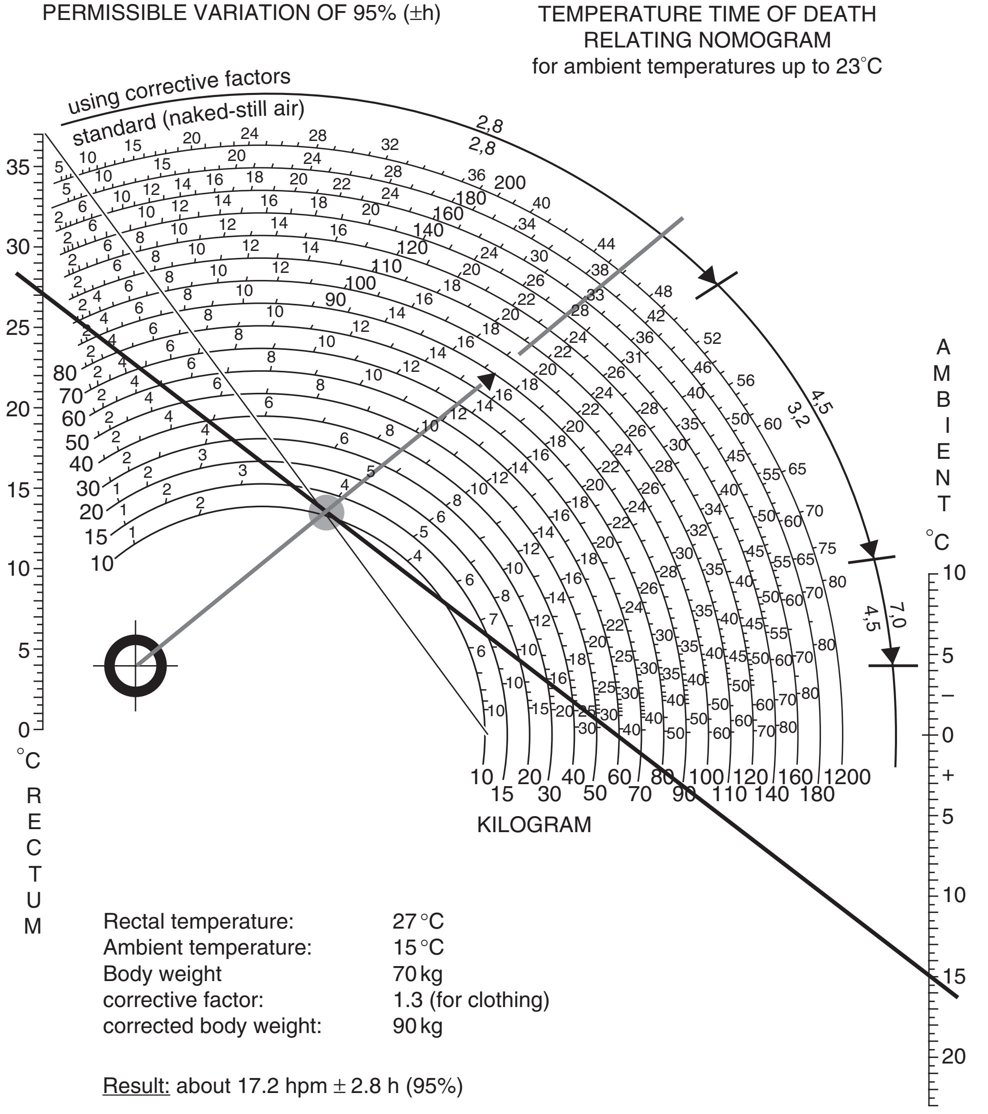

Figure 1.2 Clauss Henßge's nomogram for the determination of time since death from body temperature. (Reproduced from Henßge, C. and Madea, B. (2004) Estimation of time since death. *Forensic Science International*, **144**, 167–175. With permission from Elsevier.) The nomogram works as follows (a) A straight line is drawn between the rectal temperature and the ambient temperature. In the case illustrated here the line is therefore drawn from 27 °C to 15 °C. (b) The 'standard' is a naked body lying in an extended position in still air and therefore 'corrective factors' need to be applied for any situations other than this. These factors are listed by Henßge *et al*. (2002). In this example, the body was found wearing three thin layers of dry clothes in still air and therefore the corrective factor is 1.3. The weight of the body is now multiplied by the corrective factor. The body weighed 70 kg and therefore 70 × 1.3 = 91 kg. The nomogram goes up in units of ten and therefore 91 kg is rounded down to 90 kg. (c) A second straight line is drawn from the centre of the circle that is found at the left-hand side of the nomogram so that it hits the intersection of the nomogram's diagonal line and that drawn between the rectal temperature and the ambient temperature in step (a). The line is then continued until it hits the outermost circle. (d) Where the line drawn in step (c) hits the 90 kg semicircle is the time since death (17.2 hours). Where the line hits the outermost circle one can read off the 95% confidence limits (2.8 hours). Therefore, the person is judged to have been dead for 17.2 + 2.8 hours (95% CI).

left exposed to the sun or if there is reason to believe that it was moved after death. In the latter situation, the body would have been exposed to at least two different environments and could therefore have spent time cooling at two very different rates. This is not to say that temperature measurements are pointless but one should be aware of possible complicating factors.

Body temperature, like most biological measurements of the PMI can be classed as a 'rate method'. Rate methods are those in which events are initiated or stopped at the time of death and the subsequent rate of change provides an estimate of elapsed time. Other examples include the increase in the potassium ion concentration in the vitreous humor of the eye, the development of rigor mortis and the growth of maggots on the dead body. Rate methods become increasingly inaccurate the longer the PMI because they suffer from being influenced by a wide variety of biotic and abiotic factors but as long as their limitations are recognized they can be extremely useful and if there is concordance between several different methods then the time of death can be predicted with a fair degree of confidence. Furthermore, in the absence of any other evidence an indication is more useful to a police investigation than nothing at all. The other methods of determining the time since death are known as 'concurrence methods' and they work by evaluating the occurrence of events that happened at known times at or around the time of death. Typical concurrence events would be finding that the victim's watch had stopped at a particular time as a consequence of being smashed (e.g. following a fall or during a struggle) or that mobile phone records indicated that the victim must have been alive until at least a certain date and time.

Chemical changes

Owing to the lack of oxygen, after death cellular processes switch from aerobic to anaerobic and there are dramatic increases and decreases in specific metabolites. Furthermore, as membrane integrity is lost metabolites redistribute within and between tissues. These changes do not take place uniformly throughout the body at the same time. For example, energy metabolism ceases more rapidly in the blood than it does in the vitreous humor of the eye. A number of workers have attempted to estimate the PMI by measuring chemical changes after death (e.g. Vass *et al*., 2002). Unfortunately, few comparative studies have been made between different chemical measurements or between chemical measurements and other existing techniques. In addition, most studies to date lack field data and their reliability could potentially be adversely affected by environmental factors such as temperature and ante mortem factors such as age, drug use and disease (Henßge & Madea, 2004; Madea & Musshoff, 2007). The most commonly used chemical measurement of PMI is the determination of potassium ion concentration in the vitreous humor of the eye although there are marked discrepancies between authors concerning its reliability (Chapter 2).

Hypostasis

Between 20 and 120 minutes after death hypostasis (also called *livor mortis* and post mortem lividity) is usually seen – it can be found in all bodies but may be difficult to observe. Hypostasis is a purple or reddish purple discoloration of the skin caused by the blood settling in the veins and capillaries of the dependent parts of the body. Blood plasma also settles to the dependent regions and this causes oedema (fluid accumulation) and the formation of blisters on the surface of the skin. If the person is lying on their back, hypostasis will develop in the back and those body surfaces adjacent to the ground whilst if the person is hanging by their neck, pronounced hypostasis will develop in their hands, forearms and lower legs. It starts as a series of blotches that then spread and deepen in colour with time. Initially, the blood remains in the blood vessels but eventually the blood cells haemolyse (break down and rupture) and the pigment diffuses out into the surrounding tissues, where it may be metabolized to sulphaemoglobin that gives rise to a greenish discoloration. Sulphaemoglobin is not present in normal blood although it may be formed after exposure to drugs such as sulphonamides. This emphasizes the need to be aware that normal decomposition processes may mimic those that are induced before death or by the action that induced death.

The rate of development of hypostasis varies from body to body and is also influenced by underlying medical conditions, such as circulatory disease. Consequently, there is some variation in the literature about when events begin and when they reach their maximal effect. Indeed, hypostasis may not develop at all in infants, the elderly or those suffering from anaemia. Some of the literature suggests that after about 10–12 hours of a body remaining in a set position, the discoloration caused by hypostasis becomes ‘fixed’ (Fig. 1.3). Furthermore, if the body is then moved and left in a different position a second area of discoloration forms. Two or more distinct patterns of discoloration therefore indicate movement of the body. However, according to Saukko & Knight (2004) there is so much variation in the time it takes for ‘fixation’ to develop, if it develops at all, that it is not a particularly reliable forensic indicator of the PMI or evidence of movement after death.

Figure 1.3 Characteristic pattern of hypostasis and pressure pallor resulting from a dead body lying on its back. The reddening results from the settling of blood in the veins whilst the pale regions are where the pressure of the body against the underlying substrate has constricted the vessels. (Reproduced from Shepherd, R. (2003) *Simpson’s Forensic Medicine*, 12th edn. Copyright 2003, Hodder Arnold, London.)

Pressure, whether from tight fitting clothes such as belts and bra straps, a ligature around the neck, ropes used to bind hands together, or corrugations in the surface on which the body is resting, will prevent the underlying blood vessels from filling with blood and therefore these regions will appear paler than their surroundings – this is known as 'pressure pallor' or 'contact pallor'. Whilst the body is fresh, it is possible to distinguish between ante mortem bruising and hypostasis because bruising results from the leakage of blood out of damaged blood vessels into the surrounding tissues and the consequent formation of clots. By contrast, in hypostasis the blood is restricted to dilated blood vessels although as time passes and tissues decay, blood begins to leak out of the vessels and it becomes more difficult to distinguish between the two.

Initially, blood remains liquid within the circulatory system after death, rather than coagulating, because of the release of fibrinolysins from the capillary walls. These chemicals destroy fibrinogen and therefore prevent clots from forming. However, wounds inflicted after death do not bleed profusely because the heart is no longer beating and therefore blood pressure is not maintained. Blood from even a severed artery therefore trickles out as a consequence of gravity rather than being spurted out as it might if inflicted during life. A common question that arises when a person's body is found at the bottom of a building after suffering a great fall is whether or not they were still alive when they hit the floor. This is important because it is possible for a murderer to attempt to mask the wounds caused by a violent assault within the much greater trauma that would result from a fall – especially if the fall could be construed as an accident or suicide. If the victim was already dead then their body might bleed a lot less than if they were still alive at the time of impact. Furthermore, if the person was bleeding before being thrown it would be expected that bloodstains would be found near the point from which the body fell and/or cast from it during the fall (Chapter 2). Unlike the situation on land, in the case of drowning or a dead body disposed of in a lake or river, there may be a considerable loss of blood from wounds. After initially sinking, a dead body tends to rise to the surface owing to the accumulation of gas from the decay process and then floats face downwards. Consequently, the blood pools in the facial and dependent regions and wounds affecting these areas after death may bleed profusely.

Changes in muscle tone

Immediately after death, the muscles usually become flaccid and the joints relax such that a person's height may increase by as much as 3 cm. Furthermore, the body may be found in a posture that would be highly uncomfortable in life. Once consciousness is lost, a standing individual collapses without making any attempt to break their fall whilst a seated individual slumps forwards (usually) and may fall to the floor unless supported. Consequently, the body may receive injuries which might themselves have been life-threatening had the person not already been dead. The relaxation of muscles can lead to the sphincters loosening, and the release of urine and faeces or the regurgitation of gut contents at or shortly after the moment of death. Suffocation can lead to the victim urinating involuntarily but this may also happen naturally at the time of death. Therefore, it would be unwise to make

Figure 1.4 *Rigor mortis* in the lower limbs. Note how the legs remain in a fixed, rigid position despite the lack of support. (Reproduced from Saukko, P. and Knight, B. (2004) *Knight's Forensic Pathology*, 3rd edn. Copyright 2004, Hodder Arnold.)

too much of such findings unless there was other evidence to indicate that criminal activity may have been involved. By contrast, when a person is in a coma the volume of urine in the bladder can increase markedly because they are not responsive to stimuli that would normally wake them up. Consequently, an unusually distended bladder is an indication that a person was comatose for several hours before they died.

Approximately 3–4 hours after death, *rigor mortis*, the stiffening of muscles and limbs becomes noticeable and the whole body becomes rigid by about 12 hours (Fig. 1.4). The condition can, however, be broken by pulling forcefully on the affected limbs. Rigor is usually first noticeable in the small muscles of the face and those being used most actively prior to death. Rigor affects both the skeletal and the smooth muscles. When it affects the *arrector pili* muscles it can result in the scalp and body hairs standing on end – this can make it look as though the person died in a state of shock. The *arrector pili* are smooth muscles that run from the superficial dermis of the skin to the side of the hair follicles. Normally our hair emerges at an angle to the skin surface but when the *arrector pili* are stimulated to contract – for example as a consequence of the body's response to cold or stress – the hair is pulled into a more upright position. This also gives rise to the phenomenon of 'goose bumps'. The rigor that follows death can give rise to a similar appearance.

Rigor mortis is brought about by the rise in the intracellular concentration of calcium ions in muscle cells that follows death, as the membranes around the sarcoplasmic reticulum and the cell surface become leaky and calcium ions are therefore able move down their concentration gradient into the cytoplasm of the muscle cells. This rise causes the regulatory proteins troponin and tropomyosin to move aside, thereby permitting the muscle filaments actin and myosin to bind together to form cross bridges. This is possible because the head of a myosin molecule would already be charged with ATP before death. However, actin and myosin, once bound, are unable to detach from one another because this process requires the presence of ATP – and this is no longer being formed. Thus, the actin and myosin filaments remain linked together by the immobilized cross bridges, resulting in the stiffened condition of dead muscles. Subsequently, *rigor mortis* gradually subsides as the proteins begin to degrade and it disappears after about 36 hours. The speed of development of *rigor mortis* and its duration are both heavily influenced by environmental temperature with onset commencing earlier and duration shorter at high environmental temperatures. By contrast, onset is delayed at low temperatures and at a constant 4 °C may last for at least 16 days with partial stiffening still detectable up until 28 days after death (Varetto & Curto, 2004). Children tend to develop *rigor mortis* sooner than adults whilst onset is said to be delayed if death was owing to asphyxiation or poisoning with carbon monoxide. The extent and degree of *rigor mortis* is therefore not an especially accurate measure of the PMI.

Heat stiffening is distinct from rigor mortis and results from the body being exposed to extreme heat. It causes the body to exhibit what is known as a 'pugilistic posture' (Chapter 5) and evidence of severe burning will inevitably be apparent. Exposure to very low temperatures will also cause the body to stiffen but can prevent the onset of *rigor mortis* entirely. In this case, the body will become flaccid when it is warmed up and may then subsequently exhibit *rigor mortis*. In this way, a murderer may confuse a police investigation by storing his victim in a freezer immediately after death before disposing of the body some time later. There is a considerable literature in the food science sector on means of distinguishing between fresh meat and that which has been frozen but there are far fewer studies on human tissues. Miras *et al*., (2001) have suggested that it would be possible to distinguish muscle tissue that had previously been frozen by its higher levels of the enzyme short-chain 3-hydroxyacyl-CoA dehydrogenase but it is uncertain how effective this would be in practise and would presumably rely on the body being discovered within a few hours of defrosting.

Unlike *rigor mortis*, 'cadaveric rigidity' (also called 'cadaveric spasm') sets in immediately after death and according to Shepherd (2003) is a 'forensic rarity'. It may affect part or all of the body and is said to be associated with individuals who were extremely stressed, emotionally and physically, immediately before they died. However, one would have thought that this would include most murder victims and also many who die of painful medical conditions, so there must be some other reason why it is not found more frequently. Nevertheless, its occurrence can provide useful indications of a person's last actions such as their hands may be found firmly grasping hair from their attacker or an object in a vain attempt to prevent themselves from drowning (Fig. 1.5). Persons who commit suicide by shooting themselves may be found with the gun so tightly held that it would have been impossible for a second person to have arranged the corpse in this manner after death. However, there is no evidence to suggest that majority of people who kill themselves in this way exhibit this trait.

Indications of poisoning

Sometimes the cause of death may result in striking changes to normal skin coloration. For example, deaths from carbon monoxide poisoning often result in a cherry red / pink coloration to the skin, lips and internal body organs (Fig. 1.6) although if the body is not discovered until several hours after death the coloration may not be immediately apparent owing to the settling of the blood to the dependent regions.

Figure 1.5 Cadaveric rigidity. This person grasped at vegetation before falling into water. (Reproduced from Shepherd, R. (2003) *Simpson's Forensic Medicine*, 12th edn. Copyright 2003, Hodder Arnold, London.)

Figure 1.6 Cherry-red coloured hypostasis as a consequence of carbon monoxide poisoning causing the formation of carboxyhaemoglobin. (Reproduced from Shepherd, R. (2003) *Simpson's Forensic Medicine*, 12th edn. Copyright 2003, Hodder Arnold, London.)

Carbon monoxide gas forms during the combustion of many substances and poisoning is a common feature of accidental deaths in which people are exposed to fumes from a faulty gas boiler or during fires and suicides in which the victim breaths in vehicle exhaust fumes. Carbon monoxide poisoning may also be the cause of death in homicides resulting from arson or where the flue to a fire or gas boiler is deliberately blocked. Carbon monoxide has much greater affinity than oxygen for the haeme molecule of haemoglobin and therefore, even at very low atmospheric concentrations it will rapidly replace it and thereby reduce the oxygen carrying capacity of the blood. When carbon monoxide binds with haemoglobin in the blood or myoglobin in the muscles it forms carboxyhaemoglobin and carboxymyoglobin respectively and they are responsible for the pink coloration. There are cases in which carbon monoxide poisoning does not result in the formation of a cherry pink coloration (Carson & Esslinger, 2001) and it can be difficult to spot when the victim is dark skinned – though it may be apparent in the lighter regions such as the palms of the hands or inside the lips or the tongue. There are big differences in susceptibility to carbon monoxide poisoning and this is at least partly a consequence of age, size and general health. For example, children tend to be more susceptible owing to their higher respiration rate.

Cyanide poisoning also results in the skin developing cherry red coloration although it is said to be somewhat darker than that caused by carbon monoxide. Cyanide ingestion is sometimes used as means of suicide and homicide but cyanide is also a potentially lethal component of the smoke formed during the combustion of many substances (e.g. wool, plastics) and its effect in conjunction with carbon monoxide is additive since they work by different mechanisms. Indeed, a person inhaling smoke may die of cyanide poisoning before there is marked rise in the levels of carboxyhaemoglobin. Cyanide affects a variety of enzymes and cell processes but has its principal effect through the inhibition of cytochrome oxidase and thereby prevents the production of ATP via oxidative phosphorylation. The cherry red coloration results from the increased oxygenation of the blood in the veins as a consequence of the inability of cells to utilize oxygen for aerobic metabolism.

Cyanide poisoning can also cause cyanosis – a bluish tinge to the skin, fingernails and mucous membranes – although the term is derived from the blue–green colour cyan rather than the chemical cyanide. Cyanosis may be localized or more widespread and be found on its own or in conjunction with the cherry red skin coloration. It is caused by a reduction in the level of oxygen in the blood and therefore darker deoxygenated blood imparts colour to the tissues, blood vessels, and capillaries rather than the normal bright red oxygenated blood. Cyanosis is therefore a common symptom of a whole range of conditions that interfere with the supply of oxygenated blood to the tissues including carbon monoxide poisoning, a heart attack and asphyxia from hanging. Cyanide has the reputation for causing rapid, near instantaneous death, but although this can occur a lot depends on the nature of the cyanide and its means of delivery (e.g. breathing in gaseous hydrogen cyanide, ingestion of a salt in solid or liquid form or absorption through the skin) and the dose. Death may occur within minutes or hours of acquiring a lethal dose and involve a long period of struggling to breathe so cyanosis is to be expected.

Bloat

The intestines are packed with bacteria and these do not die with the person. These micro-organisms break down the dead cells of the intestines, while some, especially the *Clostridia* and the enterobacteria, start to invade the other body parts. At the same time, the body undergoes its own intrinsic breakdown, known as autolysis, that results from the release of enzymes from the lysosomes (subcellular organelles that contain digestive enzymes) thereby causing cells to digest themselves and chemicals, such as the stomach acids, from the dead cells and tissues. The pancreas, for example, is packed with digestive enzymes, and so rapidly digests itself. Autolysis may also occur on a more restricted scale in a living person as a consequence of certain diseases.

Figure 1.7 Late bloat stage of decomposition. The body is about 7 days old and exhibits pronounced swelling owing to accumulation of gas. Note discoloration of the skin and exudates from the mouth and nose. (Reproduced from Shepherd, R. (2003) *Simpson's Forensic Medicine*, 12th edn. Copyright 2003, Hodder Arnold, London.)

The decomposing tissues release green substances and gas which make the skin discoloured and blistered, starting on the abdomen in the area above the caecum (Fig. 1.7). The front of the body swells, the tongue may protrude and fluid from the lungs oozes out of the mouth and nostrils (Fig. 1.8). This is accompanied by a terrible smell as gasses such as hydrogen sulphide and mercaptans, sulphur-containing organic molecules, are produced as end products of bacterial metabolism. Methane (which does not smell) is also produced in large quantities and contributes to the swelling of the body. In the UK, this stage is reached after about 4–6 days during spring and summer but would take longer during colder winter weather. The accumulation of gas can become so severe that the abdominal wall ruptures and this may lead to concerns over whether the wound was caused maliciously. In 1547, the corpse of King Henry VIII underwent such extreme bloat that his coffin, which was being transported back to Windsor castle for burial, exploded overnight and dogs were found feeding on the exposed remains in the morning. This was deemed to be divine judgement on the king for his dissolution of the monasteries.

Detritivores

Blowflies and other detritivores are attracted by the odour of blood and decomposition (Fig. 1.9), and as the smell changes during the decay process so does the species of invertebrates that are attracted. Therefore, 'fresh corpses' attract different detritivores to corpses in an advanced state of decay (Table 1.2). Blowflies will lay their eggs on bodies within seconds of death occurring but do not lay their eggs on corpses once these have passed a certain state of decomposition or they have become dry or mummified. By contrast, dermestid beetles do not colonize corpses until these have started to dry out (for more details see Chapters 6 and 7).

Figure 1.8 Late bloat stage of decomposition. Note how the swelling has made recognition of facial features impossible. The tongue is forced out and the eyeballs bulge as a consequence of internal pressures. These are normal decomposition features and should not be taken as an indication of asphyxiation. (Reproduced from Dolinak, D. *et al.*, (2005) *Forensic Pathology Theory and Practice*. Copyright © 2005, Elsevier Academic Press.)

Figure 1.9 Blowfly maggots developing upon a corpse. Note how mature maggots can be seen crawling over the surface and the discoloration of the skin. (Reproduced from Klotzbach, H. *et al.*, (2004) Information is everything – a case report demonstrating the necessity of entomological knowledge at the crime scene. *Agrawal's Internet Journal of Forensic Medicine and Toxicology*, **5**, 19–21. Copyright © 2004, with permission from Elsevier.)

Putrefaction

Some authors distinguish several stages of putrefaction (decay) but the usefulness of this is uncertain. As the body enters the bloat stage, it is said to be 'actively decaying' and during this time the soft body parts rapidly disappear as a result of

Table 1.2 The sequence in which insects arrive and colonize a corpse during the decomposition process. The stages of decay merge into one another and the insects may arrive or leave sooner or later than is indicated in the table depending upon the individual circumstances. For more details see Chapters 6 and 7

Stage of decomposition	Insect
Fresh	Blowfly eggs and 1st instar larvae
	Fleshfly 1st instar larvae
	Burying beetle adults
Bloat	Blowfly eggs + 1st, 2nd, 3rd instar larvae
	Fleshfly 1st, 2nd, 3rd instar larvae
	Burying beetle adults and larvae
	Histerid beetle adults and larvae
Putrefaction	No blowfly eggs once advanced putrefaction
	Blowfly 2nd, 3rd instar larvae
	Fleshfly 2nd, 3rd instar larvae
	Blowfly & fleshfly larvae leaving corpse for pupation site
	Histerid beetle adults and larvae
	Eristalid fly larvae (liquefied regions)
	Phorid fly larvae (later stages of putrefaction)
	Piophilid fly larvae (later stages of putrefaction)
Putrid dry remains	No blowfly larvae
	Stratiomyid fly larvae
	Dermestid beetle adults and larvae
	Tineid moth larvae
	Pyralid moth larvae

autolysis and microbial, insect and other animal activity. The body then collapses in on itself as gasses are no longer retained by the skin. At this point, the body enters a stage of 'advanced decay' and, unless the body is mummified, much of the skin is lost. Obese people tend to decay faster than those of average weight and this is said to be due to the 'greater amount of liquid in the tissues whose succulence favours the development and dissemination of bacteria' (Campobasso *et al*., 2001). At first sight, this appears surprising since fat has a lower water content than other body tissues and obese individuals therefore have a lower than average water content. However, fat can act as a 'waterproofing' preventing the evaporation of water and therefore the drying out of the corpse whilst its metabolism yields large amounts of water.

Adipocere

Adipocere (grave wax or corpse wax) is formed during the decay process if the conditions are suitable and it is capable of influencing the future course of decay (Forbes *et al*., 2004; Fiedler & Graw, 2003). It is a fatty substance that is variously described as being whitish, greyish or yellowish and with a consistency ranging from

Figure 1.10 The formation of adipocere has preserved the body of this child despite it being buried for about 3 years. (Reproduced from Shepherd, R. (2003) *Simpson's Forensic Medicine*, 12th edn. Copyright 2003, Hodder Arnold, London.)

paste-like to crumbly. Extensive adipocere formation inhibits further decomposition and ensures that the body is preserved for many years (Fig. 1.10). Adipocere formation is therefore a nuisance in municipal graveyards because it prevents the authorities from recycling grave plots but very useful to forensic scientists and archaeologists who wish to autopsy long-dead bodies.

The term 'adipocere' refers to a complex of chemicals rather than a single chemical compound and it results from the breakdown of body lipids. After death, autolysis and bacterial decomposition of triglycerides, which make up the majority of the body's lipid stores, results in the production of glycerol and free fatty acids. The free fatty acids comprise a mixture of both saturated and unsaturated forms, but as adipocere formation progresses, the saturated forms become predominant. The fatty acids lower the surrounding pH and thereby reduce microbial activity and further decomposition. Adipocere has a characteristic odour the nature of which changes with time and this is used to train cadaver dogs to detect dead bodies. Extensive adipocere formation results in the body swelling and consequently the pattern of clothing, binding ropes or ligatures can become imprinted on the body surface whilst incised or puncture wounds may be closed and become difficult to detect. Adipocere formation is not exclusive to human decomposition (Forbes, *et al.*, 2005d) and this should be borne in mind if there is a possibility that human and animal remains are mixed together. For example, the bodies of animals are often found at the bottom of disused mine shafts having stumbled in or been thrown in by a farmer looking for a quick means of disposing of dead livestock. Murderers will also make use of such facilities.

Adipocere formation has been described from bodies recovered from a wide variety of conditions including fresh water, seawater and peatbogs, shallow and deep graves, tightly sealed containers, and in bodies buried but not enclosed at all (e.g. Evershed, 1992; Mellen *et al.*, 1993). Some authors mention that warm conditions may speed its formation but adipocere has been recorded from bodies recovered from seawater at a temperature of 10–12 °C and from icy glaciers (Kahana *et al*., 1999; Ambach *et al*., 1992) – the preservation of the 5300-year-old 'Iceman' found in the Tyrol region appears to be at least partly a consequence of the formation of adipocere (Sharp, 1997; Bereuter *et al*., 1997). A wide variety of durations are cited in the literature for the time taken for adipocere formation to become extensive, ranging from weeks to months to over a year. Obviously, the time will be heavily dependent upon the local conditions and it is not yet possible to use the formation of adipocere as an estimate of the PMI. However, because adipocere leaks out of the body, its presence in the soil can indicate whether a corpse was left in a particular location but then removed or if the extent of adipocere formation in the body matches that which might be expected in the surrounding soil if the body had lain there since death.

Forbes *et al*. (2005 a, b, c) conducted an extensive series of experiments on the physical and chemical factors promoting the formation of adipocere. They found that adipocere would form in soil types ranging from sandy to clayey, provided that the soils were kept moist, and also in sterile soil that was heated at 200 °C for 12 hours to remove the normal soil microbial flora. 'Bodies' buried directly in the ground tended to form adipocere more rapidly than those contained in a coffin. Interestingly, placing the 'body' in a plastic bag retarded the formation of adipocere but if the 'body' was clothed and then placed in the plastic bag adipocere formation was promoted. They suggested that this was owing to the clothing absorbing glycerol and other decay products that would otherwise inhibit the pathways through with adipocere is formed. Polyester clothing was deemed to be the most effective, probably as a consequence of its ability to retain water and, compared to cotton clothing, resistance to decay.

Mummification

Mummification occurs when a body is exposed to dry conditions coupled with extreme heat or cold, especially if there is also a strong air current to encourage the evaporation of water. It is typically seen in persons who die in deserts, such as the hot Sahara and the cold Tibetan plateau. It is also found in murder victims who are bricked up in chimneys or persons who die in well sealed centrally heated rooms. Size is important, and dead babies, owing to their large surface area to volume ratio lose water more rapidly than an adult. Newly born babies lack an active gut microbial flora and therefore not only do they lose water quickly, they may dehydrate before microbial decomposition can cause major destruction of tissues. Once a body has mummified it can remain intact for hundreds of years provided that it is in a dry environment and those insects that are capable of consuming dry organic matter (e.g. dermestid beetles and the larvae of tineid moths) do not gain access to it.

Putrid dry remains

After the skin and soft tissues are removed, the body is reduced to the hard skeleton and those structures that are more difficult to break down, such as the tendons,

Table 1.3 Summary of the stages of decomposition and their characteristic features

Stage of decomposition	Characteristics
Fresh	Body starts to cool and autolysis begins. Hypostasis and *rigor mortis* may be seen.
Bloat	Discoloration of skin surface, body swells from accumulation of gasses. Tongue protrudes, fluid expelled from orifices. Soft tissues visibly decaying. Rapid decay owing to intense microbial and invertebrate activity.
Putrefaction	Progressive loss of skin and soft tissues. Body deflates as decomposition gasses escape. Decay owing to invertebrate and microbial activity starts to slow down once soft tissues removed and body starts to dry out.
Putrid dry remains	Skin and soft tissues lost. Decay proceeds more slowly. Progressive loss of uterus/prostate gland, tendons, cartilage, fingernails, hair. Skeleton may become disarticulated through environmental and biological processes.

ligaments, fingernails and hair. Organs such as the uterus and prostate gland are also fairly resistant to decay and may last for several months if the body is kept in a well-sealed container. Because there are still traces of dead organic matter being broken down by microbes, a skeletonized body still smells of decay.

Bones also undergo a decay process referred to as diagenesis, and their chemical composition and microscopic structure changes as a consequence of microbial attack and environmental exposure. Bone decay begins soon after death and bacteria invade the bone via its natural pores and create tunnels within it (Jans *et al*., 2004). Significant changes are therefore already apparent by the time of skeletonization and invasion by soil bacteria is not thought to be of major importance. Not surprisingly, therefore, those bones that are closest to the abdominal cavity tend to exhibit the most marked microbial attack. However, it is not yet possible to use these changes to estimate the PMI. Lasczkowski *et al*. (2002) have suggested that the rate of disappearance of the chondrocyte cells (cartilage cells that produce collagen) could be used as a measure of the PMI during the first few weeks after death but more experimental work is required to confirm how reliable this approach would be. Indeed, estimating the age of skeletal remains from morphological and biochemical characteristics can only be done very crudely. For example, the association of ligaments and other soft tissues with the bones is said to indicate that the remains are less than 5 years old whilst the presence of blood pigments within the bones indicates they are less than 10 years old.

Factors affecting the speed of decay

The rapidity and extent to which a corpse is colonized by the larvae of blowflies, along with the activities of other invertebrates, microbes and vertebrates such as dogs and birds, heavily influences the speed with which a body decays. Consequently, those factors that restrict their access or reduce their activity, such as physical exclusion, lack of oxygen or the temperature being too low or too high reduces the rate of decomposition enormously.

Geographical location

The abundance and species composition of the microbial, invertebrate and vertebrate detritivore community varies between regions and this affects the speed with which a body is located, colonized and decomposed. Decay proceeds much faster in the tropics, where conditions are both hot and humid, and slower in cold or dry conditions. In the tropics, a corpse can become a moving mass of maggots within 24 hours but in the UK it would take several days to reach this stage, even during the summer. Temperatures that are too high or climates that are too dry also restrict the activity of invertebrates and microbes and thereby reduce the rate of decay.

Time of year

Bodies decay fastest in warm damp environments. Consequently, in the UK, decay is fastest during the summer months and slowest during winter. This is partly owing to the effect of the environment on microbial decay and partly through the invertebrate detritivores showing distinct patterns of seasonal activity.

Cities and large towns offer warm microclimates and therefore some blowfly species may remain active there throughout the winter period but they would be inactive in the surrounding region. In both cities and the countryside, the adults of some blowfly species enter buildings during the autumn period and attempt to overwinter indoors (e.g. in loft spaces, garages and sheds). Should a body be placed within a building where they occur and the temperature is high enough for them to be active, then colonization of the corpse will commence even in the depths of winter.

Exposure to sunlight

The effect of exposure to sunlight is case dependent. If a body is warmed by the sun's rays bacterial decay will be promoted but if there is low humidity and a strong wind the body would desiccate and mummify thereby retaining much of the its integrity. Galloway *et al.* (1989) have written a detailed account of how the human body decays under arid conditions.

A body exposed to the sun is usually visible and smellable to both vertebrate and invertebrate detritivores and this leads to its rapid dismemberment and consumption and/ or colonization and consumption. Invertebrates avoid laying their eggs on and colonizing regions of a corpse that are exposed to the full sun because the combination of desiccation and UV light would kill their delicate eggs and larvae. However, eggs laid on the under surfaces or beneath clothing or other coverings (provided that they are not too tight to restrict access) will be protected from the sun and have a more humid microenvironment. This facilitates microbial and maggot growth and consequently these covered regions may decay more rapidly than exposed body parts although a lot depends on the nature of the covering material.

Wrapping and confinement

Persons disposing of a dead body often wrap or otherwise cover it up so as to make its transport easier and/or reduce the risk of its subsequent discovery. Metal foil is commonly used as is plastic sheeting and bags and cling film. Corpses are sometimes wrapped within carpets but this must make movement extremely difficult because any carpet large enough to conceal a body is already a heavy, bulky object. Corpses are also found in the boots of vehicles, placed in suitcases or similar large containers, left within locked rooms or bricked up. It is surprising how many bodies are placed under floorboards and this is usually one of the first places that police will look for concealed evidence. All of these scenarios have their own individual effects on the rate of decomposition but the common factor is that the rate of decay is slowest where the covering is most effective at excluding oxygen, vertebrates and invertebrates. Once a body starts to decay – which happens regardless of the scenario unless the temperature is below freezing – the smell attracts detritivores of various shapes and sizes; flies usually find their way into a locked car boot whilst foxes will bite and claw their way through plastic wrapping. If the detritivores are unable to gain access then the body will decay slowly but this helps to preserve evidence should the body be eventually discovered. Furthermore, it is not unusual for murder weapons and other evidence to be enclosed or entombed with the body. Encasing a body within concrete is no guarantee of successful concealment; the smell of decay may still be detectable and when someone goes missing and a suspect starts mixing concrete it isn't long before suspicions are aroused (Preuß *et al.*, 2006). Interestingly, analysis of the composition of the concrete (a process known as petrography) can enable determination not only where and when the concrete was sourced but also how old it is and thereby, by inference, the PMI. For example, an unusual case arose in USA in which the body of a young woman was found in Nevada entombed within a home-made concrete sarcophagus (Morel, 2004). Petrographic analysis identified not only the type of concrete but that it was made within a narrow range of about 1.5–2 years previously. By contrast, anthropological analysis of the woman's remains could only place the time of death as some point between 2 and 7 years previously. It was also possible to link the sarcophagus with a concrete spattered retractable utility knife found nearby that was the probable murder weapon.

Burial underground

Buried corpses decay approximately four times slower than those left on the surface, and the deeper they are buried, the slower they decay (Dent *et al.*, 2004). The nature of the soil affects the rate of decay directly through chemical actions and indirectly through its effect on the abundance and activity of soil organisms. Microbial density varies enormously with the soil type but figures are generally in the region of 2×10^9 per gram in the top metre and 10^8 per gram at a depth of 1–8 metres (Coleman *et al.*, 2004). Heavy clay soils are poorly aerated and therefore have low oxygen levels and this reduces microbial activity and hence the rate of decay. Very acid soil reduces microbial activity but the low pH dissolves soft tissues and bone. High soil calcium content reduces chemical dissolution of the bones but will not prevent its microbial decomposition. Even a shallow covering of soil usually prevents blowflies from colonizing a body and hence reduces the rate of decomposition. However, some fly species, such as *Muscina stabulans* lay eggs on the soil surface and their larvae then burrow down to the body whilst adult coffin flies (*Conicera tibialis*), which are very small, will crawl through cracks in the soil to locate bodies a metre or more below ground. Shallow buried bodies may, however, be detected and dug up by dogs, foxes or badgers and as soon as this occurs the rate of decay will increase and there is a high probability that the body will be dismembered. Corpses are often wrapped or enclosed in something before they are buried and this will further reduce the rate of decay dependent upon the degree to which they are airtight and/or can exclude detritivores.

Hanging above ground

Bodies are usually found suspended above ground as a result of suicidal or homicidal hanging (lynching) although they may also end up within trees as a result of being hurled there by an explosion, thrown from a vehicle after a crash or knocked there after being hit by a train or vehicle. A body that is left hanging above ground may decay more slowly than one that is lying on the surface of the ground (Wyss & Cherix, 2004). This is probably because when a body is suspended in mid air, there is not a moist, dark, under-surface where flies can lay their eggs, the circulation of air will promote drying out, and many maggots would fall off whilst crawling around or be washed off by the rain.

Burial underwater

Bodies that are disposed of in water are often said to decay twice as slowly as when the body is exposed to air. This is probably largely due to the lower temperature and the rate declines with depth because of the progressively lower temperatures and oxygen levels. Bodies are said to decay more slowly in the sea than they do in freshwater because it contains fewer marine micro-organisms. In truth there is little experimental data on decay rates in marine environments and surface seawater contains similar bacterial densities to those of lakes (10^6 per ml compared with 10^5–10^7 per ml) whilst microbial populations in sediments, even at great depths, are much higher than previously thought (Azam & Malfatti, 2007; Tranvik, 1997). The rate of decay will also depend upon the abundance of aquatic invertebrate and vertebrate detritivores.

Unless they are firmly weighted down, bodies buried underwater usually float up to the surface when gas formation occurs. Bodies floating on the surface of ponds, lakes and rivers can be colonized by blowfly larvae and this, along with the exposure to higher temperature and oxygen levels (than underwater), increases the rate of decomposition. Blowflies are not found at sea though they may colonize bodies washed up on beaches.

Wounds

Wounds, whether inflicted at the time of death or immediately afterwards, allow entry of air and invertebrates into the body and can therefore speed up the rate of decay. The smell of blood is also attractive to blowflies and therefore leads to the body being discovered and exploited more quickly. However, if there is severe blood loss this may slow the bacterial colonization of the body / body parts because the microbes are no longer able to grow rapidly through the liquid medium of the blood vessels.

Infections

Pre-existing infections such as septicaemia or infected wounds can speed up the rate of decay because there are already bacteria colonizing and breaking down the body at the time of death.

Burning

Murderers often attempt to dispose of their victim's body by burning it. However, they are seldom completely successful owing to the extremely high temperatures required – identifiable human remains may still be found among the ashes produced by a crematorium, which typically operates at over 1000 °C for 2–3 hours. The temperatures reached in typical house fires are much lower than this and although they may exceed 700 °C this tends to be for relatively short periods and to occur close to the ceiling. On the floor, the temperature may only reach 166 °C – although a lot depends on the presence of combustible material. Victims of house fires, explosions and traffic and aircraft accidents are also often badly burnt. Usually, the extremities, the limbs and the head are most badly affected and the torso is the last part of the body to be fully consumed. Bodies with a high fat content burn the best and clothing, provided it is flammable, will contribute to the extent to which the body is destroyed. Sometimes the body is placed in a tyre that is then set alight as a means of providing extra fuel.

Some factors associated with burning reduce the rate of decomposition whilst others promote it, so it is difficult to generalize. For example, burning sterilizes the skin surface and dries the underlying tissues making them unsuitable for the growth of microbes and blowfly maggots but it also causes cracks through which they may invade the deeper tissues that are less affected. Similarly, although the skin surface may be charred, the temperature may not have been high enough to affect the gut microbial flora, so decomposition may commence here as normal. Some workers have found that burnt corpses retain their attractiveness to blowflies whilst others have found that it reduces their likelihood to lay eggs on the body (Avila & Goff, 1998; Catts & Goff, 1992). Obviously, a great deal depends on the degree of burning and the individual circumstances.

Burning induces chemical changes in proteins, carbohydrates, lipids and other organic molecules that may affect their suitability to support microbial and maggot growth but there is little published information on this in a forensic context. However, there is a lot of literature on how pre-slaughter conditions, storage and cooking affects the chemical composition and palatability of meat destined for human consumption (e.g. Varnam & Sutherland, 1995). Basically, when meat is cooked it causes the fats to melt and therefore they become susceptible to degradation (e.g. triglycerides break down to glycerol and fatty acids) and oxidation (e.g. the carboxylic acid group of a fatty acid chain is oxidized). The oxidation of fatty acids produces a range of chemicals that contribute to the smell of cooked meat and also undergo reactions with other chemicals to produce compounds that contribute to the taste of meat. Heating above 40–50 °C causes some proteins to become denatured (their three-dimensional shape is changed) and hydrolysed (i.e. broken down) and as the temperature continues to rise more and more proteins are affected. Denaturation causes muscle proteins to contract (hence heat stiffening) and in the process the cytoplasm of the muscle cells is forced out. Other proteins are also denatured causing further shrinkage, loss of fluid contents and therefore the tissues dry out as the water evaporates. As the temperature rises, pyrolytic reactions occur. (Pyrolytic reactions are those in which heat causes compounds to become converted into one or more products.) For example, collagen is converted into gelatine. The breakdown of proteins results in a rise in the concentration of amino acids and some of these will react with sugars in a complex, nonenzymic, reaction known as the Maillard reaction. This is important in the development of flavour although it must be remembered that what humans consider flavoursome and what invertebrate detritivores respond to may not be the same. If heating is prolonged the body will become desiccated and if the temperature is high enough it will be carbonized and turn black as all the organic matter is lost.

Chemical treatment

Murderers occasionally cover their victim's body with a chemical in order to enhance its speed of decay, reduce its likelihood of detection or simply to destroy potential incriminating evidence. It is a common belief that covering a body with lime will lead to its rapid and total destruction. In fact, it can actually contribute to the body's preservation. Lime (calcium oxide [CaO]) reacts with water to produce highly corrosive slaked lime (calcium hydroxide [$Ca(OH)_2$]) in a highly exothermic reaction (i.e. a lot of heat is produced). Indeed, so much heat is produced that although some surface corrosion takes place when a body is covered by lime, the temperature of the body becomes so high it is desiccated. A dry body can remain resistant to decay for many years and a corrosive covering deters detritivores from attacking it.

Placing a body in an acid bath destroys all the soft tissues as well as the bones but the speed and effectiveness are affected by the water content of the tissues; fat is hydrophobic and not readily solubilized and neither are gallstones – these are predominantly composed of cholesterol and variable amounts of calcium. Some plastics are also resistant to attack.

Case Study: The acid bath murders

John George Haigh earned himself a name in history as the 'acid bath murderer' – crimes for which he was hanged in Wandsworth prison in 1949 – by placing his victims in a bath of sulphuric acid after killing them. There were several victims but it was the death of his final one, Mrs Durand-Deacon that provided most of the evidence that led to his conviction. When the police investigated his property following the disappearance of Mrs Durand-Deacon they recovered a large quantity of body fat, three gallstones, part of a left foot, several bone fragments, an intact set of dentures, a bag handle and a lipstick container. There were also bloodstains on a wall but the technology of the time was only sufficient to identify them as being of human origin. The dentist of Mrs Durand-Deacon had kept plaster casts of her patient's upper and lower jaw and was therefore able to confirm the provenance of the dentures. A cast of the left foot was found to perfectly fit into one of Mrs Durand-Deacon's shoes whilst the pathologist who examined the foot confirmed that the victim had suffered from osteoarthritis in life – something that Mrs Durand-Deacon was known to have done. This indicates that even an acid bath has its limitations as a means of disposing of a dead body although it should also be noted that the remains of Haigh's other victims were never found.

Embalming is the process by which a dead body is treated with chemicals to delay or prevent its decomposition. The ancient Egyptians, amongst others, embalmed their dead for religious reasons and sought to prevent decay entirely. Similarly, Lenin's body was embalmed before being put on public display in his Moscow tomb and is constantly monitored to prevent decay. Nowadays, at least in Europe and USA, embalming is not done for religious or political purposes but to temporarily preserve the body so that it remains presentable and not a danger to health until it is buried or cremated. In the UK, this usually involves treating the body with a 2% solution of formaldehyde although the embalming fluid may also contain a variety of other chemicals. The forensic relevance of this is that embalming can compromise the subsequent chemical analysis of the body's fluids and tissues. Obviously, it is preferable that appropriate samples are taken before embalming occurs but this is not always possible or the need is not recognized in time. Embalming can reduce the level of benzodiazepines whilst the embalming of Princess Diana's body after her death in a car crash on 31st August 1997 prevented hormone analysis that would have proved whether or not she was pregnant with her lover Dodi Fayed's child. Needless to say, this spawned a 'cover-up' conspiracy. Embalming can also introduce artefacts, such as methanol, so it is helpful to have a sample of the embalming fluid to confirm whether or not this could have been the source. Not all chemical

Table 1.4 Summary of factors promoting or delaying the rate at which a body decays

Factors promoting decay	Factors delaying decay
Oxygen supply not restricted	Oxygen supply restricted
Warm temperature (15–37 °C)	Cold temperatures (<10 °C; decay will cease below 0 °C)
Humid atmosphere	Dry atmosphere
Presence of invertebrate detritivores (e.g. blowfly larvae)	Absence of invertebrate detritivores
Wasp, ant and other invertebrate predators feeding on corpse	Wasp, ant and other invertebrate predators feeding on detritivores
Wounds permitting invertebrates easier access to internal body tissues	Inability of detritivores to gain access to all or part of the corpse
Surface burning causing skin to crack and thereby allowing easier access of invertebrates and oxygen to internal tissues	Intense burning resulting in tissues becoming carbonized and drying out.
Obesity	
Suffering from septicaemia or myiasis before death	
Body exposed to the environment above ground	Burial on land or underwater (rate of decay declines with increasing depth)
Body resting on soil	Body suspended above ground (e.g. hanging)
	Formation of adipocere
	Mummification
	Embalming

analyses are affected by embalming, for example, the levels of morphine and strychnine are not altered. Blood ethanol levels may be reduced or impossible to assay following embalming but at least for the first 4 days afterwards a reliable estimation of the ante mortem levels can be made by measuring the levels in the vitreous humor – provided the eyes have not been injected with a mixture that compromises the analysis.

Discovery and recovery of human remains

Discovery

Most homicides are brought to the attention of the police soon after they occur owing to the disturbance caused, the confession of the culprit or the body being discovered in a public place. Sometimes an attempt is made at concealment but this is seldom very effective because human bodies, especially those of adults, are heavy and difficult to carry. Consequently, dead bodies are usually left close to where they fell or dragged a short distance from a path into nearby undergrowth – perhaps following a ride in the boot of a car – and they are often soon discovered by accident by a man walking his dog or children playing. Where the remains are buried the grave is usually relatively shallow and in the vicinity of where the homicide occurred.

Where an intentional search is employed it is essential that this is done in a careful and methodical manner – often the area is divided into grids and one section of the grid is searched at a time. Physically searching large areas of countryside is difficult, requires a lot of manpower and is time consuming – and therefore expensive. To speed up the search a variety of methods are employed. Dogs have an extremely well-developed sense of smell and the police employ specially trained cadaver dogs to help them locate dead bodies – American workers report that cadaver dogs work best at a temperature of 4–16 °C when the earth and atmosphere are moist and there is a wind speed of at least 8 km/hour. Dogs can detect bodies that have been dead for many years and those that are buried or sunk underwater.

Aerial photography will reveal disturbed soil and localized changes in plant growth patterns whilst infrared cameras will detect the heat given off by a dead body as it starts to decay. Grave sites can be detected by probing with a long metal rod fitted with a 'T-shaped' handle: graves are characterized by a covering of disturbed soil and it is possible to insert the probe to a much greater depth than in the surrounding soil for the same amount of applied pressure. By contrast, as a rule it becomes progressively harder to insert the probe into undisturbed soil beyond a depth of about 30 cm. The dimensions of a 'soft spot' can indicate the likelihood of it being a grave and additional soil chemistry tests might be done on the area before attempting an excavation. This approach works best where the soil is naturally undisturbed and requires experience, it is also time consuming and requires care if damage is not to be done to the buried object. A ground magnetometer can be used to scan a large area in a relatively short period of time. The device works by detecting minor differences in the magnetic properties of the underlying soil. The human body cannot be detected directly by magnetometry but the process of burial disturbs the soil profile and hence its magnetic properties. Magnetometry will also detect objects such as metal buckles and keys. However, the technique doesn't work unless there is sufficient iron oxide content in the soil and its effectiveness is compromised if the body is on a tip or waste dumping ground where the soil contains numerous metal objects. Ground penetrating radar works by projecting electronic pulses into the ground and then monitoring the way in which they return. This allows the operative to build up a three-dimensional map of the underlying soil including the position and shape of objects and the presence of voids (these would show up if the body was in a coffin or box). However, the equipment is expensive and works best where the terrain is level. Like all the other techniques it is not failsafe and may indicate the presence of a clandestine grave where there is none whilst failing to identify remains where they are known to occur. A brief summary of some of the methods used to detect bodies is given in Table 1.5 and more details on the discovery and recovery of human remains are covered by Dupras *et al.*, (2006).

Recovery

Once human remains are discovered the surrounding area should be cordoned off and a tent erected over the body to protect evidence from being lost and contaminants from being introduced. The whole surrounding area should be photographed and searched methodically for evidence. Evidence from a crime scene can consist of anything from a beer can to a bone and all surrounding objects should be photographed *in situ*, their position noted and then collected, given an identifying number and stored appropriately for future analysis. The method of retrieving a buried body depends upon the local circumstances. Strictly speaking, the term 'exhumation' should be restricted to the retrieval of a body legally buried in a coffin within a graveyard but it is also commonly used where burial was unlawful. If the body was buried legally mechanical diggers can be used to expose the coffin before it is retrieved but where the body was buried unlawfully it should be retrieved in an extremely careful manner so as to gather as much evidence as possible and to avoid damaging the remains. In all cases, the soil should be removed sequentially in layers using plastic and wooden tools and the soil hand sorted and sifted for evidence before being disposed of. In the 'hole method' the soil is removed from above and around the body until the body is fully exposed and can be removed. In the 'trench method' a 60 cm wide trench is dug around 3 sides of the grave to provide room within which to work and collect evidence. The trench is extended until it is about 60 cm below the level of the body so that the soil underneath the body can be examined. In the 'table method' a trench is dug as described above except that it is extended to include all four sides of the grave. This facilitates access to all sides of the body and is therefore the preferred method where circumstances allow. Once exposed an examination of the body in its context should take place. When the body is ready to be moved the hands and feet should be enclosed in clean plastic bags to preserve any biological/chemical evidence attached to the palms/soles or underneath the nails. The bags also protect the skin from physical damage: during the later stages of decay, the surface of the skin sloughs off and if the epidermal surface is damaged it may be impossible to take prints. Afterwards, the whole body (still in its clothes, if present) should be placed in a clean body bag and removed to a mortuary where an autopsy can take place. This ensures that evidence is kept together and reduces the possibility of contamination. If the body was buried and skeletonized it may be easier to wrap it in a white sheet and place it on a wooden board for easier transportation. It is easy to damage a body that is in the late stages of decay and cause post mortem artefacts that could be mistaken for ante mortem wounds so such bodies should be handled as little as possible and treated gently.

Health and safety should be a priority both at the crime scene and within the laboratory when examining the evidence. Extreme care should be taken when handling samples collected from corpses. Decaying bodies contain many bacteria and fungi, some of which are pathogenic and there is always the possibility that the victim was suffering from a transmissible disease. The risks extend beyond the tissues of the body as, for example, both anthrax and tuberculosis spores pass unharmed through the guts of blowfly maggots and adult flies so they too can be potential sources of infection. Special care needs to be taken when handling and storing exhibits such as needles owing to the risk of HIV and Hepatitis B and Hepatitis C. Illegal cannabis grow rooms are seldom set up in accordance to building regulations and can therefore contain dangerous electrical wiring or present a fire risk.

Table 1.5 Summary of the advantages and disadvantages of the main methods of detecting dead bodies

Method	Advantages	Disadvantages
Physical search	Requires only manpower.	Manpower is expensive. Slow. Large numbers of people moving through an area may destroy evidence unless they are suitably trained.
Cadaver Dogs	Rapid, simple, cheap, nondestructive, detects old bodies and buried bodies.	Can be affected by climate. Dogs are best trained for single task (e.g. drugs or cadaver but not both).
Aerial photography	Nondestructive, provides overall picture of immediate and wider area. Databanks of the area may be available which highlight local changes.	Flight time expensive and normal cameras seldom provide sufficient resolution. Trained personnel needed for interpretation. Images may be required at different times of year.
Satellite images + spectral analysis	Nondestructive, provides overall picture of immediate and wider area. Databanks of the area may be available which highlight local changes.	Although mass graves in Iraq detected by spy satellite, the potential for locating small graves is uncertain. Suitable images not available for all regions of world and not all images are archived.
Thermal images	Nondestructive. Rapid. Can survey a wide area quickly. Will detect buried body if it is not too deep.	Most successful whilst corpse actively decaying but less effective once skeletonized. Equipment expensive and affected by wind.
Magnetometry	Nondestructive, rapid, can survey a wide area quickly. Equipment readily available. Can work through snow.	Compromised by artefacts (e.g. soil contains many metal objects) and not effective in some soil types (e.g. chalk, limestone, gravel deposits). Difficulties on rough terrain.
Ground penetrating radar (GPR)	Nondestructive, relatively rapid, can survey a wide area. Can work through snow or over water.	Expensive and requires trained operator. Usually requires smooth terrain.
Probing	Simple. Can work through snow and on rough terrain.	Potentially destructive (e.g. may damage skeletal remains), slow, requires experience.
Metal detector	Simple, cheap, quick, nondestructive. Potential if missing person contains metal medical implant.	Will only detect metal objects and to a limited depth.
Botanical survey	Simple, cheap, nondestructive. Typically used in conjunction with aerial photography.	A human corpse or burial causes the same changes to the plant community as any other dead animal or localized soil disturbance. Requires experienced botanist.

Determining the age and provenance of skeletonized remains

The longer that a person has been dead the harder it becomes to determine their time of death. Unidentified skeletons that are unearthed during construction work present particular difficulties because the police need to know whether they need to devote time and effort on an investigation and there are commercial pressures to resume building as quickly as possible. Even if the skeleton exhibits obvious signs of suspicious death (e.g. a knife still stuck in the skull) the police do not investigate crimes that were committed more than 70–75 years ago since the perpetrator would almost certainly have died and the victim's family would be several generations removed.

Radiocarbon dating

The vast majority of elements present in our bodies and the environment exist as a variety of isotopes – that is, their nuclei contain the same number of protons but a different number of neutrons. Some of these isotopes are unstable and decay through the loss of subatomic particles into other isotopic forms. For example, carbon-14 (^{14}C) decays to nitrogen-14 through the loss of beta (β) particles. The rate of decay of an element, measured as the 'half-life', depends on the instability of the isotopic form and may vary from fractions of a second to millions of years. The levels of unstable isotopes, especially ^{14}C, are useful in determining the age of both human and animal remains. Carbon-14 has a half-life of 5730 years and would have disappeared from the earth millions of years ago except for the fact that it is constantly being formed by the interaction of nitrogen in the air with cosmic rays. Once formed, the ^{14}C becomes incorporated into carbon dioxide which plants then metabolize into organic molecules when performing photosynthesis. The ^{14}C subsequently becomes incorporated into the bodies of herbivores when they eat the plants and then into the bodies of any carnivores or parasites that feed on the herbivores – consequently there is a constant cycling of ^{14}C between all living organisms. However, once an organism dies it no longer acquires new ^{14}C and the level within its body slowly declines. Because the rate of radioactive decay is constant, the level of ^{14}C present in the body provides an indication of how long the organism has been dead. Obviously, allowances have to be made through calibrations for the effects of complicating factors that influence the level of ^{14}C in the atmosphere such as solar storms and human activities (e.g. the burning of coal and other fossil fuels). Carbon-14 dates are usually expressed as 'years before present' (BP), present being the year 1950 – the year in which extensive above ground nuclear weapons testing began and thereby dramatically increased the levels of ^{14}C in the atmosphere. Carbon-14 dates are always cited as plus and minus a standard deviation (e.g. 526 ± 40 BP) to allow for errors that arise through the nature of the sample, how it was collected and the methodology used. It is therefore impossible to state the exact year in which a person died. Furthermore, traditional ^{14}C dating is insufficiently precise to accurately age the skeleton of a person who died within the last 100–200 years.

The carbon isotopes are usually extracted from collagen which is in turn extracted from the bones. This is because the mineral component of bone contains only a small amount of carbon – mostly in the form of calcium carbonate – and in buried bodies this can be affected by ion exchange with the surrounding soil.

Bomb curve radiocarbon dating

Bomb curve dating (also called bomb pulse dating) is based on the change in the ^{14}C levels in the atmosphere subsequent to the testing of nuclear weapons during the 1950s and 1960s. The nuclear explosions led to an increase in the atmospheric levels of ^{14}C followed by a decline once testing ceased – this is known as the 'bomb curve' or 'bomb pulse'. This pattern is repeated in all living organisms. The levels of ^{14}C can be measured in all tissues and the amounts reflect the carbon turnover within them. Metabolically active tissues such as the brain have high levels that mirror the atmospheric ^{14}C levels whilst those that are less active, such as the collagen content of bone, have much lower levels that reflect the year in which they were formed. It is therefore possible to determine the age of a tissue by relating its ^{14}C level to those on the atmospheric bomb curve. Tissues with a low carbon turnover that were formed before the start of nuclear weapons testing have a low level of ^{14}C whilst those formed afterwards exhibit elevated levels.

Bomb curve radiocarbon dating therefore has potential for aiding forensic investigations (Ubelaker & Buchholz, 2006). The presence of elevated ^{14}C levels in any of the tissues recovered from a dead body would suggest that the person was alive at some point after 1950. The circumstances surrounding the remains would therefore require further investigation. The precise level of ^{14}C could provide evidence of when the tissue was formed and, potentially, when the person died but there could be many years discrepancy between these two figures. Furthermore, the levels of ^{14}C in tissues are strongly affected not only by the type of tissue but also by age, growth pattern, diet, health and disease. The levels would therefore have to be considered in relation to other information. For example, whether there was evidence of osteoporosis. The use of bomb curve radiocarbon dating to determine a person's age from their teeth is described in Chapter 4.

Stable isotopes

Carbon-14 is not the only isotope that can be used to determine the age of human remains. For example, our bones contain small quantities of lead-210 (^{210}Pb) that we acquire through our food and breathing in radon-222 (^{222}Ra; this decays into ^{210}Pb) from the atmosphere. Because ^{210}Pb has a half-life of only 22.3 years its levels decline more rapidly after death than those of ^{14}C thereby making it potentially valuable for forensic studies (Swift *et al*., 2001). Isotopes that do not undergo radioactive decay are said to be 'stable'. An element may posses both unstable and stable isotopes – for example, carbon may occur as both the unstable isotope carbon-14 and the stable isotopes carbon-12 and carbon-13. Stable isotopes have many uses in forensic studies as their ratios can provide a unique identifying feature of a specimen's provenance or as an indication of previous diet or geographical origin (Anon, 2004a). For example, strontium has four stable isotopes (strontium-84, -86, -87, and -88) and because their ratios vary between geographical locations these can act as a 'signature' indicating where a person or animal was living. Strontium enters our bodies via our diet and becomes sequestered in the bones and teeth. Once formed, the tissues that make up teeth have a low metabolic turnover and the strontium is immobilized within them. The strontium isotope ratio of the teeth therefore tends to reflect that of the environment in which a person grew up. By contrast, bones are metabolically more active with new tissues being constantly formed throughout life, although the rate of renewal varies between bones. The strontium isotope ratios found in bones therefore reflects those in the environment where a person lived in the previous ten years. Beard & Johnson (2000) analysed strontium isotope ratios to differentiate between the disarticulated skeletal remains of three American servicemen that were found mixed together in a shallow grave in Viet Nam 20 years after the conflict ended. The identity of the victims was known but the remains needed to be separated from one another so that they could be returned to the appropriate family. The three servicemen grew up in different areas of America so it was possible to identify at least some of the remains by comparing the strontium isotope ratios of the teeth and bones with those found in the three regions. Because the servicemen were not stationed in Viet Nam for long before they were killed, the strontium levels in the bones were not thought to have been affected by the food and water they consumed whilst there. Although this type of analysis offers promise for future development, its effectiveness is ultimately dependent upon the availability of databases of isotope ratio analyses for different geographical regions and is potentially subject to many complicating factors. For example, human populations are increasingly mobile and our food and water is acquired from different geographical regions to where we live.

Future developments

More effective means are required to detect dead bodies, especially buried bodies. Although satellite technology has been proposed there are relatively few of these with sufficient resolution to detect the presence of a small individual grave and their flight path cannot be altered to meet the requirements of a local police force. GPR has great potential but the technology will have to be refined and made cheaper and more robust if it is gain widespread use as a field instrument for forensic investigations.

The possibility of using the radiocarbon bomb curve dating technique for forensic studies was suggested many years ago but its potential has not been widely exploited. This is probably because we still have limited data on the factors affecting the ^{14}C levels in human tissues and how biological and environmental factors affect these after death. Similarly, the use of stable isotopes in forensic science offers considerable scope but will require agreement on standardized techniques and databases of isotope distributions within and between countries to be established.

Quick quiz

(1) What is hypostasis?

(2) What is meant by the term ‘taphonomic process’. State two examples of taphonomic processes.

(3) What causes the ‘bloat’ stage of decomposition?

(4) What is adipocere and what is its forensic relevance?

(5) Why do newly born babies mummify more readily than older children and adults?

(6) Why does a buried body decay more slowly than one lying on the surface of the ground?

(7) Why does a hanging body decay more slowly than one lying on the surface of the ground?

(8) During winter, why might an exposed body decay faster if left in the centre of a city than in the outlying countryside?

(9) State one means by which burning can reduce the rate of decay of a corpse and one means by which its rate of decay might be increased.

(10) Distinguish between the ‘trench’ and the ‘hole’ methods of retrieving a dead body.

Project work

Title

The effect of freezing on the rate of decay.

Rationale

Murderers sometimes store their victim's body in a freezer before disposing of it. Freezing will cause tissue damage so once the body has thawed, does it decay at the same as rate as an unfrozen body?

Method

Bodies or tissues can be frozen for varying lengths of time and then placed above or below ground and the rate of decay, speed of colonization by invertebrates etc. compared with those of a control unfrozen body. If a thermocouple is placed on the frozen body when it is exposed, it would be possible to determine whether blowflies are deterred from laying until the surface temperature has risen to near ambient levels. Histological changes could also be assessed along with biochemical assays to determine the speed with which autolysis begins.

Title

The effect of burying in concrete on the rate of decay.

Rationale

Bodies are sometimes disposed of in the concrete foundations of buildings or bridges.

Method

Bodies or tissues, which may or may not be wrapped in clothes, would be encased in concrete and then left at varying temperatures. After varying times the body would be retrieved from the concrete and its state of decay compared with those of control bodies that were not placed in concrete. The ability to extract DNA from the bodies would be assessed and structural changes to the surrounding concrete determined.