1

Gross Post-Mortem Changes in the Human Body

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1.1 Introduction

All organisms die and the natural consequence of this is decomposition. The rate of decomposition is determined by numerous factors, both intrinsic to the body such as body habitus, and environmental factors such as predators, ambient temperature and humidity. Decomposition may broadly be divided into putrefaction and arrested decay, although these processes are not mutually exclusive and may be seen in the same body.

Post-mortem changes produce both artefacts that may mislead the unwary and obscure findings that point to the events immediately before, and indeed leading directly to, the death of the person. Recommended literature regarding forensic pathology is DiMaio and DiMaio (2001) and Knight and Saukko (2004). In this chapter the processes that occur in the body after death are discussed, along with the ways in which human and other environmental factors can affect these processes. The potential pitfalls faced in examination of the deceased are highlighted. In particular, some post-mortem changes may be mistaken for injuries sustained shortly before death.

1.2 The Immediate Post-Mortem Period

While most people know what death is, it is remarkably difficult to define scientifically and is best considered a process during which the cells and tissues that make up an organism cease to function. This is not the same as the 'time of death' recorded on the death certification, which is usually the time at which life is pronounced extinct by a suitably qualified person. In the UK, to diagnose brain death, a series of appropriate tests are performed twice at different times and the time of death is considered to be the time of the first set of tests. The tests include shining a torch into both eyes to see if they react to the light, stroking the cornea, pinching the nose, inserting ice-cold water in each ear, trying to provoke gagging or coughing by placing a plastic tube down the trachea, amongst other tests (National Health Service 2015).

One of the first notable features is that thermoregulation stops and the body temperature will naturally move towards ambient temperature. In most cases, this means the body will cool, but in particularly warm climates the body may actually increase in temperature.

The cooling of the body has long been of interest to the forensic community, particularly with respect to estimating the post-mortem interval (PMI). A historical review on the early work of estimating time since death is described by Knight and Madea (2016). A common 'rule of thumb' is that

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a body tends to cool at a rate of one degree Celsius per hour. A slightly more refined version takes into account the sigmoid nature of the cooling curve and assumes that the body does not begin to cool for around three hours after death, but cools at around one degree Celsius per hour thereafter, called the 'initial temperature plateau' (Al-Alousi *et al.* 2002). The authors politely submit that such calculations are so 'rough and ready' as to be of no real value in criminal investigations. By way of example, the case of *R v Lattimore and Leighton* (1974) involved a body recovered from a fire scene. Because of the possibility of sexual activity, a rectal temperature was not taken at the scene and later excessive reliance on post-mortem phenomena to estimate the time of death (particularly given that the body had been exposed to an unusually high ambient temperature) became an important aspect of the case with respect to the defendants' alibis. This ultimately led to a successful appeal and the case initiated research funded by the UK Home Office. Unfortunately, this extensive and expensive study only confirmed the unreliabilities, which had been known for years.

A more refined calculation is the Henssge equation and nomogram that take into account numerous factors including body weight, gender, body coverings, whether the body is wet or dry and ambient temperature (Henssge and Madea 2004; Henssge *et al.* 2002; Madea and Henssge 2016). The nomogram is useful, but as with any hand-drawn graphical method there is potential for user error. While the equation may appear daunting, there are now apps available for smartphones that can perform the calculation with relative ease. It should also be noted that any estimate of the PMI is based on a 'normal' initial body temperature, but particularly in cases of overwhelming infection or strenuous exercise, the initial temperature may be higher, and indeed in cases of sepsis, a transient post-mortem rise in temperature may be seen. Equally, hypothermia will cause a low core body temperature in life, also affecting estimates of the PMI. Even without such extreme changes, it is known that the human core temperature may vary under normal circumstances (the changes associated with the menstrual cycle are so well recognised that they can be used for family planning) and so one must bear in mind that there is an inherent potential error of up to two hours in any PMI calculation, and even the Henssge calculation includes a range of ±2.8 hours as a minimum range, rising to as much as ±7 hours.

Furthermore, the so-called 'normal temperature' in any individual may vary by as much as 1°C from the assumed 37.4, so all calculations start with a built-in potential error of up to 2 hours. It is also the case that the ambient temperature is based on a single measurement, and as this temperature can fluctuate over time, both outdoors and indoors with automatic central heating, its measurement may not accurately reflect the average temperature to which the body has been exposed throughout the post-mortem period.

Concurrently with cooling, rigor mortis (post-mortem stiffening) will develop as the muscles become depleted of adenosine triphosphate (ATP) and the muscle fibres permanently cross-link. As the reader may recall from his or her studies of basic physiology, muscle fibres are composed of actin and myosin, with the myosin heads binding to actin during muscle contraction and hydrolysing ATP to adenosine diphosphate (ADP) to allow the myosin to release the actin. Once ATP is depleted then cross-linking of the actin/myosin becomes permanent until decomposition causes breakdown of the molecules, or mechanical force is applied as discussed below. A logical corollary of this is that individuals who die shortly after exercise may have already depleted their stores of energy and ATP and therefore may develop rigor mortis more rapidly than an identical person who died at rest.

Rigor mortis is first observed in the small muscle groups such as the fingers, eyelids and lower jaw, which has produced the age-old practices of 'pennies on the eyelids', and the timely application of a jaw bandage or prop. The appearance of a slack-jawed, half-staring body can be highly distressing to relatives. Furthermore, if the eyes remain open, a dark discoloration occurs in the exposed conjunctiva, the so-called *tâche noire de la sclérotique* (Figure 1.1). In the early stages of its development, this may be mistaken for petechial haemorrhage (pinpoint haemorrhages resulting from

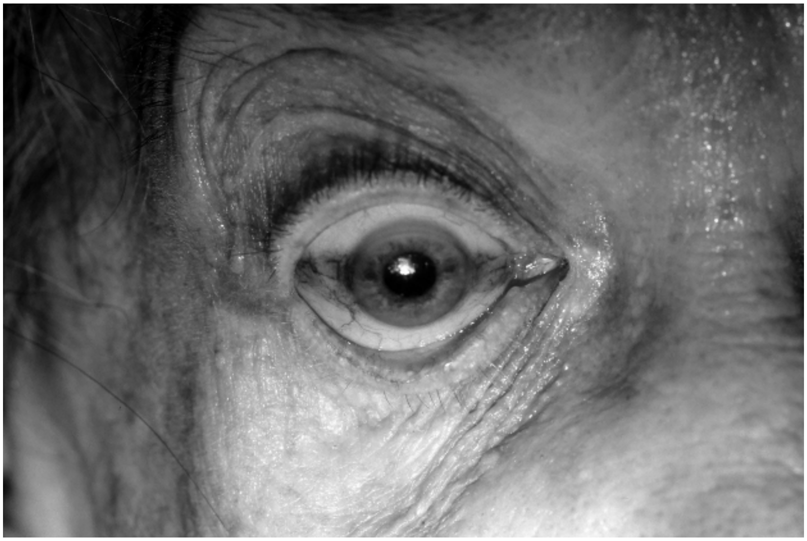

Figure 1.1 The *tâche noire de la sclérotique*, a post-mortem artefact.

ruptured venules, a common finding in strangulation), which the inexperienced may interpret as a sign of asphyxial death.

Rigor mortis then gradually becomes apparent in larger muscle groups until the body is essentially stiff. As the muscle decomposes, rigor mortis will pass. The rate at which rigor appears and disappears is extremely variable, as is its intensity. Individuals with large muscle bulk can develop very strong degrees of rigor, while particularly cachexic elderly people with very low muscle mass may show only weak rigor, or in extreme cases no recognisable rigor mortis at all. The 'strength' of rigor mortis is not a matter of forensic relevance. However, there are two aspects of rigor mortis that are worthy of consideration by the forensic pathologist. First, rigor in the heart can make it appear contracted and hypertrophic; therefore any assessment of cardiac hypertrophy should also include weight as well as wall thickness. Second, rigor developing in the muscles of the iris may cause dilation or contraction after death and therefore clinically useful signs such as the pinpoint pupils of the opiate overdose may be compromised. The pupils will react to mydriatic and meiotic drugs such as atropine or pilocarpine for a few hours after death. This phenomenon was extensively studied in the 1960s and 1970s as a method of estimating time of recent death, but proved to be totally unreliable (Madea 1994, 2016; Prasad 2003).

Some authors argue that rigor mortis can occur instantaneously (cadaveric spasm) (Figures 1.2 and 1.3), although this is by no means universally accepted (Pirch *et al*. 2013).

Rigor mortis can be 'broken' by physical force. If a body has been lying in an unusual position, this may occur when the body is manipulated during transfer to the mortuary and so any assessment of the degree of rigor mortis in the mortuary should take this into account. It has also been shown that it is possible for rigor mortis to become re-established after being mechanically broken, albeit more weakly than the original (Krompecher *et al*. 2008). Although it is rare that this phenomenon is likely to have forensic relevance, one of the authors (MAG) has seen such a case where a weapon was placed in the hand of a decedent in order to stage a scene of a suicidal shooting.

Similarly, once active circulation of blood ceases, blood will tend to gravitate to the most dependant parts of the body, producing a dark discoloration known as hypostasis, livor mortis or lividity, alternating with pallid areas of 'contact flattening' (Figure 1.4). This usually relates to where the body

Figure 1.2 A sketch of a case of cadaveric spasm from a 19th-century pathology textbook showing a soldier who is enjoying a beverage while his head has been blown off by a shell explosion.

Figure 1.3 A razor blade clutched in the hand, an apparent example of cadaveric spasm.

Figure 1.4 Clear sparing in hypostasis from the body lying on a hard surface and the small blood vessels being compressed, preventing hypostasis developing in these areas.

is in contact with the surface on which it lies, although pressure from clothing can also lead to regions of pallor. This can sometimes be so well defined as to allow the embossed brand name in the elasticated waistband of some brands of underwear to be read upon the surface of the underlying discoloured skin.

Hypostasis also occurs within the internal organs, and there also it can cause pitfalls for the unwary. In particular, hypostasis in the left ventricle of the heart may mimic a posterior myocardial infarct (death of cardiac muscle resulting from inadequate blood flow) and hypostasis in the intestines can be mistaken for ischaemia (injury from lack of oxygen) or infarction (tissue death from lack of oxygen). Artefactual post-mortem haemorrhage in the neck muscles (the Prinsloo Gordon artefact) should not be mistaken for evidence of strangulation and it is recommended that the head is opened before the neck is dissected to minimise the risk of this developing. Over time haemolysis occurs and the hypostasis becomes 'fixed', that is to say if the body is moved the hypostasis will not move to the new position. Again, the rate at which hypostasis develops and becomes fixed is highly variable, and not of value in estimating the PMI. Some factors alter the colour of hypostasis, in particular carbon monoxide poisoning causes cherry red hypostasis and cyanide poisoning causes brick red hypostasis. Blue/brown hypostasis is seen in cases where methaemoglobin is produced, such as poisoning with chlorate weed killers. Extreme cold may cause pink discoloration. While under no circumstances should such observations replace adequate toxicological analysis, they may assist in directing the observer towards a possible cause of death.

Overall, rigor mortis and hypostasis cannot give an accurate estimate of the time of death. However, if the pattern of these phenomena does not match the position in which the body is found, this may be of value in indicating that the body has been moved sufficiently long after death for these features to be present, which may in itself be of value to the investigation of the cause of death.

It is also relevant that non-forensically trained persons may make observations regarding bodies feeling cold or rigor mortis being present. Given that direct observation of such features by an experienced practitioner cannot offer a precise time of death, using such second-hand observations to make pronouncements would be unwise. So-called 'undertaker's bruises' seen over the shoulders should not be mistaken for evidence of intravital trauma.

1.3 Subsequent Weeks

Even as the very early post-mortem changes become apparent, the processes that produce the features of decomposition are developing. Autolysis refers to the chemical breakdown of tissue, and tends to be first observed in the pancreas where escape of the proteolytic enzymes causes digestion of the organ itself. This will rapidly become apparent on histological examination, although naked eye appearances are less clear and if necessary, microscopic examination may be needed to differentiate between a haemorrhagic, autolytic pancreas and one that was truly inflamed in life. Simultaneously, the active processes that prevent bacteria escaping the bowel fail and the microorganisms that colonise the gut will migrate through the intestinal wall and begin to break down tissue (Finley *et al*. 2014). Haemolysis and the associated degradation of haemoglobin causes the classic green coloration associated with decomposition, and the high bacterial load in the caecum means that the first sign of decomposition that is usually noticed is green discoloration of the abdominal wall in the right lower quadrant of the abdomen, spreading to the rest of the abdominal wall. As bacteria propagate along blood vessels, they can cause haemolysis that stains the course of the vessels, known as 'marbling'. Marbling of the veins of the forearms and groins has sometimes been misinterpreted as evidence of intravenous drug use. Bacterial activity can also generate ethanol (alcohol) that may be a confounding factor in toxicological analysis. For this reason alcohol levels in the vitreous humour (eye fluid) are more reliable in cases where decomposition is beginning to occur (Kugelberg and Jones 2007).

At this stage, the skin will also begin to blister and slough, and fluid may begin to purge from bodily orifices. Sloughing may begin to obscure injuries, but loss of the epidermis may cause tattoos and old scars to be more clearly discernible. Purge fluid should not be confused with bleeding and considered evidence of, for example, sexual assault. Putrefaction gas will also begin to generate, which is usually most apparent in the abdomen and scrotum.

At the same time as the external aspects of the body decay, similar processes will be occurring internally. Changes in the pancreas are noted above, and the changes of decomposition manifest in different organs at different rates and in different ways. The brain, lacking a fibrous supporting structure, develops the well-recognised 'Swiss cheese' artefact before liquefying. In buried or encoffined bodies, or when adipocere has formed, the brain's putrefaction may arrest at the Swiss Cheese stage, and be found in this condition hundreds of years later (Fiedler *et al*. 2015). More fibrous organs such as the heart and uterus tend to retain their appearance for longer, and calcified structures (including calcified atheromatous vessels) may be readily identified for prolonged periods. The spleen may soften and this should not be confused with the diffluent spleen of systemic sepsis. Fat will often liquefy, coating the viscera in a slippery translucent yellow film. The blood, while initially remaining liquid, will begin to form post-mortem clots. This tends to be an admixture of red and white jelly-like material (sometimes described as having a 'turkey fat and cranberry jelly' appearance) that should be readily distinguished from the firmer, more organised and granular thrombus that occurs in life.

While such changes do hamper the examination of the body, this should never preclude a full autopsy examination when required, as macroscopic and microscopic features are often surprisingly well preserved compared to what may be expected based on external examination. As with the features discussed in the early post-mortem period, the rate at which such changes develop is extremely variable and therefore even greater ranges of PMI exist.

1.4 Other Post-Mortem Modifications

1.4.1 Scavenging

The dead organism is a source of nutrition for any number of predators: insects may deposit eggs very early in the peri-mortem period. Beloved, but hungry family pets will bite the hand and face that no longer feeds them (Colard *et al*. 2015; Tsokos and Schulz 1999). In the wild, carnivores can cause extensive and rapid tissue destruction, the extent and nature of which is very much dependent upon the local fauna, and knowledge of what animals may have access to a body should be obtained when assessing the appearance of that body (Dabbs and Martin 2013; O'Brien *et al*. 2010; Young *et al*. 2015). The role of entomology is well established in forensic investigation; detailed discussion is extensively covered elsewhere in this work and is beyond the scope of this chapter (Chapter 13). Suffice to say, a case with insect activity and infestation warrants the involvement of an experienced forensic entomologist, therefore such advice should be obtained, and the appropriate samples taken, before the body is moved. The site of each sample should be carefully recorded. In the case of *R v Sutcliffe* (1981), the well-documented 'Yorkshire Ripper' case, one of the victims had been partially moved from shade to sunlight and different fauna were present in shaded and exposed parts of the body (Bilton 2003).

The body of another of Sutcliffe's victims, found in a city centre, was colonised by the larvae of a fly found more commonly in the vicinity of cows and cowsheds. This led to the assumption that the woman had been transported from a rural setting, and led to the fruitless redirection of the inquiry for many weeks. The significance of such evidence may not be apparent immediately and the authors are of the view that retention of material that does not result in significant evidence is vastly preferable to the loss of material that may, at a later date, become important.

Post-mortem predation produces its own challenges for assessment of the body. On the one hand, any tissue loss may alter or efface injuries or stigmata of disease, but on the other hand, predation can mimic injuries, for example maggots burrowing through the skin may give the appearance of a shotgun wound on cursory examination or ant bites may give the appearance of abrasions (Byard and Heath 2014; Campobasso *et al*. 2009).

1.4.2 Arrested Decay

Bodies that lie in very dry environments may become naturally desiccated, also called natural mummification (Chapter 8). In contrast to putrefactive decomposition, which commonly obscures or destroys injuries and external marks, mummification has a tendency to preserve tissue and features may be readily identifiable for many years, even centuries. Putrefaction and mummification may be seen in a single cadaver. Mummification is most commonly seen in the extremities in such circumstances, with putrefaction of the torso.

1.4.3 Adipocere

This is a relatively uncommon phenomenon, sometimes referred to as 'grave wax' characterised by hydrolysis and hydrogenation of body fat by bacteria (Chapter 2). Bacteria in an anaerobic environment produce a waxy cast of tissue containing palmitic, oleic and stearic fatty acids. Although this is often seen externally, it is a process that can affect any body fat that is exposed to the appropriate conditions, and therefore can also be seen, for example, in association with hepatic steatosis (fatty liver) and mesenteric fat.

In the so-called 'Moors Murders' (*R v Brady and Hindley* 1963), the saponification of the fatty tissues led to extremely good preservation of the first two bodies recovered. Likewise, when a third body was recovered in 1985, rehydration in a solution of polyethylene glycol restored the facial features to a degree of normality.

A gruesome example of artificial and deliberate creation of adipocere was the 'hand of glory'. This was a candle created from the severed hand of a hanged murderer, ideally with the deceased's hair for the wick, preserved and said to render people motionless or unlock doors, and was therefore considered a highly desirable item for burglars and other persons with nefarious intent. The authors are not aware of any peer-reviewed literature detailing the efficacy of this item, but those interested may wish to read the poem 'The Hand of Glory' in the Ingoldsby Legends published by Richard Barham between 1840 and 1847 (Ingoldsby 1870).

Sleep all who sleep, wake all who wake
But be as the dead for the dead man's sake

1.4.4 Maceration

Maceration is a very particular form of post-mortem change that is typically only encountered in intrauterine death (IUD). As the normal uterine cavity is sterile (unless infection is present), then putrefaction does not occur and decomposition results entirely from autolysis. Skin slip begins to appear within 48 hours of IUD. The skin becomes progressively more dried out and friable, concomitant changes occur in the internal organs, and the whole body undergoes progressive shrinkage. Eventually, if amniotic fluid has been completely lost or re-absorbed, the end product is the shrunken brittle *foetus papyraceus* (Keeling 1978). In a long buried body, the general changes throughout the maternal cadaver will mask these changes.

Maceration from a pathology point of view should not be confused with maceration as a bone preparing technique used in forensic anthropology. Sometimes forensic bones have adhering soft tissues, which make direct observation of the bone difficult. The process of removing soft tissue can be done by different maceration techniques such as submerging in heated water (Lee *et al*. 2010; White *et al*. 2012).

1.4.5 Bodies Recovered from Water

Bodies recovered from water present their own particular challenges (Chapter 9). The first is to determine whether the cause of death is drowning, natural disease or injury sustained prior to immersion or while the body is in the water. If a body is recovered quickly, classic features such as the *champignon de mousse* (literally a mushroom of foam) and overlapping, crepitant, hyperinflated lungs (*emphysema aequosum*) may point to drowning as a cause of death, which may be altered by resuscitation attempts. The *champignon de mousse* is a very transient finding at the best of times, and has often disappeared by the time of autopsy if there is any delay between recovery of the body and examination. Sometimes the *champignon* is copious, and reappears as fast as it is wiped away; this can be very distressing when a body has been prepared for viewing by the relatives only a few minutes before. In the initial phase, bodies will tend to float if the water is sufficiently deep. Simple physics will usually cause the body to float face down with the limbs dependent. Far be it for the authors to disagree with literary genius, but forensic pathology would not appear to support the following contention by Aldous Huxley (Huxley 1933):

Second Philosopher's Song

If, O my Lesbia, I should commit,
Not fornication, dear, but suicide,
My Thames-blown body (Pliny vouches it)
Would drift face upwards on the oily tide
With the other garbage, till it putrefied.

But you, if all your lovers' frozen hearts
Conspired to send you, desperate, to drown –

Your maiden modesty would float face down,
And men would weep upon your hinder parts.

'Tis the Lord's doing. Marvellous is the plan
By which this best of worlds is wisely planned.
One law he made for women, one for man:
We bow the head and do not understand.

In shallower bodies of water, the knuckles and lower limbs may brush against rough surfaces and cause abrasion that may be misinterpreted by the unwary as evidence that the deceased had been beaten, or had made attempts at self-defence. Even with true, ante-mortem injuries, water will tend to wash away blood patterns associated with injuries. Post-mortem artefacts may occur if the body strikes solid objects causing fractures, and most pathologists who work near a body of water large enough for boating will be familiar with the regular, parallel incised wounds caused by the passage of a propeller across the body (Figure 1.5).

With time, bodies that are not recovered will sink. The thicker skin of the palms and soles will become waterlogged, giving a pale, wrinkled appearance such as may be observed in one who has overindulged in bathing or has undertaken household chores, giving rise to the description of washerwoman change (Figure 1.6). The skin of the hands and feet can slough in totality. Fingerprint impressions may often be recovered from the under-surfaces of these degloved digits.

In most cases the water in which the body sinks will be relatively cold and therefore acts to retard decomposition (De Donno *et al*. 2014; Mateus and Vieira 2014). However, this will also increase the time that the body is exposed to aquatic predators. Such creatures tend to focus on exposed areas

Figure 1.5 Propeller injuries. The regular, parallel-incised wounds are the result of the propeller passing over the body as the boat moves through the water.

Figure 1.6 So-called 'washerwoman change'. The waterlogged skin becomes wrinkled and may slough off. The sloughed skin can still be used to obtain fingerprints.

(often the hands and face), which causes significant difficulties in using the face for identification, and will obscure or erase injuries to the soft tissues of the face that are all too common in interpersonal violence.

A common finding in bodies that have undergone prolonged immersion or even burial is 'pink teeth'. In the case of *R v Christie* (1953), the pathologist insisted that this phenomenon was the result of poisoning with coal gas, but in reality the presence of such a change is of limited, if any, pathological significance. Middle ear haemorrhage is also common, but most likely results from hydrostatic pressure rather than drowning *per se*.

Although immersion in cold water will retard decomposition, it will not completely halt it, and eventually gas will be produced (as discussed above) that causes the body to become buoyant once again and to return to the surface. This is colloquially referred to as 'bloat and float', a somewhat distasteful but accurate description of what occurs. In flowing water, there may be specific places where bodies tend to be found, which may be many miles from where the body entered the water. Equally, a body may become entangled close to the place where it entered the water and may be found there. Bodies in tidal rivers may travel back and forth with the tide, but ultimately remain close to the point of entry into the water.

Many findings have been proposed as 'diagnostic' of drowning. In the authors' opinion most are, at best, spurious and at worst misleading. Probably the best-known test is to seek diatoms. Diatoms are silicaceous microorganisms and different species exist in different proportions in different bodies of water. Testing is predicated upon the principle that if an unbreathing body is deposited in water then the water, and by extension the diatoms in it, enters the lungs, but in the absence of an active circulation are not transported to distant organs. If, however, the person is alive, then diatoms enter the lungs, cross into the circulation and are deposited elsewhere in the body. This is said to confirm drowning, and the species and proportions of diatoms would, in theory, suggest in which body of water the person drowned. While there may be some merit in this, the question of whether a body entering water is 'diatom free' prior to the incident, the shortage of experts who can perform detailed analysis of diatom species, and the presence of such organisms in soil and even some toothpaste, to some extent undermine the utility of the test.

More recently, molecular biological methods utilising polymerase chain reaction (PCR) to identify bacterioplankton (Kakizaki *et al*. 2008; Rutty *et al*. 2015) have been developed and at least one trial has shown them to be useful in clinical practice. This method has the advantage of requiring less tissue retention and does not require organs to be dissolved in hot acid, a process that has implications in the era of Work Health and Safety (WH&S) rules.

1.4.6 Artificial Preservation, Burial and Cremation

Human beings interact with the dead, and these interactions have their own impact upon the dead. While a detailed discussion of cultural and religious practices is beyond the scope of this chapter, the changes caused by deliberate human actions are worthy of consideration and may have a bearing on the interpretation of findings (Green 2006).

These matters are extensively covered in 'Dealing with Death' (Green and Green 2006) and in 'Essentials of Autopsy Practice' (Rutty 2001, 2004), to which those interested should refer. The attitude to the dead is very much culturally determined, and it is self-evident that the mummified bodies in the ornate tombs of pharaohs in the Valley of the Kings in Egypt will produce post-mortem appearances that differ greatly from the findings in a cremated body or a body from a Zoroastrian 'Tower of Silence', where vultures cleaned corpses as part of a burial rite (Boyce 1979). This practice of disposal by exposure to aerial predators is fast dying out. The Indian vulture population has been decimated by the practice of treating cattle with non-steroidal anti-inflammatory drugs (NSAIDS). The birds, lacking the necessary liver enzymes, die shortly after feasting on the corpses of cattle so treated (Taggart *et al*. 2009).

In general, funerary practices tend to either hasten the breakdown of the body or retard it. The most destructive practice is probably cremation where, with a modern efficient crematorium, a body can be reduced to calcined bone fragments and ash in a matter of hours and leave next to nothing for an investigator to examine (Bohnert *et al*. 1998; Eckert *et al*. 1988; Ubelaker 2009) (Chapter 21).

On the other hand, preservation can allow relatively easy interpretation of findings. The most relevant practice with respect to deaths in the late 20th and early 21st centuries is the increasing prevalence of embalming. Introduction of chemicals can preserve bodies to a high standard for many years (such as the body of Vladimir Lenin in Moscow) (Aufderheide 2003), although in the authors' experience there is a considerable degree of variation in the quality of the embalming process. Although embalming tends to render bodies more firm and difficult to manipulate, the preservation of the surface of the body and internal organs can greatly assist in the assessment of injuries and disease even many months or years after death. However the embalming process may produce lesions that are important to recognise. Cannulae are often inserted into the carotid vessels or the axillae and groins to instil embalming fluid and therefore stitched incised wounds may be apparent at these sites. Similarly, a plastic 'button' may be present, particularly on the abdomen as the result of the injection of cavity fluid in the embalming process. Some embalming involves the introduction of a sharp cutting ended trocar that can leave large puncture wounds in underlying organs, particularly the liver or heart, and should not be misinterpreted as ante-mortem stab wounds. It should be borne in mind, that while embalming fluids vary in their composition, many contain not only formalin, but also ethanol and glycerine that will interfere with some post-mortem toxicological analysis (Chapter 20).

1.5 Skeletonisation

Eventually, many bodies are reduced to skeletal remains and at this point examination and interpretation moves towards the expertise of the (forensic) anthropologist. The time for this to occur varies greatly. The recovery of partial or complete skeletal remains is far from uncommon. For the forensic practitioner there are two questions of immediate significance, specifically whether the remains are human or non-human and whether they are recent enough to warrant a criminal investigation. The former issue is usually relatively simple, although the latter may be less so. As the PMI increases, bones tend to become lighter in weight and drier.

While it is self-evident that the loss of internal and external soft tissue will reduce the evidence available, skeletal features will be useful in determining features such as age class, sex and stature of the deceased. The presence of skeletal trauma may assist in determining a likely cause and manner of death, and other features including medical interventions following fractures, prostheses, and cosmetic or reconstructive dental work, may assist in identifying the individual. Isotope analysis can point to where in the world a person may have lived in his childhood. In the 'Torso in the Thames' case, when a young boy's torso was discovered in the River Thames (UK) in 2001, such analysis allowed investigators to identify an area in Africa where the deceased had lived, which is clearly of value in investigations involving decedents whose identity is unknown (Hoskins 2012; Sanders 2003).

A recent and well-publicised example of the information available from skeletal remains is the discovery of the body of Richard III (1483–1485), the last English king to die in The Battle of Bosworth, in Leicester (UK) in 2012. A range of forensic examinations has not only confirmed his identity but also provided a wealth of information regarding his appearance, life and ultimate death (Buckley *et al*. 2013).

As this chapter is being written, a new method for determining the PMI based on degradation of skeletal muscle has been published. Whether this is to become a vital weapon in the forensic armoury or another false dawn remains to be seen (Pittner *et al*. 2015) (Chapter 10).

1.6 Conclusion and Future Research

As alluded to earlier, there have been many efforts to utilise the changes affecting the body after death to elicit a PMI, but mostly these have met with limited success. It is generally agreed that many of the features that result from post-mortem changes are not sufficiently uniform or accurate to provide precise information regarding the PMI, and any estimates made on, for example, body temperature should be regarded as just that and include appropriately wide possible ranges. To the frustration of many forensic pathologists, examination of the body may ultimately lead them to express the opinion that the person died at some point between the last time that he or she was reliably known to be alive and the point where they are declared legally dead. More recently, taphonomic processes have been studied at facilities known as 'body farms', research facilities where relatively specific conditions can be recreated and used as experimental models. The first such facility was set up at the University of Tennessee in 1981, with additional facilities opening across the USA since then (Chapter 35). A similar establishment has been recently set up at the University of Technology Sydney in Australia called AFTER, Australian Facility for Taphonomic Experimental Research.

In the last few years, the 'virtopsy' approach, using radiological techniques to examine the internal structures of the body, has been the subject of considerable research in forensic medicine. Such an approach has some advantages, particularly for faith groups for whom an invasive autopsy contradicts their belief systems. The authors' view is that at present such an approach may be useful in some cases, but in homicidal deaths, while radiology often provides a useful adjunct, a traditional autopsy is still the most appropriate method of examination.

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