Forensic Anthropology: A primer for courts

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Forensic anthropology

A PRIMER FOR COURTS

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Forensic anthropology: a primer for courts
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The judicial primers project is a unique collaboration between members of the judiciary, the Royal Society and the Royal Society of Edinburgh. The primers have been created under the direction of a Steering Group initially chaired by Lord Hughes of Ombersley who was succeeded by Dame Anne Rafferty DBE, and are designed to assist the judiciary when handling scientific evidence in the courtroom. They have been written by leading scientists and members of the judiciary, peer reviewed by practitioners and approved by the Councils of the Royal Society and the Royal Society of Edinburgh.

Each primer presents an easily understood, accurate position on the scientific topic in question, and considers the limitations of the science and the challenges associated with its application. The way scientific evidence is used can vary between jurisdictions, but the underpinning science and methodologies remain consistent. For this reason we trust these primers will prove helpful in many jurisdictions throughout the world and assist the judiciary in their understanding of scientific topics. The primers are not intended to replace expert scientific evidence; they are intended to help understand it and assess it, by providing a basic, and so far as possible uncontroversial, statement of the underlying science.

The production of this primer on forensic anthropology has been led by Professor Dame Sue Black DBE FRSE. We are most grateful to her, to the Executive Director of the Royal Society, Dr Julie Maxton CBE, the Chief Executive of the Royal Society of Edinburgh, Dr Rebekah Widdowfield, and the members of the Primers Steering Group, the Editorial Board and the Writing Group. Please see the back page for a full list of acknowledgements.

Sir Adrian Smith
President of the Royal Society

Sir John Ball
President of the Royal Society of Edinburgh

1. Introduction and scope

This primer aims to present to the judiciary a scientific understanding of the role of the forensic anthropologist in criminal, coronial and fatal accident inquiries and humanitarian casework[1]. It outlines the types of analyses that a forensic anthropologist may undertake and will give guidance on the science that underpins the work of the forensic anthropologist, allowing an understanding of the strengths and limitations of their methods and critical findings.

The primer is set out in a number of sections, beginning with a general introduction and then moving on to the specific analyses that a forensic anthropologist is able to undertake: identification, trauma analysis and the changes that occur to a body after death, known as forensic taphonomy. It finishes with three short sections outlining specialist areas which some forensic anthropologists might be involved in, including age in the living estimations, craniofacial depiction and anatomical comparisons from images.

1. Forensic anthropologists can be involved in local, national and international criminal cases, fatal accident inquiries, coronial investigations, assisting with location and identification of the deceased after mass fatality events or identification of the disappeared after civil unrest such as occurred during the Spanish Civil War (1936 – 1939) and the Kosovo War (1998 – 1999).

2. Definition of forensic anthropology

Forensic anthropology can be defined as:

> "The study of humans using biological, social, and cultural anthropology to assist with the identification of the living and the dead, the recovery and repatriation of the deceased, and the interpretation of circumstances surrounding death." (Márquez-Grant and Roberts, 2021)

Forensic anthropologists have a detailed knowledge of skeletal anatomy, human variation and the many factors that can influence the appearance and properties of bone during life and after death. The forensic anthropologist applies this knowledge and the developed methods of analysis of bones of the skeleton to assist the courts.

2.1 The role of the forensic anthropologist

The role of the forensic anthropologist has traditionally focused on assisting in the identification of the deceased, in cases where the body is no longer recognisable, ie if it is extensively decomposed, skeletonised[2], incomplete, burnt or highly fragmented. This can occur in several different circumstances, which may be either non-suspicious or related to criminal activity. Forensic anthropological techniques can be particularly useful in cases where there is no presumptive identity, making it difficult to obtain reference deoxyribonucleic acid (DNA) samples or ante-mortem dental or fingerprint records. Anthropological methods are also helpful when remains are incomplete and no teeth or fingerprints are present, or in cases where DNA is badly degraded or destroyed, eg because of burning or embalming.

Research and development in other areas, such as taphonomy (the study of factors affecting the decomposition of human remains), facial approximation and recognition and estimation of age in the living, have widened the scope of the discipline and its applications to criminal, coronial and humanitarian investigations. Forensic anthropologists can also use their expertise in skeletal anatomy to assist with the interpretation of traumatic injuries that occurred shortly before or around the time of death (ante-mortem and peri-mortem) and post-mortem damage (deliberate or otherwise) which occurred after death. Some forensic anthropologists are also skilled in the analysis of burnt human remains or tool marks associated with dismemberment.

2. Relates to situations where there is loss of soft tissue and just the skeleton remains.

2.2 Forensic anthropology evidence

Forensic anthropologists often work in collaboration with other experts, such as forensic pathologists, odontologists, radiologists, entomologists, DNA experts and environmental scientists; although they each have their own unique set of skills, there are some areas where the scientific disciplines overlap.

There is a clear distinction between the forensic anthropologist and the forensic pathologist in the UK concerning the determination of a cause, or manner, of death. In some European countries, the forensic anthropologist may have a medical qualification and sometimes an additional qualification in forensic pathology. In the UK the forensic anthropologist generally has a doctorate (PhD) or Master of Science (MSc) degree in human anatomy, physical/biological anthropology, forensic anthropology or osteoarchaeology. This means that although it is legitimate for UK-trained forensic anthropologists to comment on the skeletal growth and development of a child, for example, or physically reconstruct fragmented remains and interpret peri-mortem modifications to bone (trauma) they are not qualified to determine a cause of death and should not attempt to do so since that is the sole remit of the forensic pathologist.

It is equally important that margins of error associated with techniques are made explicit. Many of the results derived from anthropological examinations are estimates; therefore, where appropriate, standard deviations[3], ranges and levels of scientific support should always be provided when they are based on peer-reviewed literature. An example might be stature estimation calculated from femoral length, where a typical result should be presented as 167 cm ± 3 cm (see Section 3.7). Another example would be an age estimate, based on the appearance of the sternal end of a rib, which should be presented as 24 – 32 years rather than as a single mean[4] value of 28 years (see Section 3.7).

3. Standard deviation measures the dispersion of a dataset relative to its mean.
4. The mean is the mathematical average for two or more numbers.

2.3 Qualifications, competency and regulation of forensic anthropology

In May 2018, the Royal Anthropological Institute of Great Britain and Ireland (RAI) developed, in association with the Forensic Regulator of England and Wales, a Code of Practice for Forensic Anthropology[5]. At the core of the Code of Practice lies the requirement to demonstrate competency as stated in Section 5.1.1:

> "5.1.1 Forensic Anthropologists must maintain professional expertise and demonstrate continued competency in each of the categories in which they practice[6] for example through relevant certification and recertification (by an appropriate professional body for example the Royal Anthropological Institute or the Chartered Institute for Archaeologists) and record continuous professional development and current practice within the field."

The Code also emphasises the need for peer review:

> "5.1.2 Forensic Anthropologists must have systems in place to enable peer review/critical conclusions check of all casework reports prior to submission[7]."

The certification scheme provided by the RAI[8] divides practitioners into levels of competency, which enables the judiciary (and those wishing to engage the service of a forensic anthropologist) to confirm the level of experience of the practitioner and also predict the likely limitations of their knowledge. The three levels of seniority are summarised below:

- Chartered Forensic Anthropologist (Ch FA) – The highest level of certification. These are highly experienced practitioners who have courtroom experience.
- Forensic Anthropologist II (Cert. FA-II) – This level includes practitioners who have evidenced competence in both their practical and theoretical knowledge of forensic anthropology. They may not yet have given evidence in a courtroom, but they will be mentored by an FA-I to assist them in this regard.
- Forensic Anthropologist III (Cert. FA-III) – The practitioners in this level have evidenced that they have some experience and knowledge in the field of forensic anthropology. They may not have yet had real field experience of a case, but they will be mentored by either a Chartered Forensic Anthropologist or a Cert. FA-II. Cert. FA-III practitioners are not sufficiently experienced to give evidence in court.

5. https://www.gov.uk/government/publications/forensic-anthropology-code-of-practice (accessed January 2022).
6. See Section 4 of the Code of Practice for Forensic Anthropology.
7. See Section 7.3 of the Code of Practice for Forensic Anthropology.
8. https://www.therai.org.uk/forensic-anthropology (accessed January 2022).

3. Identification of the deceased

Forensic anthropology involves the identification and analysis of the human skeleton from the early stages of development in utero through to adulthood and old age. Forensic anthropologists work with both complete and incomplete human remains and with remains that are disrupted (where a body/body parts have become separated and scattered). The forensic anthropologist will create what is termed a 'biological profile' to aid in the personal identification of an individual. As a core set of observations, the biological profile includes, where feasible, the estimation of population of origin[9], biological sex, age at death and stature of an individual. More individualising features can include information about disease, past injuries, congenital abnormalities, surgery and dental treatment or bone anomalies[10] that could be recorded in ante-mortem medical records. While, most of the time, forensic anthropological analyses are undertaken through direct examination of the bones, it is also possible for this to be supplemented or replaced by analysis of radiographs, computed tomography (CT) or magnetic resonance imaging (MRI) scans of the skeleton.

3.1 Triage

Forensic anthropologists analyse human bone in situations where:

- bone is suspected to be of interest to a forensic (medico-legal) investigation;
- the identification of individuals is required, eg following a mass fatality incident, non-suspicious and suspicious deaths, especially where normal identifying features, such as fingerprints, have been lost through decomposition, thermal damage or fragmentation;
- interpretation of alteration to bone requires opinion, eg burned remains, dismembered remains or analysis of trauma.

Assistance from forensic anthropologists is required to help answer the following questions:

- Is it bone?
- If it is bone, is it human?
- If it is bone and it is human, is it of forensic significance?

9. Also known as ancestry/ancestral origin or geographical region of origin.
10. Bone anomalies: areas of bone overgrowth or malformation.

3.2 Is it bone?

For undamaged bones, the first two questions are usually straightforward since skeletal material is recognisable for those with experience as complete bones have specific shapes that allow them to be classified with confidence and separated from other materials of non-human origin. It is vital that the forensic anthropologist has experience of juvenile skeletal remains as these can appear very different from mature, adult bones. This first stage of triage becomes more difficult when bones have suffered thermal damage and/or fragmentation. Usually, even small fragments of bone are recognisable to the experienced forensic anthropologist, although, if any doubt exists, chemical analysis or histological analysis (examination of thin sections of bone under a microscope) can be utilised. However, testing of this type is destructive, which can result in loss of the entirety of the bone if only a fragment was in existence, leaving little or no material upon which to undertake any further analysis. As a result, any non-destructive analysis should be carried out before the use of destructive analysis techniques.

A forensic anthropologist will also be able to classify human teeth, but a detailed analysis of these would fall within the remit of the forensic odontologist.

3.3 Is it human?

Fragments of human bone can be differentiated from non-human bone if distinguishing features are present on the fragment. Bones have varying shapes that are linked with the functional role they play within the body. These shapes are influenced by biomechanical forces and the actions of muscles on the bones and these leave distinguishing marks which differ between humans and other animals. This allows whole bones and bone fragments to be linked to a species if these features are present.

To separate non-human from human bone fragments where there are no distinguishing features is a more difficult task. Therefore, additional techniques such as histological analysis, may assist. The overlap that exists between human and non-human bone histology can mean that it may not be possible to determine origin with any degree of certainty, meaning that the analysis of a bone fragment can be taken no further than confirmation that the fragment is indeed bone. If the bone or bone fragment is identified as human bone, the question arises as to whether the bone is of interest in a forensic enquiry. This may be obvious, for example in circumstances where the bone is associated with the single victim of a fatal fire.

3.4 Determining forensic significance

Human remains that are considered by the medico-legal community to require investigation are of forensic significance.

In the UK, human remains that are not of forensic significance are uncovered regularly. Commonly remains from individuals who died more than 70 – 100 years before the present date are considered to be outside the remit of a forensic investigation. There are no forensic anthropological methods for precise dating of skeletal remains although the use of radiocarbon dating, a method that uses the properties of the radioactive isotope of carbon to determine the age of an object, can give a broad date for archaeological bone.

Forensic anthropologists also become involved in humanitarian work, such as assisting in the recovery and identification of the disappeared after civil unrest and the identification of victims of mass fatality events.

3.5 The scientific underpinning

The methodologies utilised for the creation of a biological profile are based on an understanding of development, anatomy and pathology of the hard tissues of the body. The methods have been developed during the study of skeletal remains of known provenance where their population, sex, age at death, stature and any other pertinent information were all recorded at the time of collection. None of the methodologies utilised are without error. Skeletal changes are impacted by health, occupation and access to resources, diet and medical care, which means that there can be variation both within and between populations; this is known as secular trend. Many of the skeletal collections used to create the methods employed belong to past populations, who will have experienced different access to medical care and a different dietary intake; for example, many of the individuals in older collections grew to adulthood in a time before antibiotics were identified and used medically. These differences in backgrounds have the potential to cause error when these methods are applied to individuals from a modern and/or different population. Many of these standard methods for creating a biological profile have been re-tested on modern populations, however, so the error rates of the methods are known in these cases and should be presented within the anthropological report.

3.6 Accuracy[11] and reliability of metric versus morphological techniques

There are arguments both for and against each of the two methodological approaches. Morphological techniques[12] are subjective and reliant on the experience of the forensic anthropologist undertaking the assessment, although efforts have been made to standardise these observations through clear illustrations of examples. It has been argued that metric techniques[13] largely circumvent this, being more objective and qualitative. However, metric methods are not without their specific issues since the landmarks on bones are not always clear, or indeed present if remains are incomplete. Although descriptions do exist for the location of these landmarks, often their exact location is a matter of experience and is based on the subjective decision making of the anthropologist. Research has been undertaken to demonstrate whether a metric approach is more accurate than morphological techniques. Currently, the two approaches are believed to be generally comparable in accuracy and error rates (see Section 3.3 for some examples); however, for sex and population estimations from the skull this is not always the case since the underpinning metrics are not always based on comparable populations. For both methodologies, greater experience on the part of the practitioner will give better accuracy and reliability for all methods (Lewis and Garvin, 2016, Stewart, 1979) and it is usual for practitioners to use a combination of both approaches when undertaking their analysis, depending on the circumstances and their professional judgement.

Currently there is no single agreed method of presenting strength of opinion in forensic anthropological reports and this will vary according to training and the analysis being undertaken, and methods include use of strength of support statements (Providers, 2009).

11. Accuracy: the degree to which the result of a measurement, calculation or specification conforms to the correct value or a standard.
12. Morphological techniques are based on the variation in the shape of a bone, for example there are differences in shape between the pelvis of a male and a female that assist with the assessment of sex.
13. Metric techniques refer to methods that utilise measurements between different landmarks on bones to assist with assessments.

3.7 Estimation of a biological profile

The three primary identifiers, as determined by Interpol standards, are DNA, fingerprints and dental records. The ability to utilise these is dependent on the state of preservation of the remains (eg loss of soft tissue through decomposition will result in loss of fingerprints) and the ability to locate ante-mortem samples for comparison. None of the parameters that are estimated in a biological profile are considered primary identifiers. Despite this, an initial analysis by the forensic anthropologist can assist the investigating authority by providing information that will give the police a starting point to begin the search of missing persons records and potentially contact families for DNA reference samples or other ante-mortem records, if these have not already been sourced. Interpol also classes information such as evidence of previous fractures as secondary identifiers, which may also support the identification of a victim. There are no UK national identification databases, although criminal and missing persons DNA databases and criminal fingerprint databases exist.

3.7.1 Population of origin

The determination of broad population of origin within forensic anthropology can be estimated through differences in details and shapes of the skull and mandible (Hefner and Linde, 2018) or craniometrics (see Section 6.1). Population estimation can be 90% accurate (Thomas *et al.*, 2017) where broad population classifications, such as European, African and Asian, are utilised, although greater specificity may not be possible as, with population movement, increased intermingling between populations is eroding population differences.

3.7.2 Biological sex

The biological sex of the individual refers to the sex of an individual as determined by their X and Y chromosomes. It is different from gender, which is a social descriptor that may not be reflected in the skeleton of an individual. Sexual dimorphism (differences in the skeleton that relate to sex) occurs between male and female skeletons largely as a result of the changes that occur at puberty. It is not possible to assign sex to pre-pubescent individuals accurately without the use of DNA. Biological sex can be estimated using the shape (morphology) of several bones of the skeleton with the skull, pelvis and humerus giving the most accurate estimation. If metric analysis is being utilised, the pelvis and humerus give the most accurate estimations (see table below). The sexually dimorphic features of the human skeleton sit along a continuum, which can make estimation of biological sex challenging for those individuals where the features are not strongly male or strongly female; for this reason, all available features should be included to come to the most accurate conclusion.

TABLE 1

Examples of the accuracy of biological sex estimation using morphological and metric methodologies.

Bone[14]	Accuracy of biological sex estimation (morphological)
Pelvis (Bruzek, 2002)	95%
Skull (Garvin *et al.*, 2014)	85 – 92%
Humerus (Falys *et al.*, 2005)	92%
Bone	**Accuracy of biological sex estimation (metric)**
Pelvis (Ubelaker and Volk, 2002)	88%
Humerus (Rissech *et al.*, 2013)	89%

14. References included here are examples only and each forensic anthropologist will choose supporting references that are most applicable for their analysis, depending on the population of origin of the individual as well as the completeness of the remains (full skeleton, partial skeleton, fragmentation, etc).

3.7.3 Age at death

Age at death is assessed by identifying physiological changes that occur on the skeleton and relating them to chronological age. The physiological changes are influenced by factors such as lifestyle, genetics and health; therefore, age at death for both juveniles and adults is given as an age range due to the variation that exists in the timing of the physiological changes of skeletal development/deterioration between individuals. Owing to the cumulative effect of this variation, the age ranges used for adults are much larger than for juveniles.

Age at death in juveniles is calculated by observing the maturational changes that have occurred in the juvenile skeleton. As bones develop, they change in size, shape and appearance, and it is these changes that are assessed. Children develop at different rates (eg because of genetic make-up, health and dietary intake) and therefore ages are given as an age range that takes the maturational changes observed into consideration.

Age at death in adults is mostly calculated by assessing the degree of deterioration that occurs at specific areas of the skeleton as a person ages, including identified areas on the pelvic bones and the ends of some ribs. These changes are influenced by diet, health and lifestyle; therefore, there are individual variations in the rate of these changes.

3.7.4 Stature

Finally, stature is assessed by measuring the length of specified long bones within the body. These measurements are entered into population- and sex-specific equations to estimate living height. These stature estimations are presented as a mean with a standard error[15], which gives the range of the probable stature. This range is usually about 4 inches (10 cm), although it varies by population and method used (Wilson *et al.*, 2010).

TABLE 2

The estimated age ranges possible at the different stages of life of the individual.

Life Period	Age range
Fetal (Cunningham *et al.*, 2016)	The age range can be estimated within a range of weeks
Birth to late teens (Cunningham *et al.*, 2016)	The age range can be estimated within a range of months to years
Adulthood (Ubelaker and Khosrowshahi, 2019)	The age range can be estimated within a range of decades

15. Standard error – is the approximate standard deviation of the sampling distribution of the mean.

3.8 Commingling

Commingling refers to situations in which the remains of two or more individuals have, through fragmentation or decomposition, become mixed or where human material has become mixed with non-human skeletal material. This may occur where multiple bodies have been deposited together (mass grave) or after a mass fatality event such as a plane crash or explosion. The role of the forensic anthropologist in these situations is to: (1) separate non-human from human material; (2) determine the minimum number of individuals present (MNI) or the most likely number of individuals (MLNI); (3) identify those individuals who are present (providing a biological profile as necessary); and (4) reassemble each set of remains as far as possible to ensure that the commingling is resolved.

The gold standard for the re-union of fragmented remains is DNA analysis since this allows all body parts that belonged to one individual to be matched to each other. However, DNA testing can be impacted if there is a significant volume of fragments; the number of tests required overcomes local laboratory capacity; and/or there is significant contamination or degradation. In addition to this, DNA testing is both expensive and destructive, such that a small piece of tissue could be completely consumed during the testing process. Combining DNA analysis with forensic anthropological techniques that allow body parts to be matched anatomically can often be a more cost-effective approach. In the UK, findings from anthropological examinations would always be underpinned by DNA testing, unless a body part or fragment was not suitable for analysis. Examples where this might be the case include thermal damage to the point where no organic[16] matter survives, destruction of DNA by aviation fuel or use of a preservative such as formalin which results in damage to DNA.

3.9 Fragmentation

Bones can become fragmented as a result of exposure to heat, explosions or trauma, or through events that happen after death, such as animal scavenging, weathering or exposure to soil chemistry. The recognition of fragments as bone has already been addressed in Section 3.1. If the bone fragment is sufficiently large, it may yield a DNA profile. However, exposure to high or prolonged temperatures degrades DNA so this might not be possible. If a DNA profile cannot be extracted from the bone and there are no recognisable landmarks on the bone fragments, it is possible that no further conclusions can be drawn, other than that the material is bone.

16. The organic compounds in the human body are those that are carbon based, the most common are carbohydrates, proteins, lipids and nucleotides.

4. Trauma analysis

Trauma analysis focuses on the examination of skeletal injuries, such as fractures, projectile entry and exit points and tool marks. It is an essential part of forensic anthropology training; therefore, all forensic anthropologists should be able to provide a general opinion, for instance, on the timing (ante-, peri- or post-mortem) or type (sharp, blunt or ballistic force) of injury. Trauma analysis furthermore requires concomitant knowledge of the surrounding soft tissues such as skin and muscles and is often done in close collaboration with a forensic pathologist.

Trauma analysis is often based on observations with the naked eye. This can be supplemented and sometimes even replaced by the use of medical imaging techniques such as conventional radiographs, CT and sometimes MRI scans, especially where soft tissue is still present. In a limited number of cases, microscopic analysis (microscopy) might also be used and this would require the forensic anthropologist to be specifically schooled and experienced in this type of analysis.

4.1 Factors complicating trauma analysis

Trauma analysis is usually complex, with many (un)known variables affecting the extent and shape of the skeletal injury. Among others, the direction and speed of the applied force must be considered. Bone tissue is more suited to withstanding compressive (pushing) forces than tensile (pulling) forces, and, because of its elastic properties, bone tissue is more suited to resisting slow loading forces than high-velocity impacts (such as bullets). The trauma pattern is also highly dependent on the shape, size and composition of the affected skeletal element. Lastly, the age of the affected individual is an important variable because, as a rule, juvenile bones are more elastic than adult bones. Incomplete fractures are therefore more common in juveniles than in adults. This, however, does not imply that children's bones are more resistant to trauma than those of an adult.

4.2 Time of trauma

There are three time periods in which a skeletal injury can be placed: the ante-mortem period – preceding death; peri-mortem – around death; and post-mortem – after death. Differentiation between these is ordinarily based on an assessment of the following features.

4.2.1 Ante-mortem trauma

Ante-mortem trauma is defined by signs of vitality, eg a physiological response of the body to the injury. Such a healing response only occurs in living individuals, and thus signs of healing define ante-mortem trauma. In non-skeletonised material, ante-mortem trauma may be more easily distinguished from post-mortem trauma based on bleeding and inflammation responses. Such signs are, however, no longer available in skeletonised material. The earliest signs of healing that are visible with the naked eye require at least multiple days to develop, when the body starts to deposit new bone material (callus) (Galloway *et al.*, 2014). Even using microscopy, such signs require at least a few days to develop and be recognised. This means that, unless an individual survived an injury for some time, it is generally not possible for a forensic anthropologist to definitively assess a trauma as having occurred ante-mortem.

Since the healing response of the body follows a strict sequence, studying its stage of progression may allow for an opinion on the time that has elapsed between the traumatic event and death. Such information may be used to provide evidence or refute specific statements on the timing of the injury, eg in child abuse cases. It should, however, be noted that such statements require specialised knowledge of the complex process of bone healing, as numerous and partially unknown variables (eg age, health status, trauma type) all influence the rate of the healing response. Any estimation of a survival time should always stress these uncertainties. Being so complex, the investigation should generally include a combination of macroscopic (visual examination), radiological and microscopic analyses.

Bone from the recently deceased has some elasticity because of the organic components embedded in the hard, calcified matrix. This can result in specific fracture patterns called a ‘green bone response’, reminiscent of the way fresh twigs break untidily compared with the clean snap of dried twigs.

4.2.2 Post-mortem damage

When bone tissue deteriorates after death, the organic component slowly diminishes, resulting in less elastic and more brittle bone tissue. Damage can be defined as post-mortem when it shows specific features that testify to this brittle state. The time that it takes for this to occur will vary from weeks to months depending on the circumstances of deposition of the body. Another sign that may be regarded as evidence of post-mortem damage is differential decay, ie when the fracture margins show less discolouration than the rest of the bone.

4.2.3 The peri-mortem period

When a forensic anthropologist states that trauma is peri-mortem, this means that it cannot be attributed to either the ante-mortem or post-mortem period. Usually, this means that the bone still had sufficient elasticity to present a 'green bone response', but no signs of healing are visible. As the loss of a green bone response is gradual, and signs of healing might not be readily visible, some cases might be very challenging to classify. It should be noted that the meaning of the term 'peri' differs depending on whether it is used by forensic pathologists or forensic anthropologists. For forensic pathologists, it describes an event that occurs in very close temporal relation to the moment of death. For forensic anthropologists, the time frame can be much wider.

4.3 Types of trauma

Skeletal injuries present in a wide variety of ways, which are generally grouped according to the speed and surface of the applied force. Although these categories may seem distinct, and usually categorisation poses no problems, overlap does exist.

4.3.1 Ballistic trauma

Ballistic trauma is a high-speed injury caused by a projectile. The most obvious example is a gunshot injury, but any fast-moving, relatively small object might serve as a projectile. In ballistic trauma, the high velocity of the projectile causes penetration and/or shattering of the bone tissue. The remaining defect, especially when in flat bones such as the skull or the pelvis, allows for a reconstruction of the direction of the projectile. This is because an entrance wound will almost invariably be smaller than an exit wound. The outward tapering of the skeletal defect, also called 'bevelling', shows the direction of the projectile. However, one cannot determine the calibre of a projectile based on the skeletal analysis.

4.3.2 Sharp force trauma

Sharp force trauma is skeletal damage inflicted at a relatively low velocity (compared with ballistic trauma) by an edged, pointed or bevelled tool. Examples are knife cuts or saw marks. In these types of trauma, it is usually possible to ascertain the class of implement used (eg knives, hatchets, saws). A more detailed identification of the implement (eg an electric versus a hand saw) is more difficult. Linkage of a mark on the bone to an individual tool is in all but very rare cases not possible for a forensic anthropologist. It is possible to clarify the directionality of force and type of movement (eg cutting, hacking, sawing) that occurred. In cases of dismemberment this may give information on the placement of the victim relative to the perpetrator at the time of the event(s).

4.3.3 Blunt force trauma

Blunt force trauma generally constitutes the most frequent group of traumatic injuries, as it relates to all mechanical forces inflicted with a relatively large blunt object or surface. Injuries from falls, impacts, traffic accidents, etc are included in this group. Study of the extent and patterning of the skeletal injury(s) can allow for reconstruction of the direction of a force. Some fracture patterns may suggest a specific traumatic event. An example would be the typical fracture patterns seen in a fall from a height and landing in a standing position. Ordinarily, this results in fractures of the calcanei (heel bones), tibial plateaus (upper parts of the shin bones), acetabulae (hip sockets) and lumbar vertebrae (spine of the lower back).

4.4 Elements of trauma analysis

For all three groups of traumatic injury, a forensic anthropologist will consider the number of impacts as part of their assessment. It should be noted that this only relates to the number of impacts that affect the skeleton, and not the body as a whole. For ballistic and sharp force trauma, the number of impacts is usually quite exact. For blunt force trauma, especially in complex patterns, it might not be possible to make a statement beyond a minimum number of impacts.

In multiple injuries to a single location on the skeleton (eg skull), the order of impacts can often be determined by the application of Puppe's Rule (Viel *et al.*, 2009). This states that any second or subsequent fracture line usually ends at a previous one, rather than crossing it. This is because the mechanical force of the second blow will follow the path of least resistance, and thus dissipate when it encounters a previous fracture. Especially in the skull, this makes it possible to determine with some confidence which fractures occurred first, and which were subsequent.

It should be kept in mind that the more complex the trauma pattern, the less confident is the assessment of directionality, number of impacts, etc. It is also important to recognise that skeletal injuries do not happen in isolation: the effect of injuries to the surrounding soft tissues (eg muscle, nerves, blood vessels) must always be considered. Ideally, the forensic anthropologist should collaborate closely with a forensic pathologist, radiologist and/or clinical specialist.

In cases pertaining to non-accidental injury in children, trauma patterns may be presented as critical evidence in courts and used to refute or support statements by witnesses or suspects. As juvenile bone is different from adult bone, such cases require specialised knowledge of paediatric fracture patterns, paediatric behaviour and the biomechanics of juvenile bone. If this precondition is met, the provided opinion can be as detailed in juveniles as it is in adults.

In both paediatric and adult cases, it is not possible to make an exact statement on the amount of force required to produce a specific trauma.

4.5 The analysis of burned bones

A distinct group of traumatic injury is presented by the burning of bone (thermal alteration). The shielding effect of surrounding soft tissue ensures that thermal alteration of skeletal elements is almost invariably a post-mortem phenomenon, since there are hallmarks of 'fleshed burning' which indicate if the skeleton was covered by soft tissue or not at the time of exposure to fire.

With increased heat, the moist, organic and inorganic[17] components of bone tissue will vaporise or be altered in a fixed sequence. This results in a progressive discoloration of the bone, from pale yellow to brown, black and then ash grey/white. Blackened bone is also referred to as 'charred', whereas ash-grey bone material is also called 'calcined'. The discoloration is not only dependent on temperature but also on the shielding effect of soft tissue, oxygen availability and the duration of the exposure to heat.

Apart from discoloration, bone becomes progressively brittle and shrinks with increased heat. This may cause fragmentation and destruction of parts of the skeleton and the occurrence of heat-induced fractures in the remaining skeletal elements. These heat-induced fractures must be differentiated from other types of peri-mortem trauma. The latter may survive the incineration but become much harder to recognise as the thermal damage becomes more extensive.

17. Inorganic compounds and elements in the human body are any that do not contain both carbon and hydrogen and include water, iron and magnesium.

Thermal alteration will complicate any subsequent analysis of the skeletal remains. Nevertheless, identifying skeletal features may be possible in even the most heavily burned remains. The examination of burned remains by a forensic anthropologist can be pivotal for identification, especially since charred and calcined bone may no longer yield sufficient intact DNA for analysis. The forensic anthropologist is also able to advise on whether a burned body part may be suitable for DNA analysis by making an informed assessment of the possibility of survival of organic material in the bone.

The overall pattern of thermal alteration may be used to determine the state of the remains directly before the fire. If an intact body is burned, the pattern of thermal alterations is reasonably predictable, with the greatest degree of alteration usually seen in the bones of the skull, feet/hands, shins and forearms. In contrast, shielded areas such as the joint surfaces of the knees or hips are usually much less affected by the fire or may even remain unaltered. If the fire affected an already skeletonised individual or disarticulated remains, the burning pattern is more haphazard and no tissue shielding is observed.

5. Forensic taphonomy

5.1 What is forensic taphonomy?

Forensic taphonomy relates to the modifications and alterations that occur in a biological organism between the time of death and recovery of remains. This scientific field aims to recognise and document the ecological, biological and physical context and processes involved in body decomposition, to estimate time since death and to determine unusual patterns of dispersal or removal of evidence or remains that can provide indications of human or animal intervention.

5.2 Evaluation of the time since death interval

Understanding taphonomic processes that result in decomposition and disarticulation is crucial to evaluating time since death. A large number of intrinsic and extrinsic factors influence the decomposition process, such as body characteristics (age, sex, body mass, trauma, state of the body at death, clothing, etc), environmental characteristics (soil, water, weathering, etc), and location (grave, aquatic context, surface deposition, etc). Furthermore, post-mortem skeletal changes occur when there are chemical, physical or biological alterations to the bone tissue after its initial deposition or burial. These alterations occur as a result of interactions between soil, water, weather conditions, transport, bacteria, insects, scavengers and many other agents which cause structural damage to the bone.

Insects play an important role in decomposition and forensic entomology (the study of necrophagous species of insects associated with the corpse) can be used to assist with determining the early post-mortem interval (first day to several weeks after death). Thereafter, for highly decomposed or skeletonised remains, estimation of the time since death interval is based on knowledge of decomposition patterns and generalised taphonomic processes, combined with information on the specific location/context. The assessment of bone diagenesis, which are the chemical and physical changes that bone undergoes after death, by microscopical techniques (scanning and micro-CT, histology) or chemical analysis (eg collagen quantification) can greatly contribute to the evaluation of the time since death interval (TDI). Since bodies can remain in situ for years, time since death can only ever be an estimation, often spanning months or years, and is only used as a guide for investigators.

5.3 Scavenging/post-mortem damage

A wide range of post-mortem damage can occur to human remains, especially in outdoor scenes, and this can cause damage that can be misinterpreted if not correctly identified. Insect activity and carnivore scavenging critically contribute to disarticulation and dispersal of remains and often result in characteristic damage to bone. Animal chewing can also obscure evidence of trauma, and some fractures may be difficult to interpret as a result of the damage caused. For example, tooth marks can be misinterpreted as cut marks, so care should be taken to ensure accurate identification of the marks left on bone. Weathering patterns are bone modifications caused by the environment and include direct exposure to the sun, rain, soil and root growth, which can also result in bone breakage. Roots can also leave characteristic marks on bone that can be misinterpreted as cut marks by less experienced forensic anthropologists. In addition to these factors, human intervention is also considered to be a taphonomic agent as a perpetrator may alter or move the body of the victim to avoid detection, inhibit identification and hide evidence (eg dismemberment).

5.4 Methods, scientific basis and limits

Most research in forensic taphonomy focuses on determining the probable rate of post-mortem change to the body according to the environment in which it was deposited (depositional environment). Knowledge of decomposition processes is primarily based on exposed human remains from forensic contexts or experimental studies of non-human carcasses. Several scientific references based on forensic cases and laboratory experimental research, including disarticulation sequence tables, which relate the order in which body parts separate from the corpse over time, can be useful resources to estimate time since death. Scoring systems to quantify the progression of decomposition by assigning them a score which can be related to time since death are also available. The time it takes for a body to skeletonise is highly variable and context (microenvironment) specific, so it is not possible to extrapolate results directly from studies which have been carried out in places such as taphonomic facilities (known colloquially as 'body farms') to other geographical areas. Establishing the time since death is heavily context-based and therefore is an estimation that often spans months and years and is used only as a guide for investigators.

6. Niche areas of work

Some forensic anthropologists have additional skillsets and the following are examples.

6.1 Craniofacial analysis

Craniofacial analysis is most often used when other avenues of investigation have not secured an identification, as it may provide the police with a depiction of the deceased individual to use in an appeal for information to assist with the identification process. Craniofacial specialists may utilise skeletal and/or soft tissue information to create a facial depiction that can be used by the police during their investigation. These are not exact depictions of the individual while alive but reflect their features to the extent that the image may be recognised by a loved one. A variety of material may be analysed, including three-dimensional scans, photographs and direct measurements or visual assessment of the human remains, and craniofacial specialists will often refer to other anthropology, odontology and pathology reports to collect as much information as possible relating to the facial appearance of the individual (Wilkinson and Rynn, 2012). In some circumstances, analysis may include craniofacial superimposition, where the skull is compared with ante-mortem images of a missing person to ascertain the potential for an identification prior to DNA or dental identification.

6.2 Anatomical comparison techniques

Some forensic anthropologists undertake a comparison of anatomical features from images. This is most frequently employed in the investigation of indecent images of children (IIOCs),where images may only contain part of the anatomy of the victim or perpetrator, such as their hands. Anatomical comparison can be undertaken between these images and images of the victim or suspect to identify commonalities in stable anatomical features between the two sets of body areas (Black *et al.*, 2014). As an emerging technique, research is still ongoing to determine the error rates for these techniques. The method is based on known anatomical differences and utilises the translation of information from the anatomical, biometric and identification security industries and was first transferred to the forensic arena in 2006.

6.3 Estimation of age in the living

This is undertaken by the forensic anthropologist through utilising imaging techniques of radiography, CT and, increasingly, MRI to visualise skeletal areas of the body. This allows an assessment of the degree of skeletal maturation that has occurred, which is then related to a chronological age range. Areas of the body that are most frequently used are the hand/wrist and the medial (inner) end of the clavicle (collar bone), depending on the claimed age and suspected age of the individual being assessed, although other areas such as the knee or foot/ankle can also be used. As with other age estimation techniques, ages are given as a range which varies depending on the area of the body, but which usually is at least ± 1 – 1.5 years (Ekizoglu *et al.*, 2015, Krämer *et al.*, 2014). Age estimation from dentition is also usually performed at the same time by the forensic odontologist.

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