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The link between traumatic injury in soft and hard tissue

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Abstract

Forensic pathology and forensic anthropology are inherently related fields. The observations made during the autopsy and the conclusions from the anthropological analysis highlight the complementarities between the two approaches. In this review, gunshot wounds, sharp force injuries, chop wounds, blunt trauma, burned bodies, mechanical asphyxia and dismemberment will be analyzed from both perspectives. The result of this systematic review is that the conclusions stemming from the presence or absence of bone injuries must be very cautious because the observation of severe bone lesions does not always mean that this trauma was the cause of death; conversely, traumatic death, and even homicide, can be associated with a complete absence of bone lesions.

Keywords

Forensic pathology; forensic anthropology; forensic trauma; autopsy

I Introduction

Forensic pathologists attempt to solve cases based on the analysis of multiple clues, including, but not limited, to autopsy and osteological data. Bone injuries occur in more than 70% of homicides [1]. Forensic anthropology analyzes whole skeletons, but also partial skeletons or isolated bones (e.g., skulls or mandibles) found in various forensic circumstances. In European countries, forensic pathology and forensic anthropology are often performed by forensic pathologists, but this is not always the case on other continents. Forensic anthropology can prove very useful when dealing with bodies or body parts altered by decomposition, adipocere, drowning, charring, dismemberment, and/or mutilation. Solving these complex cases requires going through the entire autopsy process (photography, X ray examination, dissection, multiple sampling for toxicology, histopathology, DNA etc.) before starting on the anthropological analysis. Forensic departments perform several hundreds or even thousands of autopsies per year. When required, seasoned practitioners prepare autopsy bones for anthropological analysis, either by preparing entire remains in cases of badly altered bodies (a long and difficult process that can prove very useful in some suspicious cases), or by

preparing certain bone areas sampled from autopsy(e.g., a bone injury by a gunshot wound or a sharp force injury).

The goal of wound analysis is always to try to understand the cause of death but also the manner of death and the circumstances surrounding the death. The circumstances surrounding the death are often the main points debated in Court. A bullet that travels through a skull is probably certainly the cause of death, but the circumstances of death may be more challenging to ascertain with any degree of certainty.

There are links between soft tissue lesions observed during the autopsy process and hard tissue lesions observed during the anthropological process that will be outlined in the following paragraphs. This review aims to be a general discussion from some practical forensic cases in order to debate the evidence and pitfalls when comparing lesions on soft tissue (particularly skin) and bone. 12 forensic cases have been selected from our Medical Examiner Office for this aim. The information provided by the skeletal analysis complements the information obtained through autopsy and provides excellent photographic documentation for use in Court. Occasionally, anthropological analysis provides no further information. In these cases, the forensic pathologist and anthropologist must take the absence of further information into consideration when interpreting the available facts.

II Gunshot wounds

Autopsies of victims of gunshot wounds can be very challenging because of the multitude of weapons, projectiles, velocities, and unique features of each situation. All forensic pathologists have encountered complex situations in their daily practice.

Entry and exit wounds

Typical skin entry wounds are easily observable [e.g, 2]: they are clear, of punched-out appearance and display an abrasion ring. At close range, black residue is observed in skin entry wounds, corresponding to burned skin and gunshot residue. At an intermediate range of no more than 1m or 1.20 m, tattooing is the hallmark and at a range beyond this distance, the abrasion ring is the best indicator of a skin entry wound. Gunshot entry wounds cannot be interpreted without examining the pieces of clothes of the victim.

Skin exit wounds [2] are usually larger and more irregular than the entrance wound. There is no black aspect around the hole of exit wounds, except in cases where the body was leaning on a hard surface like a wall or the floor.

Sometimes, stating which wounds are entry wounds and which are exit wounds can be quite challenging. Atypical skin gunshot wounds are frequent. The abrasion ring is not always obvious nor even present, the entrance wound may be larger than the exit wound, and the entrance wound can be irregular [2]. Additional elements are required in order to move the investigation forward. Metallic bullet particles (lead, antimony, copper) may be detected on the entry skin wound by energy dispersive X-ray spectrometry [3]. Histopathology may show gunshot residue (soot and metal particles) in entrance wounds. Scanning electron microscopy can detect powder particles and determine the composition of metal particles in the skin entrance wound.

In particularly difficult cases, anthropological analysis is indispensable to settle these issues. Typical entrance wounds in the skull are round or oval, clear, regular, of punched out appearance, and above all display internal beveling (that is to say an enlargement in the direction of travel of the projectile) [4]. Exit wounds are irregular, usually larger than entry wounds, and display an external beveling [5]. Frequently, chipping and delamination are observed next to the entrance hole, which may be tricky to differentiate from external beveling [6]. Occasionally the skull entrance wound is larger than the exit wound and occasionally there is no beveling at all, especially when the bone is thin like in orbits or sometimes in the squamous part of the temporal bone [6].

Beveling is observed in other bones, especially when the bullet hits the edge of a long bone. But ribs, however, very often will split into two parts. Vertebrae can also lose entire parts of the bone, depending on where the bullet hit the complex 3D anatomy of the vertebra.

In the absence of beveling to determine the entrance and the exit wounds (if there is an exit wound), it is important to note that the bone tends to burst in the direction of the projectile. In cases where the autopsy is not conclusive as to which skin wounds are entrance wounds and which are exit wounds, the anthropological analysis looks for a beveling or a tendency to bursting. In one of the cases reported here a point of entry on the skin with a typical abrasion ring is visible; Fig. 1 illustrates a small hole in the cartilage of the medial portion of the third rib, in the vicinity of the medial end of the rib. Beveling is obvious in this case, along with the trend of some parts of the bone to suffer from plastic deformation in the direction of the projectile. In the case illustrated by Fig. 2, the determination of the skin entrance and exit wounds was very ambiguous. The sternum was sampled from the autopsy and displayed a

depression in the superior part of the lesion, with a trend to bursting nearer to the lower end. This would suggest that the pathway of the projectile was from top to bottom. This immediately provided clues as to which of the skin lesions were the entrance wound and which were the exit wound.

Keyhole gunshot wounds

Keyhole gunshot wounds are occasionally encountered in forensic pathology. These particular gunshot wounds are not always recognized for what they are, though they are usually quite typical. They have been reported on by a few authors in the forensic literature [e.g., 7].

The direction of travel of the bullet may be inferred from clues obtained from the analysis of the skin. Grazing is a very superficial lesion made by the projectile on the skin; the “entrance” end displays a partially abraded margin, while the “exit” end tends to split and the tears point in the direction of the bullet [6,8] (Fig. 3). Superficial perforating wounds are possible. In these cases, the skin entrance and exit wounds are very close together. The entrance tends to display a complete but eccentric ring that points to the direction the bullet came from, the exit wound tends to display a partial abrasion (only a part of its circumference) pointing in the direction of the projectile [8].

Unfortunately, these features are not always present or may be unclear, especially when the body is decomposed or altered, leaving only the anthropological analysis to yield clues as to the angle and the direction of the projectile. Sometimes, the projectile splits into two parts [7] when they hit the skull: one part enters the cranial cavity, creating an entry wound with internal beveling, and the second part of the projectile is immediately deflected, creating a contiguous exit wound with external beveling. In reality there are three possibilities: no penetration of the projectile into the cranial cavity at all, splitting into two parts, or multifragmentation [6].

The main interest of recognizing a keyhole wound is that it immediately gives the angle of the shot (most likely a tangential shot, though Delannoy et al. [9] described an experimental perpendicular shot resulting in a keyhole) and the direction of the projectile (from the bony entry wound to the contiguous exit wound).

Fig. 3 shows an example of a keyhole wound on the skin and on the skull (exocranial and endocranial aspects). In this case the missile burst into multiple fragments but one of them was larger and created a pathway through the brain, impacting the endocranial bone.

III Sharp force injuries and chop wounds

Sharp force injuries are very frequent in forensic pathology [10]. Pure sharp force injuries are caused by a weapon or tool or object that is beveled, and then sharpened, like a knife or razor, and are described as cut and/or stab wounds. Cut wounds are created by the displacement of the blade or its tip, more or less tangentially to the skin and are usually long and superficial. Stab wounds are created by the sharp tip of an instrument along a perpendicular or oblique angle of impact and are usually small and deep. The edges of sharp wounds are regular. The forensic pathologist has to distinguish between homicidal, suicidal and accidental sharp force fatalities [11,12]. Chop wounds involve instruments like axes or hatchets that act using a double mechanism (sharp and blunt).

As skin *cut wounds* are nearly always very superficial, the bones are rarely hit. *Stab wounds* are easy to recognize on the skin (Fig. 4). The forensic pathologist must indicate the direction, angle and depth of each wound. Stab bone injuries are often superficial, very small, sometimes tiny (Fig. 4) [13]. Raising of a small lamella of bone (lateral cortical hinge fracture) is possible and indicates that the blade struck a green bone (Fig. 5, same case as Fig. 4, upper left). Fig. 5 shows irregular fractures of a rib, that are possible with a sharp instrument, when the blade and/or the perpetrator and/or the victim move mid-strike [6]. Skeletal analysis can provide further information. In some cases, a stab wound of the thorax will match up with one or two rib injuries. Stab wounds on the skin may line up with cut wounds along the edge of one or more ribs, or stab wounds through one or more ribs. Lining up the skin and bone rib lesion or lesion(s) gives more precise information as to the direction and angle of the blade and to estimate the minimal depth of penetration of the blade (Fig. 4). This same process is used when a rib cut injury lines up with the stab injury of a vertebra (Fig. 4). “Mirror injuries” (Fig. 4) are possible on two adjacent ribs. Anthropological analysis is useful to ascertain that two or more lesions are due to a single strike. The pathway of the stab wound has to be reconstructed from autopsy (when possible) and/or from anthropological analysis (Fig. 4). This reconstruction of the blade pathway may yield information as to the cause of death. This can be hemorrhage if the trajectory of the blade intersects big vessels (within the thorax or within the abdominal cavity), or asphyxia when the trajectory of the blade includes the larynx, trachea, bronchi or in cases of pneumothorax.

Chop wounds are due to accident or homicide. Suicide is quite exceptional with chop wounds. They are caused by dual mechanism (sharp and blunt) instruments like axes or hatchets. The

skin injury is a long laceration with quite regular edges (Fig. 6). On bones the diagnosis is often typical: one edge is regular; the opposite edge is often irregular and the bone lesion is an open “V”(Fig. 6) [14]. It has been determined that tiny wounds with a hatchet or with a knife blade were impossible to differentiate with the naked eye [14]. Conversely SEM analysis of hatchet bone injuries reveals the characteristic “lateral pushing back” [14] feature that consists of the accumulation of fragments of bone at a distance of the bony edge mark (Fig. 6). This feature allows for differentiating between a bone injury by hatchet and by knife. Knife injury leaves a closed “V” and an uprising of the edge of the bone but no lateral pushing back [15].

IV Blunt trauma

Blunt trauma are the most frequent lesions encountered in forensic pathology. There are due to a blunt tool or object. Blunt injuries mean that there is no unevenness on the tool, and no sharp beveling of any part of the object or tool striking the victim. The strike may be very violent, but it is considered low impact in comparison with gunshot wounds, except blunt trauma occurring during an explosion or a blast [16].

On skin [8], blunt trauma leads to a bruise (ecchymosis, hematoma) or a laceration (especially when the skin presses down on a hard surface, like the scalp against the skull, the lips against the teeth or the eyebrows against the orbital surface of the frontal bone). Lacerations display irregular edges and often bridging on the floor of the lesion due to the fact that the lesions are created with a tearing mechanism rather than cut trauma.

Skull blunt trauma is very frequent and often accidental. Other causes are aggressions and suicide by falling from a heights. Bruises or lacerations on the skin are non-specific and usually cannot indicate the type of weapon that was used (Fig. 7) [17]. On bone the shape of the lesion partly represents the shape of the part of the tool that has actually hit and penetrated the bone. The kinetic energy of the blow and the shape and features of the tool determine the features of the lesion [18]. Usually the point of impact displays a particular shape when a tool or object strikes the skull, because the area of the weapon or object striking the bone is small, leading to a quite localized area where pressure is exerted. Sometimes, surprisingly no skin injury is visible at all (Fig. 8) and only at autopsy will deep hemorrhages of the subcutaneous tissue and of the muscles and an impressive depressed lesion of the cranial vault be revealed (Fig. 8). In this car accident (Fig. 9) the skull was depressed by the roof of the car. Despite of the blunt mechanism the edges of the laceration of the scalp are relatively regular. The trauma of the skull is impressive with radiating and concentric fractures. The CT scans with 3D

reconstruction are very useful in forensic pathology for visualizing blunt lesions of the bones (Fig. 9).

A depressed fracture is often associated with radiating and concentric fractures that partly disperse the kinetic energy (Fig. 9). A fall on a smooth surface, without any asperities, usually leads to no or discreet skin wounds and a “compression” of the skull, due to global pressure exerted on the skull, leading to diastatic fractures (enlargement of the edges of the fractures), and plastic deformation of the pieces of bone that cannot be put back exactly together (Fig. 10) [6].

The mechanism of injury is not always pure blunt trauma. This depends on the features of the tool but also the way the tool was used. Fig. 7 shows an area of depressed fracture with a lesion that has a precise shape, edges that are slightly irregular and small associated fractures. This has to be interpreted as a blunt/sharp mechanism. The blunter the mechanism, the more fractures are observed and the more spread out the lesion (Fig. 9 and 10) [Quatrehomme 2015]. This is because a blunt instrument exerts significant pressure on the skull without being able to penetrate it. In opposite also holds true and there is a mechanism continuity, on a spectrum of very sharp to progressively very blunt mechanism [6,15].

V Burned bodies

Autopsies of burned victims are very complicated because fire will dramatically alter the body and its structures [19,20]. Many issues arise in these cases, such as the identification of the victim, and the diagnosis of the cause, manner and circumstances of death. X rays are indispensable in order to look for projectiles or fragments of projectiles, jackets, pellets or buckshots.

From a practical point of view, there are two types of situations: either an autopsy is still possible, or it is not because only bone fragments are present in which case only an anthropological analysis is possible [21,22]. The colour of the bones depends on the temperature of the fire [e.g., 23]. The main problem is the differentiation between thermal and non-thermal fractures [19,22,24], i.e, determining if there was a preexisting trauma before the occurrence of fire. The forensic pathologist must sample areas of fractures where the bone will be cleared away from soft tissues and cleaned up. Traumatic (non-thermal) fractures (also termed as “abnormal burn patterns”, [19]) are easily seen in unburned bone areas (Fig. 11), but non thermal fractures can be masked by the intensity of alteration due to burning. Conversely thermal fractures are observed in burned areas (Fig. 12, same case as Fig. 11) if

this area is not destroyed by the fire. The naked eye is not always the best instrument to differentiate between these two types of fractures. Stereomicroscopy analysis is usually able to confirm that the area of the fracture was altered by an elevation in temperature. Fractures of the skull base are considered traumatic (non-thermal) fractures [25], if the base is not severely destroyed.

VI Mechanical asphyxia

Death by asphyxia results from oxygen deprivation: cells are no longer able to receive or utilize oxygen. Death by asphyxia is very frequent in forensic pathology, because cardio-respiratory failure is quite common. If an asphyxial syndrome is observed (visceral congestion, cyanosis, petechiae and trend to fluidity of the blood) [8], three categories of causes have to be looked for: natural deaths, toxicological deaths and mechanical asphyxia. Mechanical asphyxia results from a mechanical obstruction of the respiratory tract (which can occur at the nose and mouth, further down the aero-digestive tract, or at the trachea and level of the bronchi), known as smothering and choking; but also a compression of the neck (by strangulation or hanging) or a compression of the thorax (for example collapse of a building, positional asphyxia). Hanging is very often a suicide but homicide by hanging is possible and must always be kept in mind [26-28]. If the victim suffered from smothering or choking, examination of the nose, lips, and mouth will reveal suspicious bruises and erosions. Examination of the neck shows external signs of strangulation in the form of hand imprints (fingernail marks and bruises, manual strangulation) or with a ligature (ligature strangulation). Internal examination of the neck looks for hematoma or bruises of the muscles, luxation or fractures of the horns of the hyoid bone, the cricoid and thyroid cartilages, with associated hemorrhages. In these circumstances, histopathology is preferable to anthropological analysis because histopathology may detect tiny hemorrhages inside the muscles of the neck, the thyroid gland and along the vessels.

When the body is badly decomposed, anthropology can be highly contributive by revealing the trauma of the bone and cartilages of the neck. Unfused or partially fused horn or horns of the hyoid bone are quite common, even after 50 years of age. This non or partial fusion is visible at the bottom of the horn and must not be confused with a fracture of the hyoid bone (Fig. 13). Conversely, a fracture of the superior third of the horn or horns is associated with pressure being exerted on the neck. Recorded cases have shown that all parts of the horns of

the hyoid bone are susceptible to fracture in case of direct strike (road traffic accident, projectile to the neck or direct strike to the neck). [19-32].

VII Dismemberment

Dismemberment is a topic that typically involves advanced knowledge of both forensic pathology and forensic anthropology. Dismemberment is usually accidental, and usually involves a mode of transportation (car, bus, train, or plane). Suicide may lead to dismemberment from train impact, explosion, fall from a certain height. Animal activity is one of the most frequent cause of post-mortem dismemberment by dispersion of the body parts or bones.

Criminal dismemberment is rarer but not an exception. It is one of the most difficult situations. Body parts are usually found in a remote area or in a car trunk, garbage dump or septic tank. All of the body parts are not always released or found at the same time.

Autopsy usually provides a lot of useful information. Some of the first questions requiring answers include the identity of the victim(s), the time since death and the cause of death.

Other issues are addressed later, such as the survival time, the transportation of body parts, the influence of drugs, as well as the exact *modus operandi* [33].

The determination of the cause of death may be very challenging depending on the state of decomposition, the absence of the head and evisceration for example. The hands that might be the location of defense wounds are frequently missing. X-rays can provide important information when they turn up a projectile, a fragment of projectile or a piece of jacket inside a body part. Toxicological analysis may be of interest for the diagnosis of a toxic death or a weakening of the victim by psychotropic drugs. The main limit is the availability of blood that is absolutely required to ascertain a toxic death. Hair analysis, when available, may give useful information concerning the existence of a chronic medical condition (through presence of medication in the hair fibers) or addiction but gives no information on the cause of death. Anthropology looks for gunshot wounds and for sharp or blunt trauma. The conclusions are always limited by the absence of some body parts: for example the discovery of a nick in a rib yields interesting information; conversely the absence of ribs does not allow for ruling out a stab injury to the thorax. The hyoid bone and thyroid cartilage are often missing due to taphonomic events, especially animal activity, so that strangulation cannot be ruled out. Autopsy and anthropology are complementary in determining the *modus operandi* of the dismemberment. Skin lesion edges may appear very regular (with the naked eye and with the

microscope) and lead to the conclusion that the instrument used was very sharp. The absence of blood (naked eye and above all histopathology) along the cut edge of the skin, muscle and viscera is of paramount importance to ascertain that the victim was dead when the dismemberment occurred. For this conclusion to be drawn, multiple samples from the edges of the skin, muscles and viscera have to be examined microscopically. Splinters of bone may be observed on the edges suggesting bone dust coming from a saw. The presence of leucocytes (histopathology) in the bruises, lacerations or cuts proves that a minimum time span of 30 minutes occurred between the wound and the death of the victim [34].

Cut marks may be visible on bones because a sharp instrument like a knife or a razor is often used to cut the soft tissues down to the bone. These tiny cut marks are often little nicks on the bones and are sometimes difficult to see for the untrained eye. Bone marks left by a knife are narrow (closed “V”), those left by an axe or hatchet are wide (wide “V”) [35], with lateral pushing back) [14] and more or less square with a saw. Striae are perpendicular to the floor with an axe or similar instrument (Fig. 6); and more or less parallel to the floor with a saw. The direction of the striae indicates the direction of the movement of the instrument. The study of saw marks is a complementary anthropological field of great value in cases of dismemberment allowing for a valuable classification of the saw from the marks observed on the bones [36,37]. Fig. 14 shows a case of dismemberment where a universal saw with alternating set was used.

Cases of dismemberment may be very complex, especially when the body parts have been burnt. In these circumstances the forensic pathologist has to sample the suspicious areas of bone. It has been demonstrated that burning of the body or body parts does not hamper the diagnosis of gunshot injuries, sharp or chop trauma [38], except if the bones are severely destroyed. A thorough analysis of the bone lesions allows for distinguishing between thermal fractures or amputations and lesions due to severing that occurred before the fire.

VII Discussion

The interpretation of bone lesions must be very cautious. Bones may show signs of injury, despite the cause of death not being trauma, for example a perimortem skull indented or depressed fracture, when the cause of death is of natural or toxic origin.

Conversely the absence of bone lesions does not rule out homicide [1,6]. A stab wound of the abdomen or even the thorax does not always touch a vertebra or a rib but may lead to death by severely injuring soft tissues, especially blood vessels. A gunshot wound may affect soft

tissue but not bone. When the projectile hits the thorax, the abdomen or the limbs, the gunshot wound is not always the cause of death. Whenever a projectile perforates the skull, there is a high level of probability that the cause of death is the gunshot wound. But this is not always the case because some bullet pathways are not fatal. Some cases are trickier than others. In our Medical Examiner it has happened that a bullet penetrated the cranial cavity but the cause of death proved to be acute poisoning. The perpetrator admitted to having shot the victim after he died.

Smothering or choking does not lead to bone injury. Another issue in forensic anthropology is the frequent absence of some bones, especially some of the ribs or rib fragments, the hyoid bone and thyroid and cricoid cartilages, and the hand and wrist bones. In these cases, it is impossible to draw definitive conclusions because a stab wound through the thorax or abdomen cannot be ruled out, neither can mechanical asphyxia, or defense wounds on the forearms, the wrists or the hands.

In suicide attempts by sharp instruments, several skin lesions are seen usually on the wrist or wrists, sometimes on the abdomen and rarely on the thighs. They are parallel and superficial, usually horizontal on the wrists or abdomen and vertical on the thighs. Deeper cut wounds with an injury visible on the bone are very rare in suicides and make the practitioner reconsider the circumstances of death. Defense wounds [39] are very important to look for, as they may be small or even tiny on bones. These may occur when the victim tries to avoid the blade by moving an arm or hand in front of them or when the victim tries to grab the knife. There are usually multiple defense wounds on the skin, with no specific direction to them contrary to suicide wounds which are usually horizontal and parallel [11,12]. All of the bones of both hands (metacarpal bones, phalanx, and carpal bones), if available, must be observed thoroughly to detect defense wounds. Defense wounds can also be found on the ulna and radius, especially the anterior and medial areas of these bones.

With chop wounds the cause of death is often brain hemorrhage (if the axe hits the skull), or exsanguination (especially when one or more limbs are partly or totally severed). In some cases, the bone lesion is obvious but there was no severe hemorrhage meaning that the cause of death is not always the strike to the skull or to the limb.

With blunt trauma the presence of one or more skull fractures does not mean that the cause of death was head trauma: the skull is only the protective casing for the brain. Conversely, the absence of a skull fracture does not rule out head trauma and homicide: examples of brain injuries that can occur without skull fracture include brain contusions, epidural hematomas, subdural hematomas, intracerebral hemorrhages, and diffuse axonal injury (due to sudden

deceleration, as in a car accident). Shaken baby syndrome [40] is a good example of the absence of skin and skull lesions with the presence of subdural hematoma(s) due to a rupture of the veins of the axial convexity and retinal hemorrhages from the violent acceleration/deceleration of the brain that accompanies the shaking.

In most fire deaths, burning is minimal and the cause of death is the inhalation of smoke leading to carbon monoxide and cyanide poisoning. The characteristic pugilistic pose of the body is due to the contraction of muscle fibers resulting from the heat. The absence of this pugilistic pose is suspicious and an explanation must be found [6]: fracture of the upper limbs before carbonization, restraint due to the position of the body or by ligatures of the limbs, pressure exerted by the fall of various materials during the fire. The autopsy must search for signs of life after the fire started (in particular breathing) [8] and differentiate thermal and non thermal fractures by osteological analysis as previously seen [19]. This evidence of breathing during the fire can be soot in the respiratory tract (mouth and tongue, larynx, trachea) or positive toxicological analysis (carbon monoxide and cyanides). Occasionally, there is very little carbon monoxide in the blood at autopsy (e.g., self-immolation, heart or respiratory disease causing rapid death, especially in the elderly). In any case, if death occurred before the arson it is always very suspicious.

Differentiating between hanging and strangulation followed by hanging may be difficult [26-28]. Usually there are far more injuries of the external and internal neck in strangulation than in hanging (or even no internal damage at all in hangings) but some cases are more complex, especially when psychoactive drugs were used for criminal purposes before strangulation or hanging. Smothering can be one of the most difficult diagnoses in forensic pathology, especially in vulnerable victims (newborns or babies, the elderly, or those under the influence of psychoactive drugs) because there may be no mark on the nose and lips, no congestion of the face and no petechiae of the conjunctivae or the sclerae. Anthropological analysis brings no further information under these circumstances.

Autopsy and anthropology are complementary in cases of dismemberment [6,33]. The cause of death is often difficult to establish because parts of the body are frequently missing (head, viscera). The study of saw marks on bones is of paramount interest in these complex criminal cases.

In conclusion, the link between traumatic injuries in soft and hard tissues is not always obvious. This is demonstrated in this review through examples that include gunshot wounds, sharp force injuries, blunt trauma, burned bodies, mechanical asphyxia and dismemberment.

The only way forward for the pathologist when forensic pathology and forensic osteology and anthropology fail to yield answers is to take the context of the victim into account, as well as a great deal of data provided by the police inquiry, and by a comprehensive analysis of all the available clues (examination of the body or the remains in situ, examination of pieces of clothes, comprehensive autopsy, analysis of samples taken during the autopsy like toxicology, histopathology, entomology and so on and osteological or anthropological analysis).

Conflict of interest

The authors of this review do not have conflicts of interest to declare.

References

- [1] A. Flieger, S.C. Kölzer, S. Plenzig, S. Heinbuch, M. Kettner, F. Ramsthaler, M.A. Verhoff, Bony injuries in homicide cases (1994-2014). A retrospective study. *Int J Legal Med.* 130 (5) (2016) 1401-8.
- [2] J.M. DiMaio, Gunshot wounds. Practical aspects of firearms, ballistics and forensic Techniques. Elsevier, New York (1998), 331 p.
- [3] N. Tanaka, H. Kinoshita, A. Takakura, M. Jamal, A. Ito, M. Kumihashi, K. Tsutsui, S. Kimura, K. Ameno, Distinction between entrance and exit wounds by energy dispersive X-ray fluorescence spectrometry, *Leg Med (Tokyo)*. 22 (2016) 5-8.
- [4] G. Quatrehomme, MY Işcan, Characteristics of gunshot wounds in the skull, *J Forensic Sci.* 44 (3) (1999) 568-76.
- [5] G. Quatrehomme, MY Işcan, Gunshot wounds to the skull: comparison of entries and exits, *Forensic Sci Int.* 94 (1-2) (1998) 141-6.
- [6] G. Quatrehomme, *Traité d'Anthropologie médico-légale*. De Boeck Supérieur, Louvain-la-Neuve (Belgique) (2015), 1861 pages.
- [7] D.S. Dixon, Keyhole lesions in gunshot wounds of the skull and direction of fire, *J Forensic Sci.* 27 (3) (1982) 555-566.
- [8] D.J. DiMaio, V.J.M. DiMaio, *Forensic Pathology* (2001). CRC Press, Boca Raton.
- [9] Y. Delannoy, T. Colard, E. Le Garff, S. Humez, D. Gosset, V. Hedouin, The mechanism of the keyhole lesion reassessed: An experimental approach, *J Forensic Leg Med.* 37 (2016) 1-7.
- [10] M. Vassalini, A. Verzeletti, F. De Ferrari, Sharp force injury fatalities: a retrospective study (1982-2012) in Brescia (Italy), *J Forensic Sci.* 59 (6) (2014) 1568-1574.
- [11] C. Brunel, C. Fermanian, M. Durigon, G. Lorain de la Grandmaison, Homicidal and suicidal sharp force fatalities: autopsy parameters in relation to the manner of death, *Forensic Sci Int.* 198 (1-3) (2010) 150-154.
- [12] G. Pelletti, S. Visentin, C. Rago, G. Cecchetto, M. Montisci, Alteration of the death scene after self-stabbing: A case of sharp force suicide disguised by the victim as a homicide? *J Forensic Sci.* 62 (5) (2017) 1395-1398.
- [13] L. Komo, M. Grassberger, Experimental sharp force injuries to ribs: Multimodal morphological and geometric morphometric analyses using micro-CT, macro photography and SEM, *Forensic Sci Int.* 288 (2018) 189-200.

- [14] V. Alunni-Perret, M. Muller-Bolla, J.P. Laugier, L. Lupi-Pégurier, M.F. Bertrand, P. Staccini, M. Bolla, G. Quatrehomme, Scanning electron microscopy analysis of experimental bone hacking trauma, *J Forensic Sci.* 50 (4) (2005) 796-801.
- [15] L. Nogueira, G. Quatrehomme, M.F. Bertrand, C. Rallon, R. Ceinos, P. du Jardin, P. Adalian, V. Alunni, Comparison of macroscopic and microscopic (stereomicroscopy and scanning electron microscopy) features of bone lesions due to hatchet hacking trauma, *Int J Legal Med.* 131 (2) (2017) 465-472.
- [16] E.H. Kimmerle, J.P. Baraybar, *Skeletal trauma. Identification of injuries resulting from human rights abused and armed conflict* (2008). CRC Press, Boca Raton.
- [17] S.K. Rowbotham, S. Blau, J. Hislop-Jambrich, V. Francis, An anthropological examination of the types of skeletal fractures resulting from fatal high (>3 m) free falls, *J Forensic Sci.* (2018) doi: 10.1111/1556-4029.
- [18] A. Galloway, Fracture patterns and skeletal morphology: the axial skeleton. In: A. Galloway (ed.). *Broken bones. Anthropological analysis of blunt force trauma*, Charles C Thomas, Springfield, Ill (1999), pp.81-112.
- [19] S.A. Symes, C.W. Rainwater, E.N. Chapman, D.R. Gipson, A.L. Piper, Patterned thermal destruction of human remains in a forensic setting. In: C.W. Schmidt, S.A. Symes (eds.), *The Analysis of Burned Human Remains*, Academic Press, London (2008), p 15-54.
- [20] D.H. Ubelaker, The forensic evaluation of burned skeletal remains: a synthesis, *Forensic Sci Int.* 183 (1-3) (2009)1-5.
- [21] K. Waterhouse, Post-burning fragmentation of calcined bone: implications for remains recovery from fatal fire scenes, *J Forensic Leg Med.* 20 (8) (2013) 1112-1117.
- [22] M. Bohnert, T. Rost, S. Pollak. The degree of destruction of human bodies in relation to the duration of the fire. *Forensic Sci Int.* 95 (1) (1998) 11-21.
- [23] S.T. Ellingham, T.J. Thompson, M. Islam, G. Taylor, Estimating temperature exposure of burnt bone - A methodological review, *Sci Justice.* 55 (3) (2015) 181-188.
- [24] N.P. Herrmann, J.L. Bennett, The differentiation of traumatic and heat-related fractures in burned bone, *J Forensic Sci.* 44 (3) (1999) 461-9.
- [25] M. Bohnert, T. Rost, M. Faller-Marquardt, D. Ropohl, S. Pollak, Fractures of the base of the skull in charred bodies - post-mortem heat injuries or signs of mechanical traumatization? *Forensic. Sci. Int.* 87 (1997) 55-62.
- [26] F.C. Monticelli, H. Brandtner, S.N. Kunz, T. Keller, F. Neuhuber. Homicide by hanging: A case report and its forensic-medical aspects. *J Forensic Leg Med.* 33 (2015) 71-5.
- [27] R. Ruwanpura, C. Ariyaratne. A homicide by suspension. *Med Sci Law* 50 (4) (2010) 224-7.
- [28] S. Pollak, A. Thierauf-Emberger. Homicidal assault to the neck with subsequent simulation of self-hanging. *Forensic Sci Int.* 253 (2015) e28-32.
- [29] R. Keerthi, A. Quadri, *J Maxillofac Oral Surg.* 15 (Suppl 2) (2016) 249-252.
- [30] Y.M. Jehng, F.T.T Lee, Y.C. Pai, W.M. Choi, Hyoid bone fracture caused by blunt neck trauma, *J Acute Medicine* 2 (2012) 83-4.
- [31] T. Dalati, Isolated hyoid bone fracture. Review of an unusual entity, *Int J Oral Maxillofac Surg.* 34 (2005) 449-52.
- [32] A.J. Dickenson, Fracture of the hyoid bone following minimal trauma, *Injury* 22 (5) (1991) 420-21.
- [33] G. Quatrehomme, A strange case of dismemberment. In: M.B. Brickley, R. Ferllini (eds.), *Forensic Anthropology, Case studies from Europe*, Charles C Thomas, Springfield, Ill (2006), pp. 99-119.
- [34] R.B. Dettmeyer, Vitality, injury age, determination of skin, wound age and fracture age. In: R.B. Dettmeyer and B. Rheinhard (eds.) *Forensic Histopathology*, Springer, (2018) pp.241-263.

- [35] K.J. Reichs, Postmortem dismemberment: recovery, analysis and interpretation. In: Forensic Osteology. Advances in the Identification of Human Remains. Second edition. K.J. Reichs (ed.) (1998). C.C. Thomas, Ill, pp. 353-388.
- [36] S.A. Symes, Morphology of Saw Marks in Human Bone: Identification of Class Characteristics. Ph.D. Dissertation (1992). University of Tennessee, Knoxville.
- [37] L. Nogueira, G. Quatrehomme, C. Rallon, P. Adalian, V. Alunni, Saw marks in bones: A study of 170 experimental false start lesions, Forensic Sci Int. 268 (2016) 123-130.
- [38] V. Alunni, L. Nogueira, G. Quatrehomme, Macroscopic and stereomicroscopic comparison of hacking trauma of bones before and after carbonization, Int J Legal Med. 132 (2) (2018) 643-648.
- [39] S. O'Donovan, N.E.I. Langlois, R.W. Byard. "Defense" type wounds in suicide. Forensic Sci Med Pathol. 14 (3) (2018) 402-405.
- [40] M. Mian, J. Shah, A. Dalpiaz, R. Schwamb, Y. Miao, K. Warren, S. Khan, Shaken Baby Syndrome: a review. Fetal Pediatr Pathol. 34 (3) (2015) 169-75.

Figure caption

Fig. 1: Gunshot wound of a rib. The projectile penetrated between the bone and the cartilage of the rib. Beveling is obvious in this case (arrows) and indicates the direction of the bullet.

Fig. 2: Bullet strike to the sternum. There is a small depression in the upper part of the lesion and tendency to burst near the bottom (yellow arrows). This bursting trend indicates the direction of the projectile, from the upper to the lower part of the sternum.

Fig. 3: Keyhole lesion. Grazing of the skin with abraded margin and tears pointing in the direction of the bullet (upper left); the bone keyhole shows an entry on the left (with internal beveling) and a contiguous exit on the right (with external beveling). The white arrows show the direction of the bullet (upper right insert: bone fragments before they are glued back together; bottom right: endocranial view of the same lesion).

Fig. 4: Obvious stab wounds of the skin by a knife (left insert). Stabbing lesion of a vertebra may be tiny (center insert). Lining up the skin and rib lesions (left chest) or vertebra lesion (right chest) gives information as to the direction and angle of the blade and an estimate of the minimum depth of penetration of the blade. Mirror image (large black circle and right insert).

Fig. 5: Knife mark in a rib. Sharp mechanism (white arrow); blunt aspect (yellow arrows); a small lamella of bone is permanently raised (green arrow), indicating that the trauma occurred in a green bone. This case is the same as Fig. 4, wound # 12

Fig. 6: Chop wound. Hacking trauma with a hatchet. Skin injury on the frontal and nose areas shows a quite regular opening of the skin (right insert). Bone lesion as seen at SEM x 75. The lesion is an open "V". Usually one edge is quite regular whereas the opposite edge is irregular. There are vertical striae that indicate the vertical moving of the blade. Above all there is lateral pushing back (yellow arrows) with accumulation of bone at a distance of the edge that allows for differentiating between bone injury by a hatchet (lateral pushing back) and a knife (absence of lateral pushing back, but usually uprising of the edge).

Fig. 7: Multiple lacerations of the scalp (upper insert) and the bone indented lesion discovered at autopsy (same case). The tool used was purported to be a stone but, given the skin

lesions, it could have been a myriad of other types of tools or instruments. On bone the shape of the injury may be compatible with the part of the tool that has hit the bone.

Fig. 8: Impressive depressed lesion of the cranial vault (white arrow) with a radiating fracture (green arrow). There was surprisingly very little skin injury hiding the bone lesion (yellow arrow).

Fig. 9: Blunt trauma (car accident). The car turned over on its roof and the roof was indented into the skull. The skin lesion shows an opening with quite regular edges. The skull trauma is impressive with radiating and concentric diastatic fractures. The yellow arrows show the direction of the indented roof. 3D reconstruction is very useful for visualizing blunt lesions.

Fig. 10: Compression of the skull. A compression occurs when significant pressure is exerted on the entire skull. The result is an enlargement of the edges of the fractures (called diastatic fractures, white arrow), a plastic (permanent) deformation of the pieces of bone that cannot be put exactly back together. In this case, the victim was violently projected from standing height to the ground. The laceration of the skin was quite small (green arrow, upper insert). There is a localized depressed area (yellow arrow) that indicates an area of localized pressure (probably the angle of the pavement, green arrow at the bottom insert). Notice the radiating and concentric fractures.

Fig. 11: Burned bone. Traumatic fractures (fractures that are not due to the burning) are seen in unburned areas (arrow).

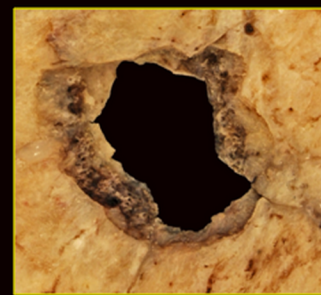
Fig. 12: Burned bone (same case as Fig. 11). Thermal fracture (fractures that are due to the burning) are seen in burned areas (yellow arrow). See the thermal line (green arrow).

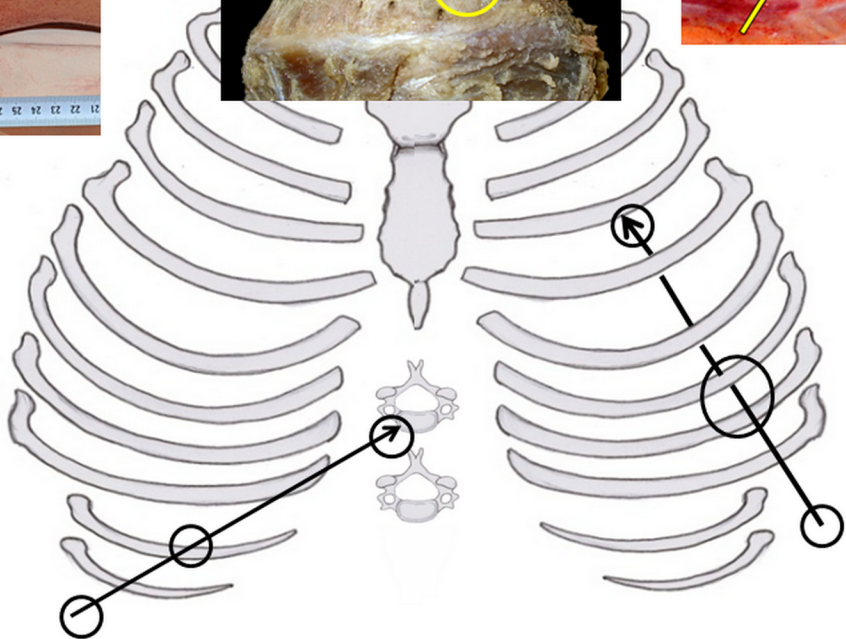
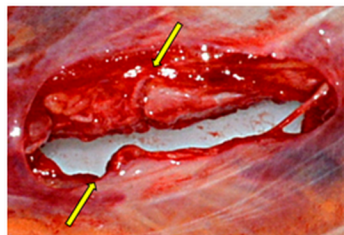
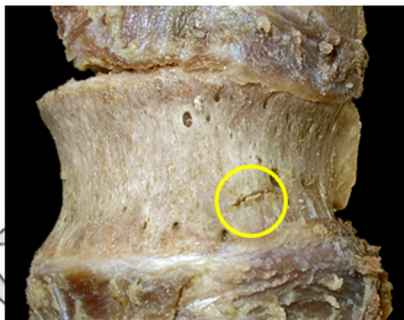
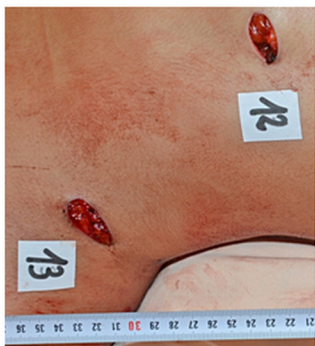
Fig. 13: Hyoid bone. An unfused horn (yellow arrow) is very frequent, on one or both sides, even after 50 years of age. In this case there is a fracture of the other horn (green arrow). Usually horn fracture(s) due to mechanical asphyxia occurs on the upper third of the horn, which is not the case here.

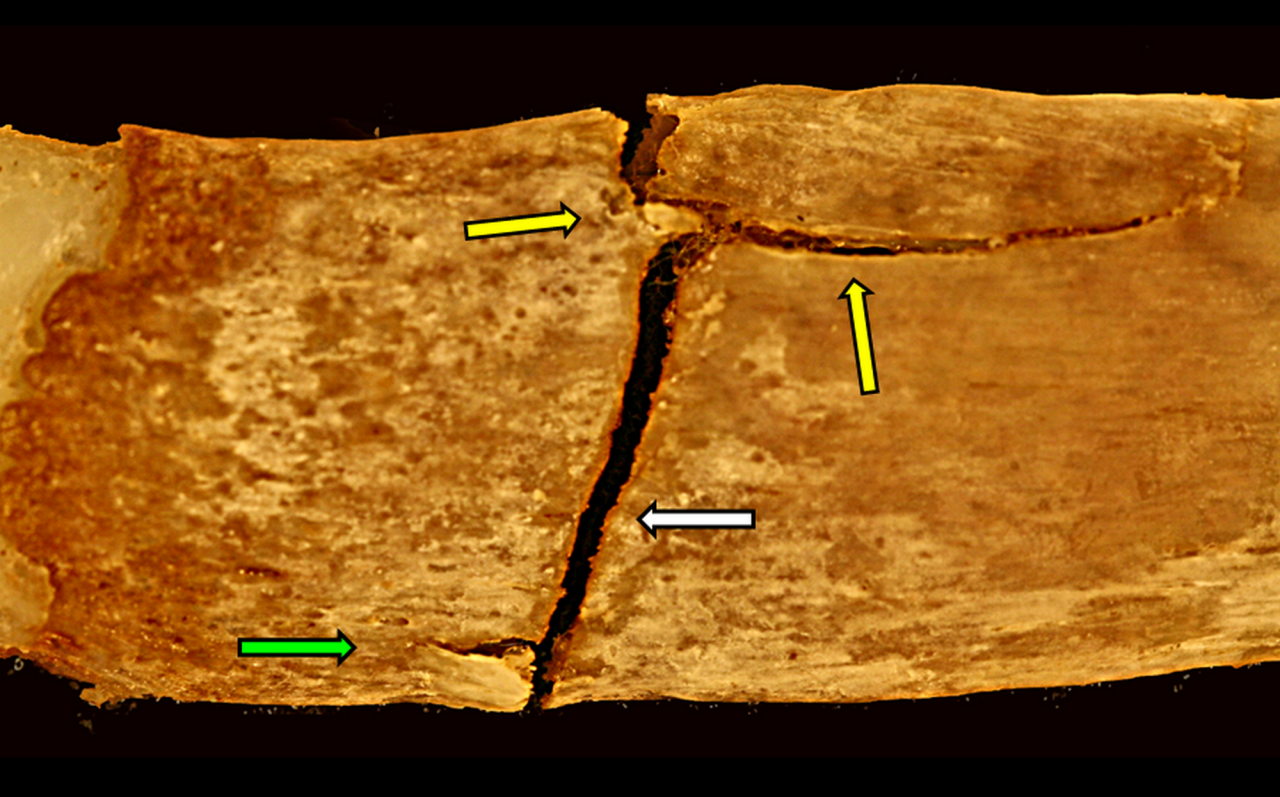
Fig. 14: Saw marks in a case of dismemberment. False start (left) made with a saw with an alternating set leaving walls that are alternately narrower and wider apart (Stereomicroscope x 10). Castings of the profiles of the saw marks (right): convex profiles (in “W”, upper right) are seen with crosscut or universal saws, whereas concave profiles (bottom right) are seen with rip saws.

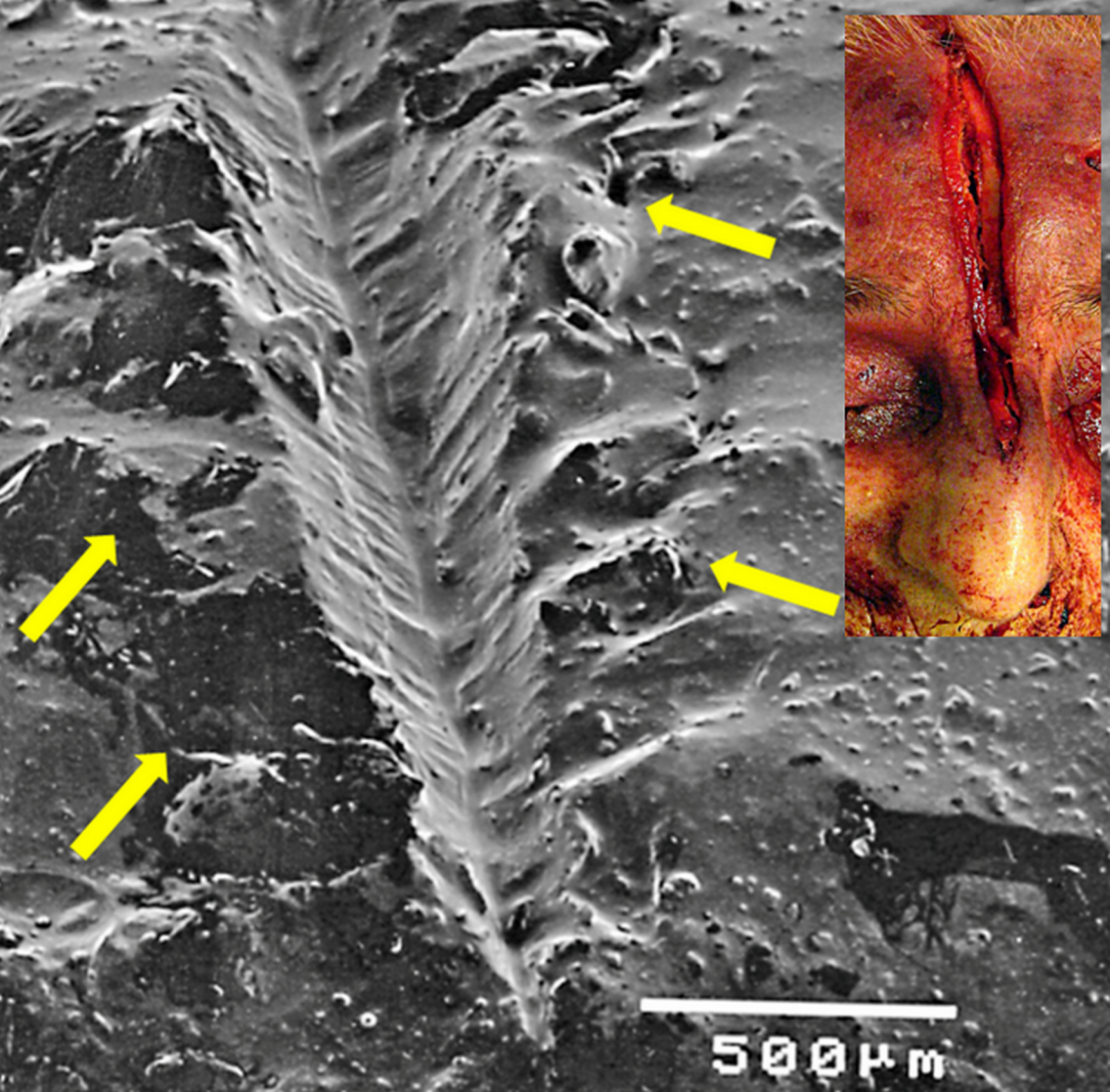


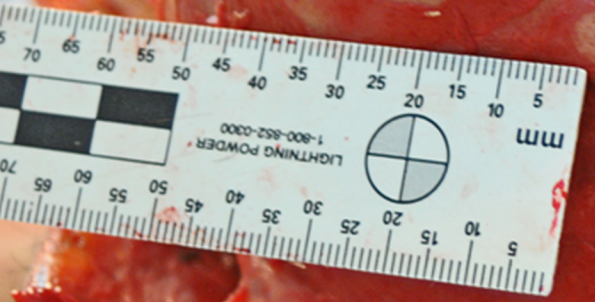
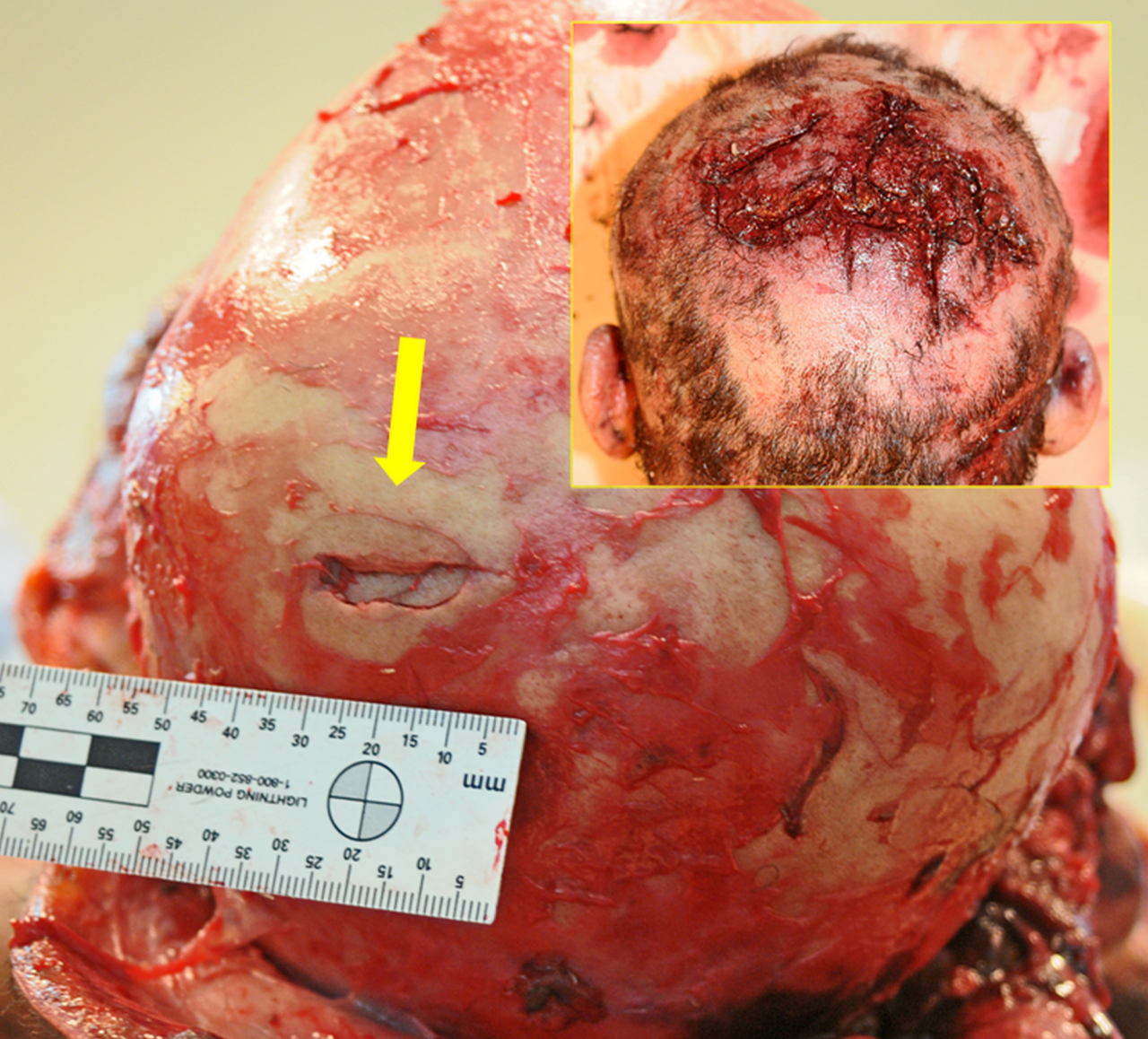


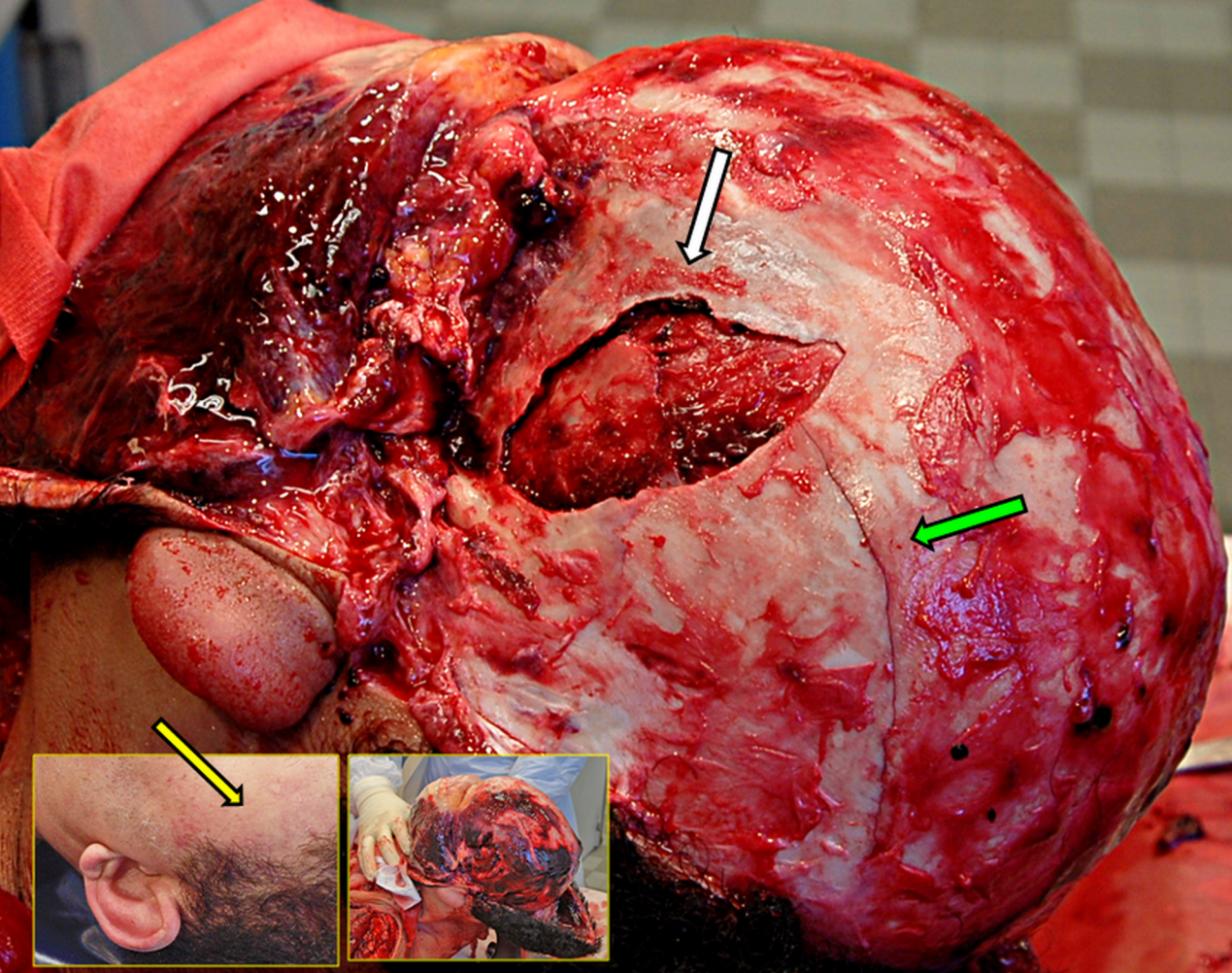


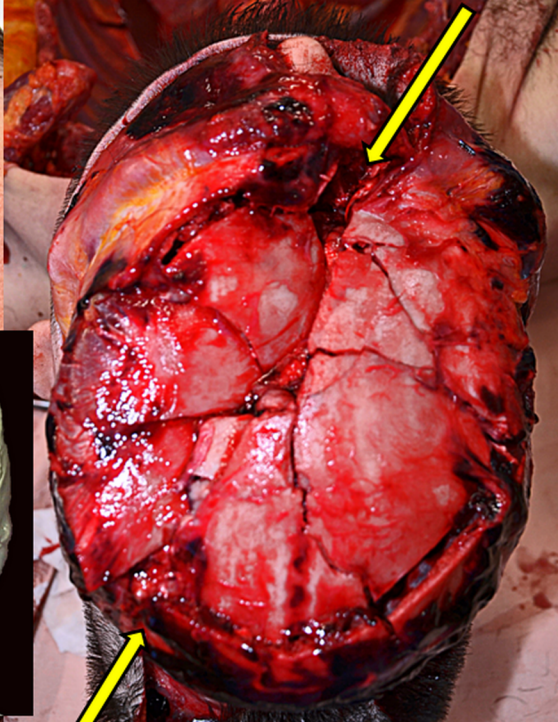


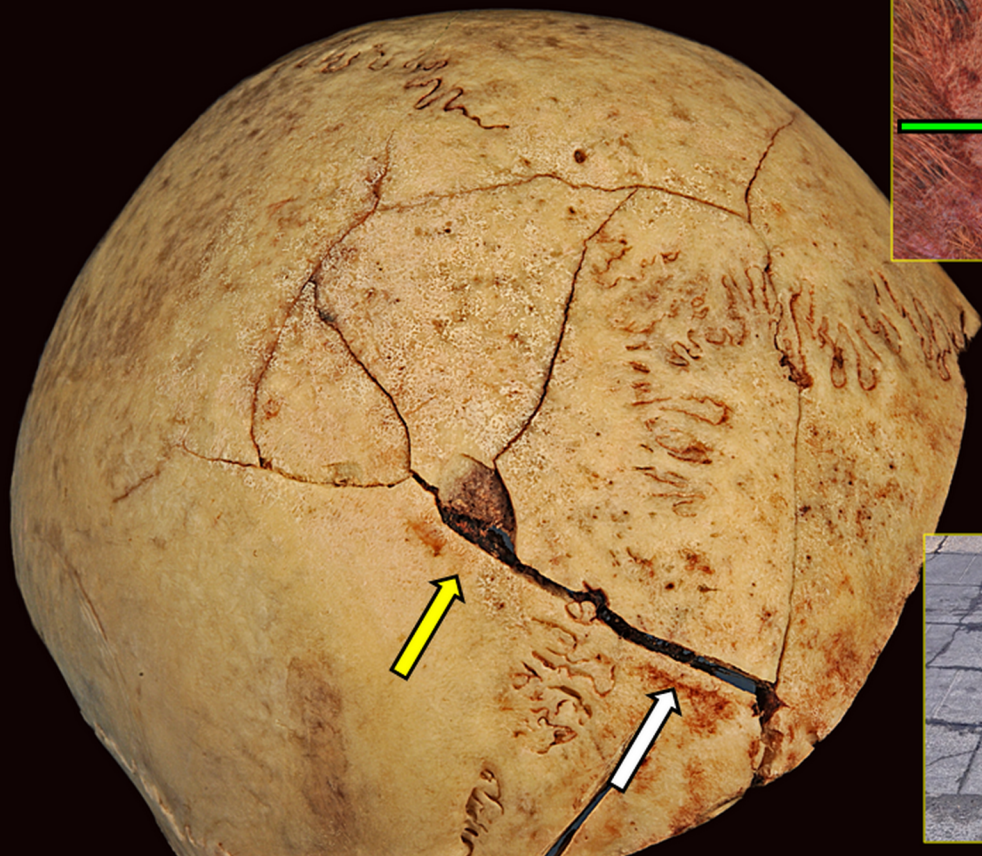


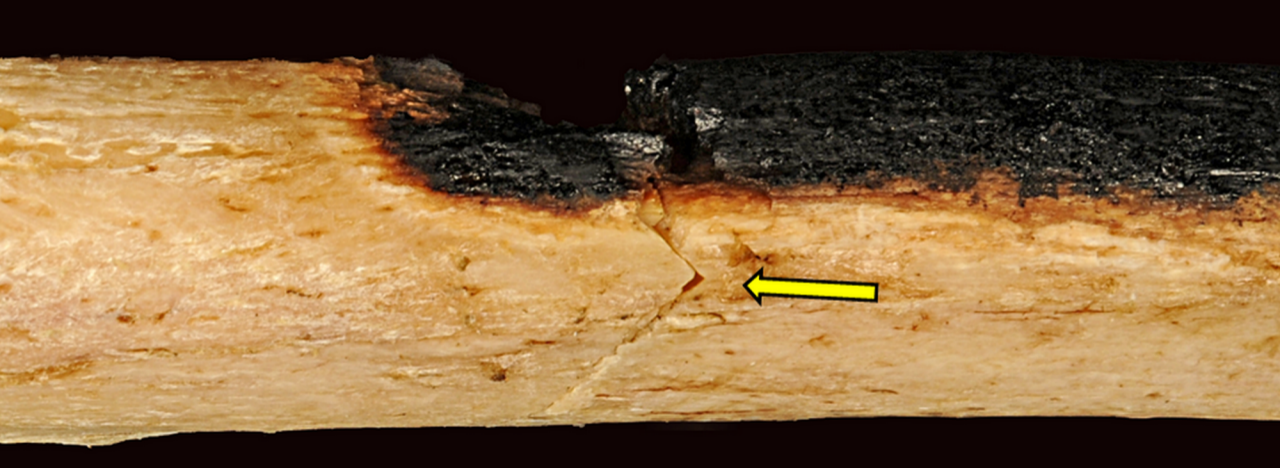




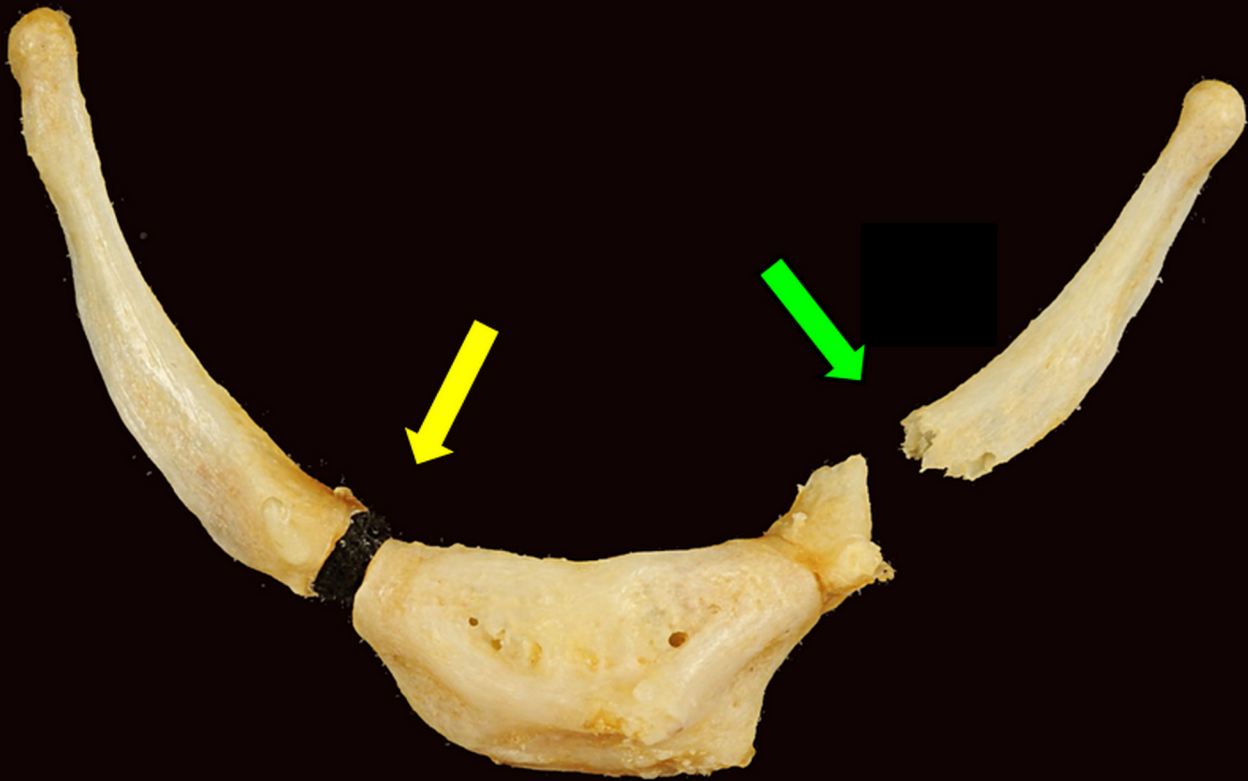












METRIC 1

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