Chapter 5

Decay Process of a Cadaver

João Pinheiro

Summary

Because forensic anthropologists and pathologists can be confronted in their professional practices with bodies or mortal remains in different states of preservation and/or decay, it is essential for this book to have a chapter that fully documents the pathway of a body from its death until disintegration.

The different ways a corpse can progress from putrefaction directly (or not) to skeletonization, passing through conservation processes such as saponification or mummification are presented here, always taking into account the forensic relevance of each stage, the time and conditions needed, as well as the duration. Full, illustrated examples of cases that have contributed to solve forensic questions are provided. Factors that might influence the speed of putrefaction and the interrelations—through chemical reactions between these processes—are also debated.

Key Words: Decay; decomposition; putrefaction; saponification; adipocere; mummification; skeletonization; disarticulation; forensic; autopsies.

1. INTRODUCTION

It is common for forensic anthropologists and pathologists to be confronted in their professional practice with bodies or human remains states of preservation and/or decay that are not entirely to their liking, such states being outside their knowledge and experience. The forensic pathologist generally feels more at ease with a fresh body, whereas the forensic anthropologist would certainly prefer to work with dry bones. Ideally, the forensic anthropologist

should always be called whenever a body appears whose morphological characteristics do not permit any identification. Such cases are usually in an advanced state of decay: with adipocere, mummified, carbonized, skeletonized, or with a mixture of all of these. Indeed, the same cadaver may reveal various states of preservation at the same time. This fact is closely connected to the different transformations that may take place in a body from the moment of death to skeletonization, upon the action of various extrinsic and intrinsic factors, which are analyzed here.

For this reason, it is fundamental that the pathologist has prior knowledge of the various alterations that take place postmortem (the object of the study of forensics called taphonomy). These alterations particularly affect the soft tissues, and are decisive not only for the time taken for skeletonization to occur, but also for the state of preservation of the cadaver *(1)*. Between a fresh cadaver and a heap of loose bones, there are a series of stages of decomposition and/or preservation that may occur when the environmental conditions are right. Various authors have drawn attention to the need to understand this process *(2,3)*, whereas some of the definitions of forensic anthropology itself, such as the one of Bass *(4)*, presuppose the existence of cases other than those skeletonized: "…the science that focuses principally on the identification of remains that are *more or less skeletonized*, in the legal context."

This journey along the taphonomic process will certainly be useful in its earlier stages for anthropologists that are not used to working with almost-fresh cadavers, and in the final phase (skeletonization) for pathologists, who are normally not too fond of working with bones.

2. DECOMPOSITION

The process by means of which a cadaver becomes a skeleton, through the destruction of the soft tissue, is quite complex. In discussing the decomposition process, it is important to remember that, as with everything in biology, the exception is the rule, or rather, that there are no two individuals alike, nor any two decomposition processes alike. This is why this stage can be difficult.

The decomposition of a body is a mixed process that varies from cellular autolysis by endogenous chemical destruction to tissue autolysis, by either the release of enzymes or external processes, resulting from the bacteria and fungus in the intestines or from outside *(5)*. Predators, ranging from insects to mammals, participate in the process and may accelerate it. It can therefore be said, with Di Maio *(6)*, that decomposition involves autolysis (the destruction of cells and organs by an aseptic chemical process) and putrefaction (because

of bacteria and fermentation). Thus, whereas common sense understands decomposition to be synonymous with putrefaction, in the forensic context, it has a much broader meaning, covering all stages from the moment of death to the dissolution of all body parts.

It is a process that varies greatly from body to body, environment to environment, according to whether the body is clothed or naked, the circumstances of the death and the place where the body is found, the climate, and so forth. For example, it is known that putrefaction occurs much faster in bodies that are left in the open air than those immersed in water, whereas buried bodies decay at a much slower rate *(7–9)*. In these cases, factors such as the length of time before the body was buried (thus allowing putrefaction to begin), the temperature at the site, the presence or absence of oxygen, the depth of the body, topography of the soil (rather than its composition), and the type of coffin used, considerably affect the speed of decomposition *(6)*. However, whereas many exhumations have little to offer to certain investigations, this should not devalue their importance. Indeed, this can never be anticipated, because there are cases in which bodies are in truly surprising states of conservation. In an autopsy performed by the author, it was possible, some months after the burial, to undertake a detailed examination, entirely unexpectedly, of a spontaneous brain hemorrhage in a body that had been buried in winter in an area of harsh climate (atmospheric temperatures between –3 and 10°C).

Decomposition may also vary within the same cadaver, with some parts of the body showing adipocere, other parts mummified, and still others only putrefied (Fig. 1). This will depend on the different "microenvironments" that develop around them, in accordance with the place where they are found. There are also various possible interconnections between these states, which makes it difficult to estimate the date of death.

The calculation of the postmortem interval (PMI), one of the most controversial and difficult problems in legal medicine, becomes more acute in cases of decomposition. Excluding the precious assistance provided by forensic entomology (a separate discipline that is not dealt with here), various methods have been used to calculate this interval, while of course taking into account the subjective nature of the individual assessment. Prieto *(9)* lists the evaluation of biomarkers like lipids, nitrogen, amino acid content, neurotransmitters, decompositional byproducts, persistence of blood remnants in bone tissue; extent of DNA deterioration; changes sustained by microanatomical skeletal structure; and carbon 14. Others have tried to study the variations of factors that influence decomposition in certain cases, either prospectively (through the formation of adipocere *[10,11]*) or retrospectively (by analyzing cases that have already been solved in order to study particularly extrinsic factors that affect it *[9,12]*).
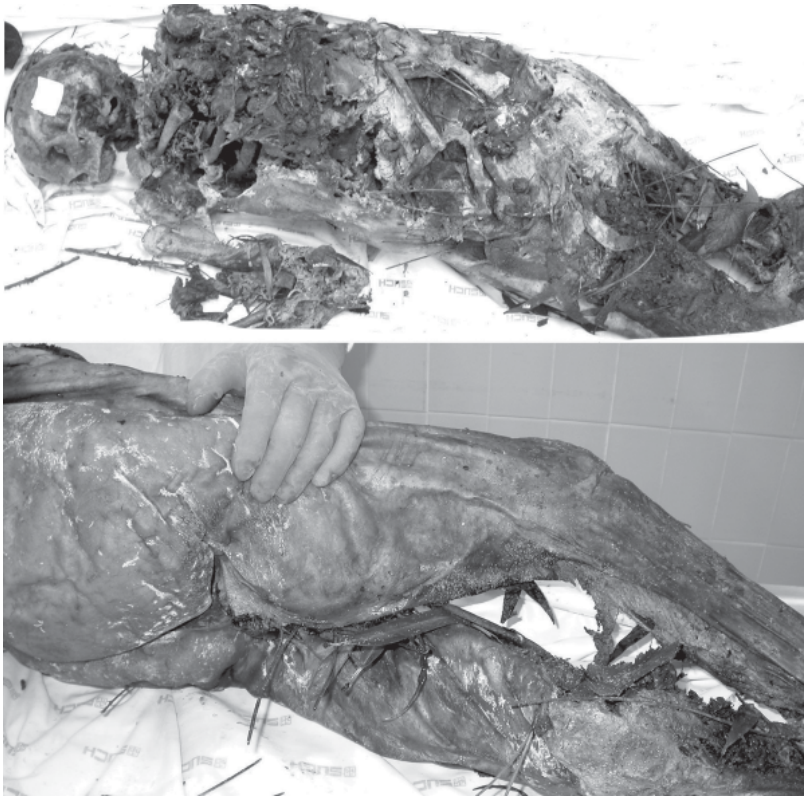
Fig. 1. Coexistence of three states of decomposition in the same body: skeletonization of the head, adipocere in the trunk organs, and mummification of the limbs. Note skin's leathery appearance. The body belongs to a 93-yr-old woman found facedown in the countryside, whose positive identification was achieved. Cause of death was ascertained.

In all cases, and despite the relevance of some of these methods, the establishment of PMI continues, for most pathologists, to be based on individual analysis and experience obtained in similar cases. And, whereas it is legitimate to suggest a date for past populations with some margin of variation, it is always very difficult to risk a prognosis in forensic cases, because there are so many factors involved, and the range of variation is so broad. This is supported by a number of authors *(8,10–13)*, who, because of the multiplicity of factors involved, find it impossible to attribute a credible time interval for each of the stages of decomposition.
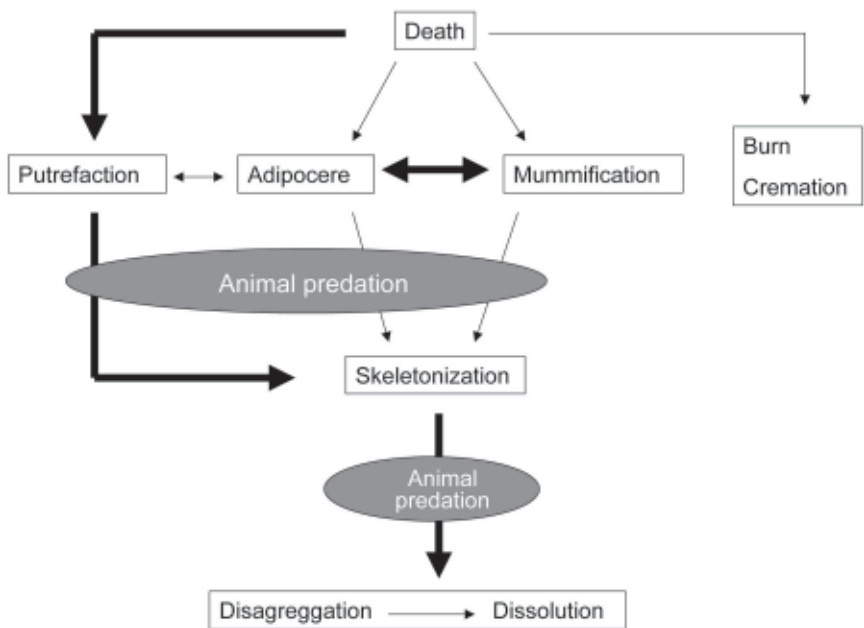
Fig. 2. Steps of body decomposition. (Adapted from ref. *5*.)

What can be done, of course, when required for a particular decomposition process, is to indicate the time suggested in the literature and validated by experience as necessary for each of the processes to take place, and from this, it is possible to get an idea of the PMI.

After death, most bodies that have not been embalmed will start putrefying quickly and will liquefy in some time, leaving only the skeleton (Fig. 2). Others, however, may pass through some of the preservation processes mentioned previously (mummification, saponification), interchangeable among themselves, which will lead eventually to skeletonization. A skeletonized body will tend to disintegrate, or alternatively, to fossilize, a process that may take millions of years. Figure 2 shows this process of decomposition, which will be discussed, as far as disaggregation or fossilization is concerned.

2.1. Putrefaction

Putrefaction is usually the first stage of decomposition, although it is not always found, and consists of the gradual dissolution of the tissues to gases,

liquids, and salts *(7)*. Not only is it the subject of numerous publications, it is also covered in any book about legal medicine and forensic pathology.

Many authors distinguish phases and stages in the putrefaction process, some of which are based on the study of the decomposition of animal carcasses. For example, Shean et al. *(14)* distinguish 4 phases (decomposition of the soft tissue, exposure of bone, remains only with connective tissue, and bone only) that are broken down into 15 stages, whereas Galloway et al. *(15)* distinguish 5 phases and 21 stages, to cite only some. Others describe these stages with great temporal precision, which, although revealing great erudition and being very successful in lessons or lectures, are inadequate for practical application given the enormous variability of the development of this process. These discrepancies between suggested periods and phases of decomposition, along with the study of animals, naturally limit the value of these findings. In the author's opinion, what is much more important than knowing the stage of putrefaction, or how long it has taken to get there, is the ability to recognize the elements that characterize clearly and objectively the stage of putrefaction, and the artifacts that this may induce, and to know its potential and limits in terms of thanatological research.

Therefore, described here chronologically are the alterations undergone by a body after the death, in a place with temperate weather. It should be emphasized that the times mentioned are merely indications and in no way exact because some of the characteristics described may appear considerably earlier or later than suggested.

2.1.1. FIRST WEEK

One of the earliest signs of putrefaction is the discoloration of the lower abdominal wall in the right iliac fossa because of the proximity of the cecum to the surface. Intestinal bacteria break down the hemoglobin into sulfohemoglobin and other colored pigments (the "green abdominal stain," as it is known in some countries), which extends from the right iliac fossa to the whole of the abdomen and thorax (Fig. 3). These bacteria are also responsible for the formation of gases, provoking edema of the face and neck. The gases released in this process (sulfuretted hydrogen, phosphoretted hydrogen, methane, carbon dioxide, ammonia and hydrogen *(7)*, and some mercaptans) are responsible for the unpleasant odor that is characteristic of these bodies. Other effects produced by gases include a marked increase in the volume of the abdomen, which is under tension, and of the scrotum and penis, which may gain extraordinary dimensions. The face and neck also increase greatly, with protrusion of the eyes and tongue, making identification difficult.
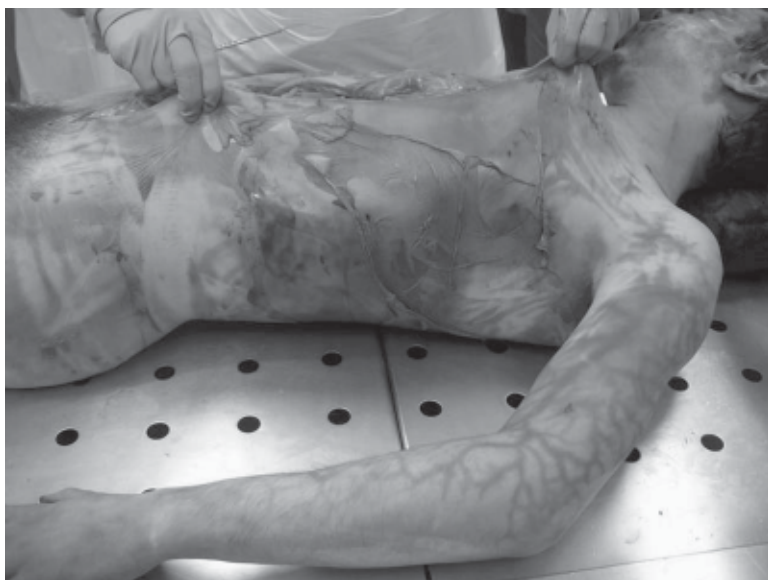
Fig. 3. The colors of putrefaction: abdominal green, which had begun in the right inguinal region; red marbling, typically on the lateral part of the trunk, shoulders, and upper limbs; reddish, purplish of the putrefactive phlyctenae. Note the skin slippage. (*See* ebook for color version of this figure.)

The phenomenon known as "marbling" in Anglo-Saxon literature (or Brouardel's "posthumous circulation," as it is better known in the Latin countries), which results from the colonization of the venous system by intestinal bacteria that hemolyze the blood, is very characteristically found at this time. It appears on the thighs and sidewalls of the abdomen, chest, and shoulders (*see* Fig. 3), first with a reddish color and, later, green.

Skin blisters containing reddish purplish serous liquid erupt in the sloping regions (*see* Figs. 3 and 9). These should be distinguished from the phlyctenae that result from burns; phlyctenae containing a serous liquid are of course characteristic of second-degree burns, but they are usually surrounded by an erythematous ring, something that is not found in putrefactive blisters.

The epidermis becomes fragile and tears easily, which means that it may come off in large areas, leaving the red dermis visible, similar to what happens with first- and second-degree burns (Fig. 4). Such patches may also be caused by the bursting of the phlyctenae, when these are large and contain liquid under pressure. The skin may also come off on the fingertips, which, of course, hinders the taking of fingerprints.

Fig. 4. Skin slippage, leaving the dermis visible. For the inexperienced, this can be confused with second-degree burns. On both hands and feet, and like burns or drowning, the skin can be removed like a glove. Fingerprints will then be difficult to obtain.

In hairy areas, hairs will come off at the slightest pressure. This phase of putrefaction may also provide some curious aspects, such as the "gloves" made of skin on the hands (*see* Fig. 4), or the use of the hair by birds for nest building *(6)*.

2.1.2. SECOND AND THIRD WEEKS

The increase of pressure on the abdomen produced by putrefactive gases leads to the ejection of feces and urine, and there have been cases described of uterine prolapse, and even of a postmortem birth *(5,7)*. This pressure also leads to the expulsion of liquids from any orifice, particularly in the early stages, from the mouth and nostrils. As this liquid is often bloody, it can lead to complications for differential diagnosis because inexperienced pathologists may confuse these cases with cases of violent death (Fig. 5). Tracheobronchial foam may also be produced by the same mechanism that creates a mixture of air with the tracheobronchial liquids. Internally, small gas bubbles are frequently found in the soft viscera, giving these organs a "foamy" appearance.

Fig. 5. Purging of a bloody liquid from nostrils because of the gaseous dilatation of the abdomen. Note the abrasions under the breasts, which could be erroneously considered antemortem, but were produced, in fact, by skin pressure with postmortem exsiccation.

2.1.3. FOLLOWING WEEKS

The green color gradually darkens to black, making identification even more difficult. The association of this with edema and the formation of gas in the head lead to an increase in its size and the flattening of anatomical prominences, causing an "africanization" of features, known in some places as "blackman's head" (Fig. 6). This phenomenon may arise, however, much earlier. The swelling of the face, in fact, begins immediately in the first week, depending on environmental conditions, and is accompanied by protrusion of the tongue between the dental arches.

Fig. 6. Stage of advanced putrefaction with gaseous bloating and larval infestation, causing obvious problems in the identification of the victims.

The cadaver in this state gives the impression of being a very heavy individual. However, this is a false impression because it is effectively the volume that is increased and not the weight, which may even be reduced because of the presence of the gases *(6)*.

This phase coincides with infestation by maggots, which dig holes and pathways in the skin and tissues, opening up routes for other bacteria from the environment (Fig. 7). The combined action of the proteolytic enzymes of the maggots and the voracious appetite of other predators greatly accelerates putrefaction at this stage.

2.1.3.1. Organs

Internal decomposition takes place at a slower pace, and it is sometimes surprising how many diagnostic elements may be collected from a cadaver whose state of putrefaction appears to have little to reveal. It is commonplace to say that *putrefaction is the greatest enemy of the pathologist*. However, this unquestionable truth is often counteracted by fortunate exceptions, which justifies using all the rigor and detail normally demanded by a standard autopsy for these cadavers as well. The frequently given excuse that there is no point in taking the necropsy or dissection much further because the putrefied
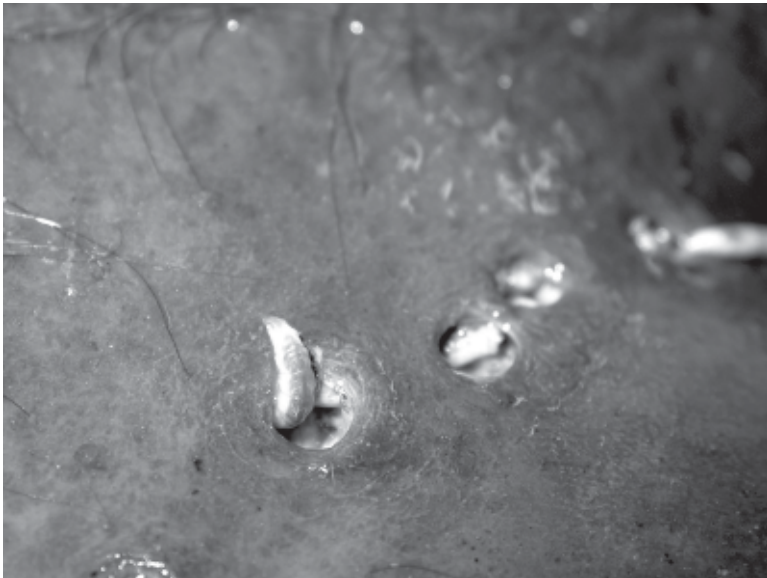
Fig. 7. Maggots digging holes and sinuses via proteolytic enzymes, opening the access to external bacteria that will speed up the putrefaction process.

body has little forensic value, is largely the result of the chronic laziness of some professionals.

The proliferation of microbes leads the internal organs and internal vessels to acquire a winey purplish hue, although some organs, such as the liver or stomach, may more commonly be a dark brownish green.

Putrefaction takes place at this level at different speeds:

1. The intestines, suprarenal glands, and spleen may putrefy in hours.
2. The encephalon discolors, becoming grayish pink and liquefies in about 1 mo (Fig. 8); signs of brain disease disappear (e.g., meningeal hemorrhages, tumors).
3. The heart is moderately resistant. The coronary arteries remain visible for many months, allowing the diagnosis of valve and coronary disorders, and coronary thromboses in necropsies that seem doomed to failure, a circumstance that is well known among pathologists that work daily in the autopsy rooms.
4. Kidneys, lungs, and bladder are also resistant (Fig. 8).
5. The prostate and uterus are the least vulnerable.

The capsules of the kidney, spleen, and liver resist putrefaction more than their respective parenchymas, and these organs transform into sacs
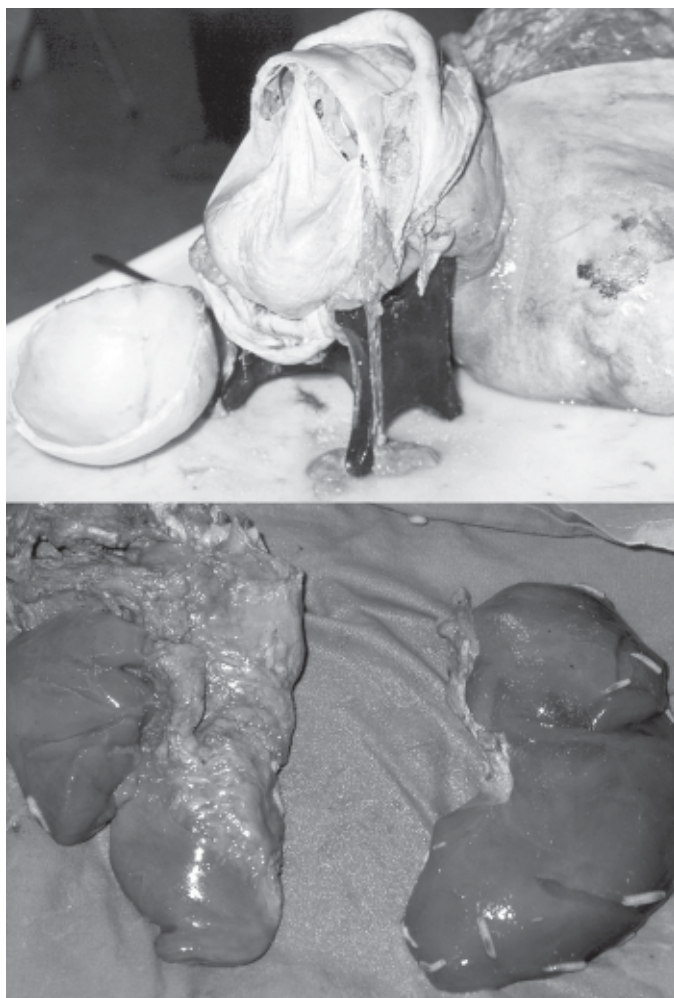
Fig. 8. Encephalon (from another case) discolors (grayish) and liquefies in 15 d to 1 mo, depending on the conditions involved. However, heart, lungs, and (especially) kidneys moderately resist putrefaction. These belong to the body of a girl in adipocere, buried in soil for approx 2.5 mo (the same as in Fig. 11).

containing a pasty liquid, winey red in color, which will later burst, making it then impossible to recognize the organs.

These different rates of decay of the organs may be proportional to the amount of muscular and conjunctive tissue they contain, according to some authors, cited by Gordon et al. *(7)*.

2.1.4. LATER ALTERATIONS (MONTHS)

The viscera and soft tissues disintegrate, whereas organs such as the uterus, heart, and prostate last longer, as do tendon tissues and ligaments attached to the bones.

The body will then finally enter into the phase of skeletonization, depending on the place where it is found and the season of the year. Some fragments of skin, protected by clothing or that come between the body and the support surface, may remain preserved, mummified, or with adipocere (*see* Fig. 1).

2.1.5. PUTREFACTION OF A BODY EXPOSED TO THE AIR

The rate at which a body decomposes is extremely variable. In the author's experience, for the bodies of patients who have died in the hospital in the summer and are not refrigerated (Portugal has a temperate, Mediterranean climate), a single afternoon is enough for the process to start. In fact, the earlier it starts, the faster it will be.

Various factors influence the speed of putrefaction: the atmospheric temperature and humidity level *(10)*, the movement of air, state of hydration of the tissues and nutritional state of the victim, age, and respective cause of death *(5,7)*. Thus, low temperatures, which inhibit the growth of bacteria, retard the process considerably. The optimum temperature for the activation of bacteria responsible for putrefaction is 37.5°C *(7)*. In a simultaneous double homicide autopsied by the author, the effect of temperature on the rate of putrefaction in each of the corpses found at home was clearly perceptible (Fig. 9). Exposure to warm humid air, and the movement of this, also accelerates putrefaction *(7)*.

In tissues that are greatly hydrated, with a higher liquid content, such as occurs in cases of deaths through chronic congestive heart failure, putrefaction is faster. Victims who are dehydrated or who had suffered from vomiting and diarrhea resist much longer.

The process is faster in children than in adults and also in more obese people than in thinner individuals *(6,7)*. However, newborn infants show some resistance to the start of the process.

Di Maio *(7)* claims that bodies wearing heavy clothes putrefy more quickly than those that are more lightly dressed, whereas other authors stress that a clothed body decomposes less quickly than a naked one *(15)*. It is also necessary to take into account the kind of fiber that is used in the clothing, whether natural or synthetic.

Of course, someone who dies of septicemia or from some acute infection will already contain a proliferation of bacteria, which means that the
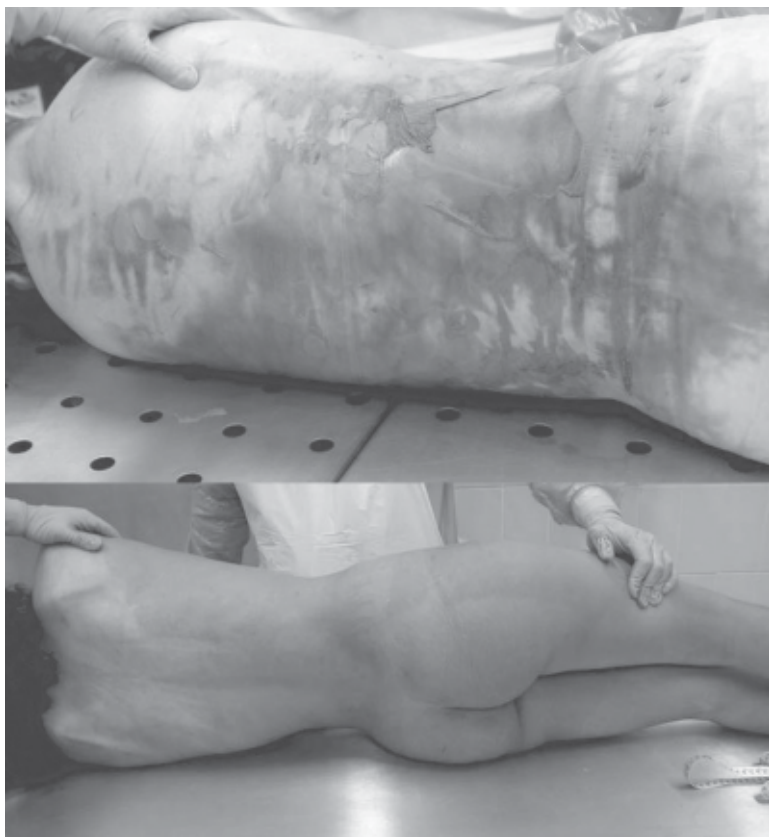
Fig. 9. Different stages of putrefaction observed in two bodies, both shot at home and recovered 3 d after the crime, on a moderate winter day. The man on the top had a heater working near him; the girl lay on the floor of her bedroom, without any source of heating.

process will be significantly accelerated. This acceleration will be greater in the trunk than in the limbs, certainly for the same reason (that is, the absence of bacteria in the muscular tissue of the limbs, as opposed to the abundance in the organs of the trunk, especially the abdomen).

The presence of traumatic lesions caused by a blunt instrument or firearm may also affect the speed of decomposition *(15)*, in that they open up holes through which air and insects may enter. Flies, however, tend to prefer the natural openings.

Fig. 10. Decomposition in water showing the first signs of adipocere in a victim drowned in the central Atlantic Ocean for 8 d: a white, waxy appearance, complete slippage, without hair. Note the little injuries on the posterior head, without bloody infiltration, meaning a postmortem lesion by teeth of marine predators. The detail shows the colonization of the larynx by known comestible marine predators: mussels, goose barnacles, crabs.

2.1.6. *Decomposition of an Immersed Body*

As has already been mentioned, decomposition is slower in water than for a body exposed to the air, because of both the lower temperatures and degree of protection that the water offers from insects and predatory mammals. However, one should not forget that there are also sea and bird predators whose action, in exposing areas of adipose tissue to the water, also promotes adipocere (Fig. 10).

Normally, a body floats head down because the head does not develop gas formation as easily as the abdomen or thorax, which causes fluids to gravitate to the head. This means that putrefaction is more visible on the face and front of the neck, making identification more difficult. The appearance is also significantly different from a putrefied body because it is frequently associated with saponification, with a general peeling of the skin, and accentuated white coloring (*see* Fig. 10). Bodies acquire a waxy white
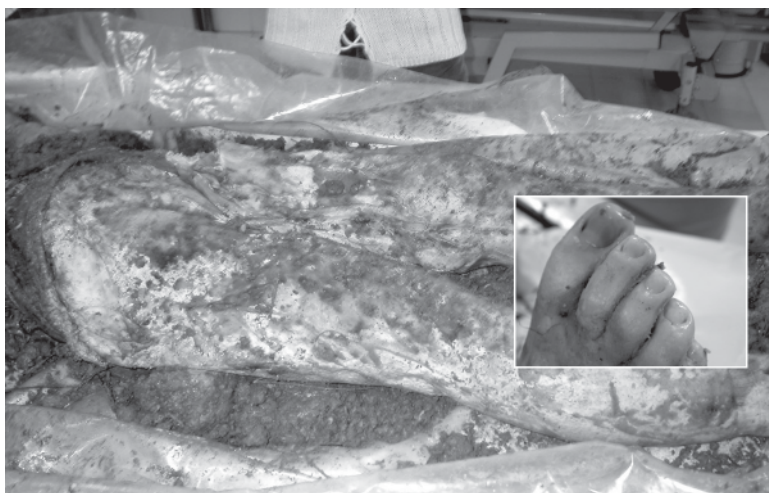
Fig. 11. Buried corpses decay at much slower rate than immersed or air exposed bodies. Observe the excellent preservation of the body of a girl, after 2.5 mo of burying, conserved in adipocere. Note the unexpected detail of the toes.

hue, and the appearance of the head without hair makes it difficult to identify; indeed, some professionals have been ill advisedly led to believe that such cases had been subjected to oncological therapies. Because of the putrefactive process, the bodies float continuously, even when they have been attached with stones for example, to make them sink to the bottom (*see* Fig. 12).

Putrefaction is also faster in warmer stagnant waters that contain decomposing organic matter, such as industrial effluents, and so forth. It is also faster in fresh water than in saltwater *(7)*. Some authors *(5,8)* contest this last point, however, on the grounds that bacterial colonization results much more from bacteria in the digestive tract and airways of the victim than from the aquatic flora. Finally, as soon as the body has been removed from the water, putrefaction accelerates considerably.

2.1.7. DECOMPOSITION AFTER BURIAL

It has been demonstrated that this is the process in which putrefaction advances least, in relation to bodies left in the open air or in the water (Fig. 11). For this reason, in some Brazilian states with scarce resources where there are no conditions of refrigeration, the medicolegal services bury the bodies in order to prevent them from decaying, exhuming them some days

later when the autopsy may be carried out. Thus, the soil functions as a kind of primitive refrigeration chamber.

This slower rate of decomposition is for obvious reasons: the absence of air, inaccessibility to predators, and low temperature. The time taken before burial also affects the whole process. If putrefaction had not yet begun, the body will remain in a better state of preservation than if the process had already gotten underway.

The kind of soil and depth at which a body is buried are also factors to be taken into account. The process is faster in damp, porous soils and in bodies that are buried near the surface *(5,7,8)*. The topography of the land is, however, more important than the type of terrain. If the body is buried in a valley or below the water table, the action of water will also be felt *(5,8)*.

Bodies buried deeply in coffins decompose more slowly that when they are in shallow graves—the temperatures are lower, there is less air, and they are less affected by water *(5,7,8)*. The type of coffin also influences the decomposition process. Laminated wooden coffins rot quickly, whereas those made of zinc or lead offer better protection.

2.2. Adipocere

The formation of adipocere is a natural preservation process that has been known for centuries. Its name, attributed to Fourcroy in 1789, comes from the combination of the Latin *adipo-* (fat) and *cera* (wax) *(5)*. This process, which some wrongly consider as a part of putrefaction *(6,7)*, is known as *saponification*.

It is a variable and irregular process, only occasionally involving the whole body, which results from the hydrolysis and hydrogenation of the adipose tissue. This produces a waxy, fatty substance that is brittle; in color, it is yellowish off-white (*see* Figs. 11 and 12), although when stained by decayed matter or blood, may acquire reddish, grayish, or gray-green tones (*see* Fig. 10). It also gives off a characteristic "earthy, cheesy, and ammoniacal" odor, which may be recognized by dogs trained to discover human remains *(11)*.

Despite some points that are controversial and unclear, the biochemical sequence of the formation of adipocere is, today, largely well established. The process begins immediately after death *(10,11)*, with the hydrolysis (mediated by enzymes) of the triglycerides, which cleave the fatty acids from the glycerol molecules, giving rise to a mixture of unsaturated (palmitoleic acid, oleic acid, linoleic acid) and saturated (myristic acid, palmitic acid, stearic acid) fatty acids *(16)*. As the process advances, the quantity of fatty acids increases, and the triglycerides diminish until they disappear completely *(11)*. When there are sufficient enzymes and water, decomposition will continue

Fig. 12. Saponified body of a woman (both women and children are more likely to saponify) attached to stones to sink in a domestic well (suicide). Note the discoloration and the fat appearance of the skin.

with the hydrogenization of unsaturated fatty acids into saturated, after which the process is considered complete and stable. However, during hydrolysis and hydrogenization, some other products are formed. Free fatty acids may attach to sodium and potassium ions of the interstitial liquid and cellular water, and later, to calcium ions, forming fatty acid salts. The subsequent action of some microorganisms leads to the formation of 10-hydroxy fatty acids—the most common of which is 10-hydroxy stearic *(11,16,17)*—and, according to Takatori *(17)* of 10-oxo fatty acids. This author has shown that bacteria, such as *Pseudomonas*, *Staphylococcus aureus*, and *Clostridium perfringens*, produce 10-hydroxystearic acid from oleic acid, whereas *Micrococcus luteus* produces oxo fatty acids *(17)*. These acids, and their respective soaps, as well as participating in the formation of adipocere, also help to stabilize it. This stability may be attributed to the action of ionic, covalent, hydrogen bonds between the carboxyl terminal of the fatty acids and the hydroxyl groups *(16)*. These substances and glycerol form a matrix with fiber residues, nerves, and muscles, which gives a degree of solidity to the saponified mixture *(5)*.

At the moment of death, the body's fatty acid content is 1%, but with adipocere, in the first month, it goes up to 20%, and at 3 mo is 70% *(5)*. It is thought that the process is only superficial and therefore does not involve the viscera *(7)*. However, whereas subcutaneous fat is the most affected, internal structures containing adipose tissue, such as the mesentery, epiploon (omentum), perirenal fat, or organs with pathological processes involving a lipidic metabolism, may also be involved.

2.2.1. CONDITIONS

Saponification requires some heat, necessary for the development of the microbes referred to in the previous subheading, as well as water, which may be exogenous or from the organism itself *(1,5)*. For this reason, it generally appears in damp environments *(5)* in bodies immersed in cold water with a low oxygen content *(1,10)*. Pfeiffer *(16)* associates the persistence of adipocere to the presence of Gram-negative microorganisms, which are known to develop in anaerobic environments.

However, saponification is also found—much more often than is thought—in tombs, crypts, and graves, even dry ones, in a few days; the water from the organism is enough to set in motion the chemical transformations necessary for the process. Adipocere benefits from a process of self-promotion, because it inhibits putrefaction, increasing acidity and dehydration, thus reducing the growth and spread of putrefactive organisms.

Women (*see* Fig. 8) and children are much more likely to undergo this preservation process because they have a greater fat content. For the same reasons, the parts of the body that tend most to saponification are the cheeks, eye sockets, chest, abdominal wall, and buttocks.

2.2.2. CHRONOLOGY

Adipocere may last for decades, even centuries. It can form between 3 and 12 mo *(5–7,11,10,18)*, although this is variable; the first signs may be visible as early as the third week after death *(5,11,10,19)* or even earlier (8 d), as was the case of a victim of drowning in the central Atlantic Ocean (Portuguese coast) autopsied by the author,[*] where atmospheric temperatures ranged from 16 to 30°C (average of 20°C), and the average of sea water temperature was 18°C (*see* Fig. 10).

Studies carried out in the area of marine taphonomy cited by Kahana *(12)* consider that, in cold waters (4°C), some 12–18 mo are required for saponification, whereas in waters of between 15 and 22°C, only 2–3 mo are needed; very high temperatures are necessary for the process to be evident in 1–3 wk. However, other reports are highly contradictory. The same author reports bodies recovered from a wreck of a Belgian ship in the China Sea, saponified at 38 d in water temperatures of between 10 and 12°C, among other discrepancies. It should be emphasized that in the same sample, three bodies were

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[*] During the period this body was submersed, weather was similar, with the exception of a day when meteorological conditions had suffered a sudden change, with an increase of both atmospheric temperature (to 35°C) and the temperature of the sea water, which ranged from 19 to 36°C.

found later (after 433 d) with adipocere, but with some parts skeletonized. Studies of controlled decomposition in samples of pig carcasses *(11)* in shallow graves have shown that there is no correlation between stages of saponification and the period of decomposition, which once more confirms the variability of the whole process and the probable intervention of other factors as yet unstudied, such as temperature, humidity, pH, clothing, and soil type.

These findings reinforce the idea that has been argued consistently in this text as to the lack of confidence in estimates of PMI based on states of decomposition of the body.

The decay of the adipocere is not completely clarified because it has been alleged that soil microbiota including bacteria, fungus, and algae may play a role in this decomposition. Pfeiffer *(16)* suggests that the maintenance of adipocere is associated with the development of Gram-negatives in a slightly anaerobic environment, and that its decay has to do with exposure to conditions of aerobiosis and to the presence of Gram-positive bacteria. This fact has been confirmed for many by practical experience, because a saponified body that has been removed from its environment for autopsy starts to decay much more rapidly than it did before its removal.

2.2.3. FORENSIC VALUE

The medicolegal interest of saponification lies not only in the possibilities it offers for identification because it conserves some bodily forms, but also in determining the cause of death. It is, however, rare for a body conserved only through adipocere to be recognized by the face, given the physiognomic distortions that are common despite preservation (*see* Fig. 10).

In Portugal, an eminently maritime country, it is curious to note that the majority of saponified bodies come from domestic wells because of either suicide (a very common method in the elderly rural population) (*see* Fig. 12) or accidental falls. This state of conservation of the body often permits medicolegal determination of the cause of death. For this purpose, saponification may be very important, particularly in situations of death by firearm because the preserved fatty organs may reveal the bullet's trajectory (Fig. 13). The author performed an autopsy on a victim of the Balkan War of the 1990s in Kosovo, where it was possible to reconstruct approximately the paths of two projectiles in a body that was completely saponified, but where the organs were difficult to distinguish.

Lakes, rivers, seas, and wells are also often used to hide murder victims, for which reason great attention should be paid to bodies recovered from water; one should not, as so many experts unfortunately do, leap to the easy conclusion of death by drowning. *A body recovered from the water may have died of*
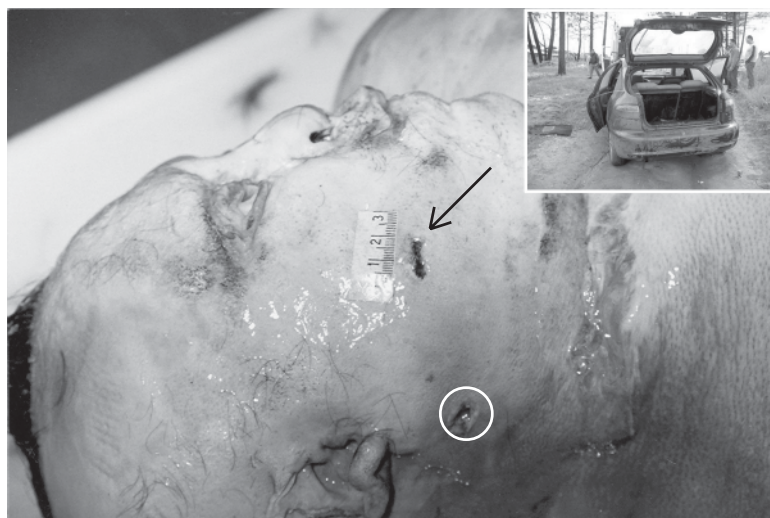
Fig. 13. A saponified head of a homicide victim, found closed inside the back of his car, sunk in a lake to hide the body. The author could recover the four bullets and determine its pathway. Two of the shots penetrated the body through the same hole seen on the face (arrow). Another entrance hole can be noted below the ear (circle). Note the preserved aspect of the face that could lead, but with some difficulty, to a positive identification. (*See* Fig. 3, Chapter 7 to observe the X-ray.)

anything, even drowning. Among many examples present in the literature, Dix *(19)* tells of four separate cases of homicides, accidentally collected from Lake Missouri, all saponified.

2.3. Mummification

This is a process of natural or artificial conservation, which consists of the dehydration and *exsiccation* (the process of drying up) of tissues. It may be partial and coexist with other forms of conservation and/or putrefaction (*see* Fig. 1). It extends more easily to the whole body than other processes, such as saponification *(8)*.

It is characterized by dryness and brittle, torn skin on the prominences (cheeks, forehead, sides of the back, and hips), generally brown in color, though coexisting with white, green, or black zones because of colonization by fungus (*see* Fig. 1), just as leather jackets look after they have been left for some time in a musty wardrobe and start to become mildewed.

As for the internal organs, the process varies in relation to the time since death, and they may be partially mummified, putrefied, with adipocere, or

even absent. Radanov et al. *(20)* describe an extreme and unique case of the natural mummification of a brain, which was surprising, taking into account the softness of brain tissue, as well its fatty composition. The body had come from a mass grave with 39 other bodies and had been buried for 40–50 yr, at a shallow depth in a stony terrain, exposed to sunlight.

It is common for there to be slight adipocere in mummified bodies. Indeed, there is a close interconnection between these two processes; the use of the water from the body for hydrolysis of fats contributes also to the exsiccation of tissues *(5,8)*. This relationship is extendable to the biochemical level, as has been demonstrated by Makristathis et al. *(21)*, who detected in mummies the same constituents of saponification: palmitic, oleic, and 10-hydroxystearic acid, among other substances.

2.3.1. CONDITIONS

As is to be expected, mummification is found in dry, ventilated environments *(1,5)* and generally, though not always, in warm places where the body loses fluids through evaporation *(5,6)*: closed rooms, attics, wardrobes and pantries, barns, stairwells, and so on. More extensive and complete mummification occurs in desert environments; indeed, this preservation process was practiced by the ancient Egyptians, who added spices and herbs to the heat *(1,5,8)*.

Mummification also takes place in icy environments, not only because of the dryness of the air, but also because of the low growth of bacteria at such temperatures. A frozen mummy approx 5000 yr old (known as the Tyrolean Iceman) discovered in the Alps in 1991 has become famous as a veritable star of anthropology, like others from Peru that are also thousands of years old *(21)*. The former, however, raises the question of knowing whether mummification, which is by definition related to exposure to dry air, may take place in the snow. Ambach and Ambach *(22)* justify this from a physical point of view, given that evaporation may occur from a frozen body through a superficial covering of snow (porous and air-permeable), if the weather conditions establish a water vapor pressure gradient between the snow layers.

Makristathis et al. *(21)* compared the composition of the fat of mummified bodies from different parts of the world: the Tyrolean Iceman; two bodies found in alpine glaciers near to this; a body that had been immersed for 50 yr in an Austrian mountain lake; two bodies buried in the permafrost of Siberia; two Peruvian mummies, one from the Andes (500 yr old) and one from the Peruvian desert (1000 yr old); and three fresh bodies as a control. The composition of fatty acids was very similar between the samples of fresh bodies and those from the dry mummification of Peru, in which no significant concentrations of 10-hydroxystearic acid were found, with oleic acid predominating. These were

also the best preserved bodies. In addition, all those conserved in ice or in contact with water showed a high concentration of 10-hydroxystearic acid, suggesting the association of this acid with conditions of conservation in water. The Tyrolean Iceman was situated somewhere between the mummies conserved dry and those from the ice, and was in a much better state of preservation than many more recent bodies, only tens of years old, also from glaciers. This can be explained by the rapid initial desiccation caused by the cold mountain winds, followed by a burial in ice with periods in water.

Dehydration before death may also favor this process. Indeed, this is similar to an ancient Japanese practice of natural self-mummification, according to which bonzes (Buddhist monks), nearing the end of their lives, would progressively reduce their solid food intake, then the liquid, so that they were practically desiccated at the moment of death. They were buried, and then exhumed 3 yr later, when they were found to be already mummified, without any other kind of intervention *(23)*.

2.3.2. CHRONOLOGY

The time necessary for mummification to take place is not well documented because of the long periods that usually occur before the body is discovered. It certainly takes some weeks *(5,7,8)* and, in the early stages, is mixed with putrefactive alterations, especially in the internal organs. In the deserts of Arizona, corpses exposed to the air require between 11 d and 1 mo to mummify *(15)*. After they are dry, they may last years, even centuries *(5,7,8)*.

The action of predators (*see* Fig. 2) in this phase may accelerate the disintegration of the exsiccated tissues, which are fragile and brittle; fragments of parchment-like skin, tendons, and ligaments attached to the bones may remain for much longer, however.

2.3.3. FORENSIC VALUE

Mummification can have significant medicolegal relevance for the two great objectives of forensic anthropology, identification of the body and establishing cause of death. Concerning the former, mummies are often found in a surprising state of preservation (Fig. 14), and it is usually much easier to investigate the victim's identity in these situations than with adipocere. Concerning the latter, large lesions may be preserved. However, the detection of ecchymosis or wounds may be made difficult or impossible because of discoloration, artifacts, and the action of fungus.

Cadavers in this state are sometimes the victims of homicides that have been left in a place propitious to mummification. It can also be found in cases of natural death of people that live alone. It is a very common process in

Fig. 14. The hands of a clerical mummified in a crypt (18th century). The perfection of the details is surprising.

fetuses or newborn infants, who mummify much more rapidly and completely, often because of the types of graves or ventilated domestic locations where they are deposited (Fig. 15).

Autopsies in these cases require particular dexterity because the skin, which is brittle and disintegrates easily, is difficult to dissect. Some methods of softening the tissues to permit better observation and histological study *(5)* have been described; one of these involves the use of a solution of 20% poly-ethylene glycol, with controlled pH of 8.0 and the addition of 1% Stericol to inhibit the growth of bacteria and fungus *(24)*.

2.4. Skeletonization

As the name suggests, this consists of the removal of all soft tissue from the bone, and is the field *par excellence* of the forensic anthropologist.

A body that has been reduced merely to its bones may be, however, present in its totality, thus constituting a complete skeleton (Fig. 16). Different states of preservation may nonetheless coexist, as mentioned previously, of which one may be skeletonization, which will be, in this case, partial. When this happens, the classic scenario is skeletonization of the cranium (which has the least soft tissues), mummification of the extremities, and saponification of the back (*see* Fig. 1). The natural and most frequent tendency, if conditions are propitious, is for complete skeletonization.

In the certain (and very frequent) case of a group of bones (Fig. 17)—sometimes already eroded, found in a church cemetery, obviously in a phase subsequent to skeletonization, when the bones are completely disarticulated and fragmented—it seems incorrect to designate this as a skeleton or body in
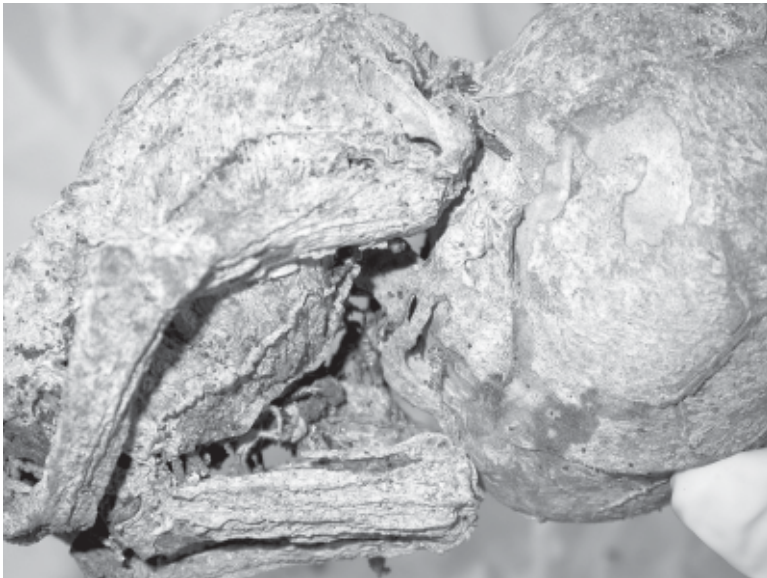
Fig. 15. A mummified fetus of approx 28 wk found in a crypt after rebuilding a cemetery. The attachment of the umbilical cord suggests a probable live-born infant.
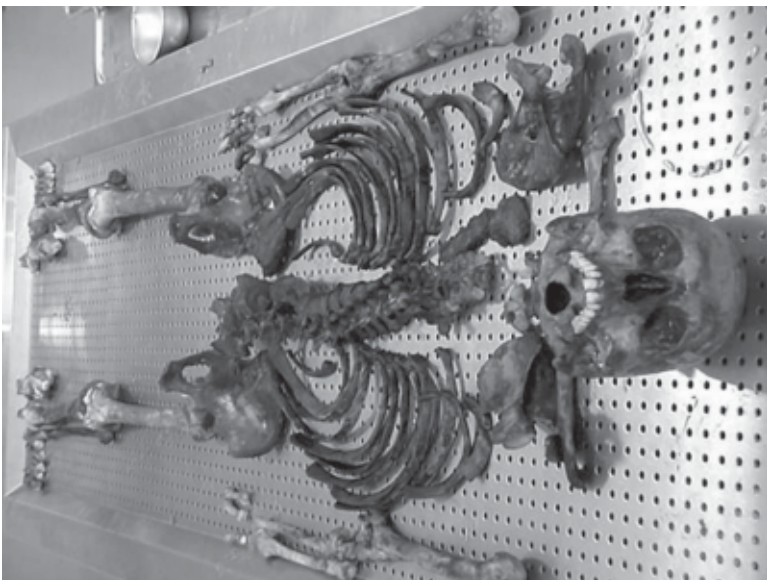

Fig. 16. A complete skeletonized body at the autopsy room after the inventory.

Fig. 17. Ossuary (and not a skeletonized body) containing more than one individual.

skeletonization. The term *ossuary*, frequently used in forensic practice, would seem to be more suitable. It should be noted that these piles may include bones that have been disturbed and mixed up, and therefore belong to different individuals; this naturally requires specific methods of analysis *(25)*.

2.4.1. CONDITIONS

The time required for a body to become a skeleton is very variable because skeletonization is a complex phenomenon involving the intervention of multiple factors. Many studies have been carried out (often based on the decomposition of animals) to assess the influence of each of the taphonomic variables *(26)* on the preservation of the body and to quantify the average time taken for each phase of decomposition of the cadaver *(15,27,28)*. Recall that the higher the temperature and humidity, the greater the rate of decomposition and skeletonization, and that it is also important whether or not the body is buried, among many other factors already described in relation to general decomposition. Clark et al. *(1)* point out that a body buried in a warm environment may skeletonize as quickly as a body exposed to the air in a temperate environment, always depending on factors like the depth at which it is found, soil type, and so on.

As was mentioned with regard to mummification, the ligaments and some tendons are the soft tissues that most resist leaving the bone. Skin, soft tissues, and organs are lost much earlier. Disarticulation consists in the disappearance of the soft tissues, which, in living beings, hold bones together within a joint *(3)*. Thus, even when each bone is in the right place, the skeleton is considered disarticulated whenever the soft tissues do not join the bones together.

Disarticulation is very common in skeletonization and, in unburied bodies, takes place in a cephalic–caudal direction, and from the center to the periphery, that is to say, the head (without the jaw) usually separates first from the spine and then, the other limbs *(29)*. Dirkmaat and Sienickis *(30)* have proposed the following sequence for human disarticulation in bodies exposed to the air: first the head, because of the accessibility of its cavities to insects, followed by the sternum and clavicle; the upper limbs decompose much faster than the lower ones; the pelvis separates much later than the trunk, and the ribs do so in different degrees; the feet, often in socks and shoes, last much longer than the rest. The vertebral column, although exposed early, is one of the last to break up because of the strong costovertebral and intervertebral ligaments. Unprotected hands and feet are, however, the first to disarticulate, sometimes even before the head separates *(3)*. For bodies that have come out of water, Haglund *(31)* established that the areas that lose their soft tissues first, leaving the bones visible, are those covered by soft layers of tissue like the head, hands, and front of legs. Disarticulation begins with the bones of the hand and wrists, bones of the feet and ankles, jaw, and cranium. Finally, the legs and arms separate.

2.4.2. CHRONOLOGY

The skeletonization process varies greatly in accordance with the place where the body is found (in the open air, it is much faster than in an enclosed environment) and the season of the year (the autumn conserves better than the peak of summer). Various authors *(6,27,32)* have documented that, in a warm, damp environment, complete skeletonization may occur between 1 and 2 wk. The author performed an autopsy on a homicide victim that had skeletonized completely in 15 d at home *(33)*. The most extreme case is reported by Clark et al. *(1)*, in which skeletonization occurred in 3 d in a very humid environment where there was great insect activity; at the other extreme, there are cases of freezing that may take thousands of years. Knight *(5)* estimates, however, that in temperate climates, a period of 12–18 mo is normal for skeletonization with tendons, periosteum, and ligaments present, and around 3 yr for a "clean" skeleton.

Fig. 18. Blunt trauma of the head on a skeletonized body of a murder victim, hidden in a ditch for 5 yr. With only the bones, the forensic pathologist and anthropologist arrive to the presumable cause of death.

The bone gradually wears away in the meantime, with fractures, decalcification, and dissolution because of the combined action of various factors, such as acidic soils and water, in a process that begins, for some authors *(15)*, after 9 mo of exposure. After the complete separation of the bony parts, this disaggregation accelerates markedly, until the body may even disappear completely.

2.4.3. FORENSIC VALUE

Despite being the most impoverished stage of decomposition from the point of view of legal medicine, skeletonization is undoubtedly an important, and sometimes unique, source of information for determination of violent death by firearms, or blunt or sharp instruments. Furthermore, there are a number of examples that demonstrate the relevance of skeletons for the identification process.

The author's experience includes the case of a skeletonized body found in a ditch at the person's home, after being hidden 5 yr, killed with a blunt instrument (Fig. 18). In another situation in which the author participated concerning a multiple murder in an African country, it was possible, based on

a multidisciplinary study of the mostly skeletonized remains, to solve questions of identification and to determine the cause of death, which the case had raised *(34)*.

Finally, it is in this state of skeletonization that most victims of political genocide and/or crimes against humanity across the world are found, such as in the Balkans, East Timor, Latin America, Africa, and Iraq. The International Criminal Tribunal for the former Yugoslavia, in the trial at The Hague of those presumed responsible for the abuse of human rights in the Balkan conflicts, made use of this kind of expertise in decomposed bodies. The investigations were carried out by multidisciplinary teams under the auspices of the United Nations, which included forensic pathologists and anthropologists from around the world, some from organizations like the Equipo Argentino de Antropologia Forense or Physicians for Human Rights, which have proven essential for the demonstration of these crimes. These missions have truly galvanized this common adventure of forensic pathology and forensic anthropology—well documented in an article by Steadman *(2)*—which has not only efficiently resolved questions that were raised, but has also established some highly stimulating challenges for the future, permitting a more effective administration of justice and thus, the pacific cohabitation of peoples in a happier, healthier, and less violent world.

3. CONCLUSION

At the end of this chapter, the hope is to have given a perspective of the main alterations a human body might suffer until it is found or even completely disappears. Forensic anthropologists as well as forensic pathologists must be familiarized with these processes in order to be prepared to get involved as experts in cases for which they are called. Nobody ever knows in which state a cadaver will be presented. Thus, it is good practice that immediate and midputrefaction is not an unknown matter for forensic anthropologists. In the same way, forensic pathologists should also know how to deal with bare bones.

Interdisciplinarity is then essential. Referred everywhere *(2,33,35–37)* and permanently requested, it will be the issue of Chapter 7, and mentioned often in other chapters of this book.

This type of multidisciplinary experience has been conducted in Portugal in the last 5 yr, using the knowledge of these concepts and processes, with significant success both in terms of civil purposes and even for the administration of the justice regarding the penal law. An example of the first is, among some cases of successful identification and distinction between more than an

individual in cemeteries graves, the identification of an old female (who disappeared after a family quarrel and was found decapitated in a river) partially by personal belongings, but confirmed trough exuberant pathological vascular disorders of the leg bones *(38)*. Concerning criminal justice, the author and forensic anthropologist Eugénia Cunha (two coeditors of this book) performed some successful cases on victims of homicides already presented *(33,34)*.

This spirit, embodied by the whole philosophy of this book, must be kept and developed, not only in the international situations in which forensic professionals can be asked to participate, but also in routine cases in each country, as is shown, in Chapter 7.

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