ALFRIED WIECZOREK | WILFRIED ROSENDAHL EDS.

MUMMIES OF THE WORLD

AMERICAN EXHIBITIONS, INC.

rem | Curt-Engelhorn-Stiftung für die Reiss-Engelhorn-Museen

PRESTEL

MUMMIES OF THE WORLD

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Edited by

Alfried Wieczorek
Wilfried Rosendahl

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This book was published in conjunction with the exhibition "Mummies of the World", which tours selected venues in the United States from July 2010 through July 2013.

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EXHIBITION AND RESEARCH—THE GERMAN MUMMY PROJECT

In 2007, the Reiss-Engelhorn-Museen in Mannheim (Germany) presented the exhibition "Mummies—The Dream of Eternal Life" for the first time. This original version of this book was created in conjunction with that exhibition, and was based largely on the results of the scientific research of the German Mummy Project. The current volume has been revised to include updated research results.

The German Mummy Project was created in 2004, when 20 mummies were rediscovered in a storage area of the Reiss-Engelhorn-Museen. The project is now one of the largest interdisciplinary mummy research projects worldwide. With a team of 15 scientists from several different countries, more than 50 mummies from museum collections and crypts have been studied.

The German Mummy Project is sponsored by the Curt Engelhorn Foundation for the Reiss-Engelhorn-Museen, under the direction of Professor Dr. Alfried Wieczorek and Project Leader Dr. Wilfried Rosendahl.

The "Mummies of the World" exhibition that will travel to seven of the largest museums and science centres in the United States from July 2010 to July 2013, is based on the German exhibition and the newest results from the German Mummy Project.

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Foreword

In 2004, 20 mummies were "rediscovered" during the remodelling of a storage area of the Reiss-Engelhorn-Museen in Mannheim, Germany. This unique discovery placed an obligation on the Reiss-Engelhorn-Museen to store the mummies in a more respectful and secure manner in the future.

Finiteness and decay are part of the human condition. Mummies are the embodiment of the fight against these aspects of the human condition. Despite its alleged exclusion from the modern way of thinking, death is always present. Despite the desire to defy death, it requires a devoted preoccupation to lead to the preservation of the body. This desire has now moved into the antemortem world through the guise of "anti-aging". Cultures of the past considered the conservation of the unanimated body solely a postmortem phenomenon. The complex desire to snatch humans away from the ravages of decomposition can be seen in the bodies of 7,000-year-old mummies from the Chinchorro culture of northern Chile and southern Peru. There is a paradox to these mummies: the more efficient the method of preservation, the more brutal the destruction of the corpse had to be.

Mummies are fascinating in many ways. They raise questions by their mere existence and offer more questions than answers when studied. Like messengers, they contain within them information about environmental conditions, lifestyle, health and beliefs of people from the past. In contrast to rather abstract skeletons, mummies perhaps allow visitors a more concrete encounter with the people of the distant past. Moving away from the natural cycle of life and death has its price: the faces of mummies do not deny death, but show the viewers their own inevitable fate.

The Reiss-Engelhorn-Museen developed the idea of presenting the results of the research of the German Mummy Project to the public by preparing a comprehensive exhibition about the lives, natural history and cultural history of the mummies in the collection. The exhibition showed natural and artificial mummification throughout the ages, from the remnants of dinosaurs to modern attempts to preserve the body. We wish to thank all of the museums and institutions who loaned mummies and artefacts for the exhibition for their generous support.

We also wish to express our gratitude to all of the research partners of the Germany Mummy Project. Several renowned scientists and institutions from Europe and North America came together to form a broad interdisciplinary program of mummy research. The use of modern research methods provided insight into the mummies. All investigations undertaken by the German Mummy Project were designed to be minimally invasive; destructive physical sampling was strictly limited. Analyses of data generated from medical imaging (CT scanning), and biochemical testing such as isotopic analysis and radiocarbon dating enabled researchers to determine the sex; estimate age-at-death and living height; and establish the origin of the deceased, as well as discover information about the eating habits, health and cause of death of individual mummies. The work of the German Mummy Project has now established the Reiss-Engelhorn-Museen as an important centre for research in mummy studies.

We would like to thank the sponsors for their help with the project. Finally, we would like to thank all of the authors of this volume.

Alfried Wieczorek
CEO of the Curt-Engelhorn-Stiftung
Director General of the Reiss-Engelhorn-Museen

Wilfried Rosendahl
Deputy Director "Archaeology and World Cultures" at the Reiss-Engelhorn-Museen
Director of the German Mummy Project

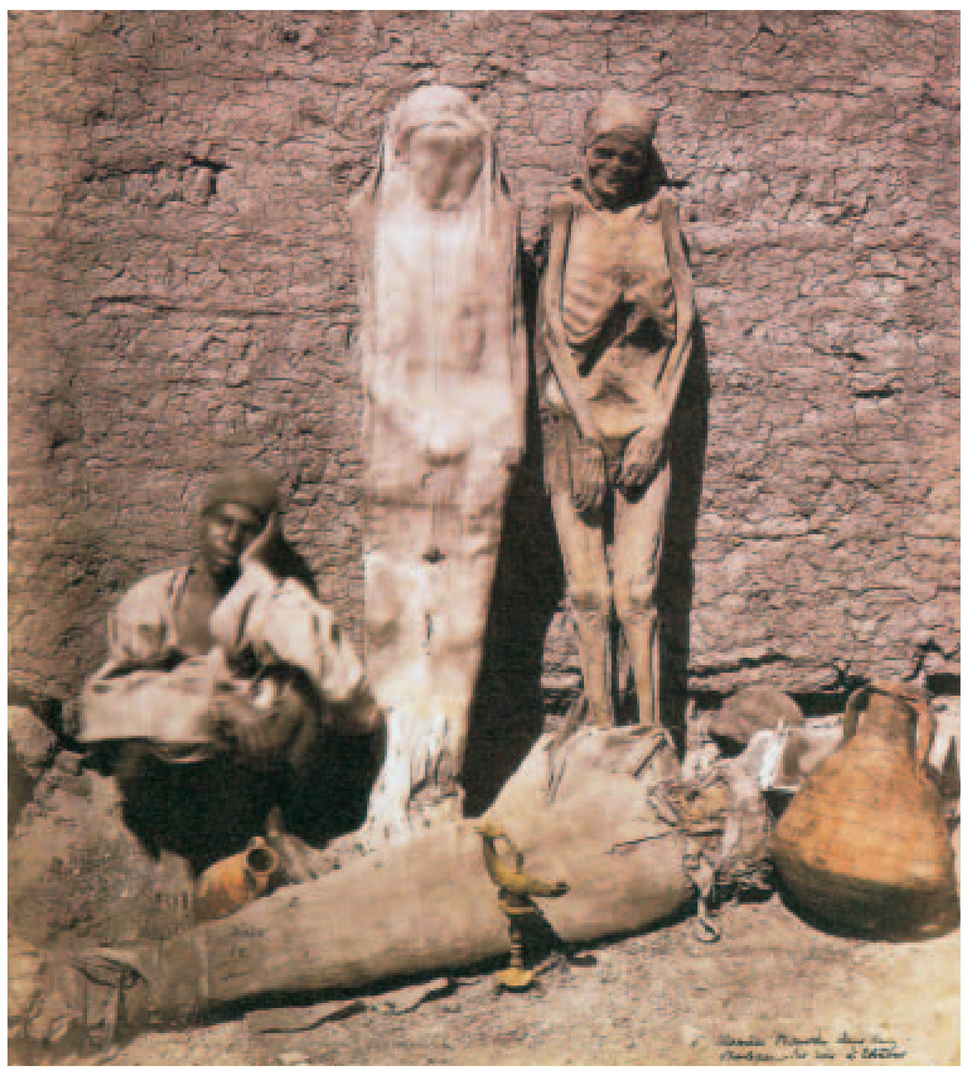
Mumia, Mummies and Mummification—An Introduction

WILFRIED ROSENDAHL

The Persian word “mum”, like the Arabic word “mumiya”, described a wax or wax-like substance. “Mumiya” was a well-known, widespread medicinal remedy found in the ground. In mineralogical terms it is known as ozokerite, bitumen or asphalt. In the 11th century the Arabic word “mumiya” entered into the Latin vocabulary of Western Europe as “mumia”, denoting a healing substance. Over time, the demand for medicinal *mumia* grew so large that it became increasingly difficult to supply the Arab and European markets. Reports stating that a type of *mumia* was found in Egyptian mummies existed from as early as the 12th century. With the passage of time, the copious amounts of resin, oils and other materials used in embalming hardened into a blackish brown, tar-like substance which looked very similar to natural *mumia*. The mention of the word *mumia* in various other texts led Europeans to transfer its meaning to the preserved Egyptian bodies themselves.

The modern English word “mummy” derives from the Latin *mumia*. For a long time this term was used only to refer to the embalmed corpses with intact soft tissues that were found in Egypt. Today, the term “mummy” describes any human or animal body which has not decayed and which has preserved soft tissues, due to either natural or artificial circumstances, regardless of its place of origin. The process leading to the creation of a mummy is known as mummification. A distinction must be made between natural mummification, arising from circumstances of climate or terrain, and intentional mummification. The term “intentional” instead of “artificial” mummification is preferable, since it includes not only mummification through various embalming and conservation techniques (artificial mummification), but also the conscious or deliberate exposure or subjection of a corpse to a naturally mummifying environment. For example, many mummies from pre-Columbian civilizations show no traces of artificial mummification. Nevertheless, on the basis of the, sometimes unusual, burial sites in areas that are favorable for natural mummification, it is possible that the dead were deliberately laid to rest there. People probably knew that bodies would maintain their physical condition in such places.

Interest in mummies and mummification dates far back in time. The Greek travel writer Herodotus, writing



1 Mummies excavated from the Valley of the Kings in Thebes. Historical photograph by Félix Bonfils, c. 1870.

in the 5th century BC, gave detailed information about artificial mummification and different types of embalming. Four centuries later, the Roman author Diodorus Siculus provided an even more detailed report. The works of classical authors were not the only source of information about artificial mummification in medieval Europe: mummification was also mentioned in the Bible (Genesis 50).

In Europe, the beginning of a more widespread interest in ancient Egyptian mummies dated back to the 13th century and was linked to the demand for the drug *mumia*. By the 16th and 17th centuries the substance had become one of the most commonly used medicines in Europe.

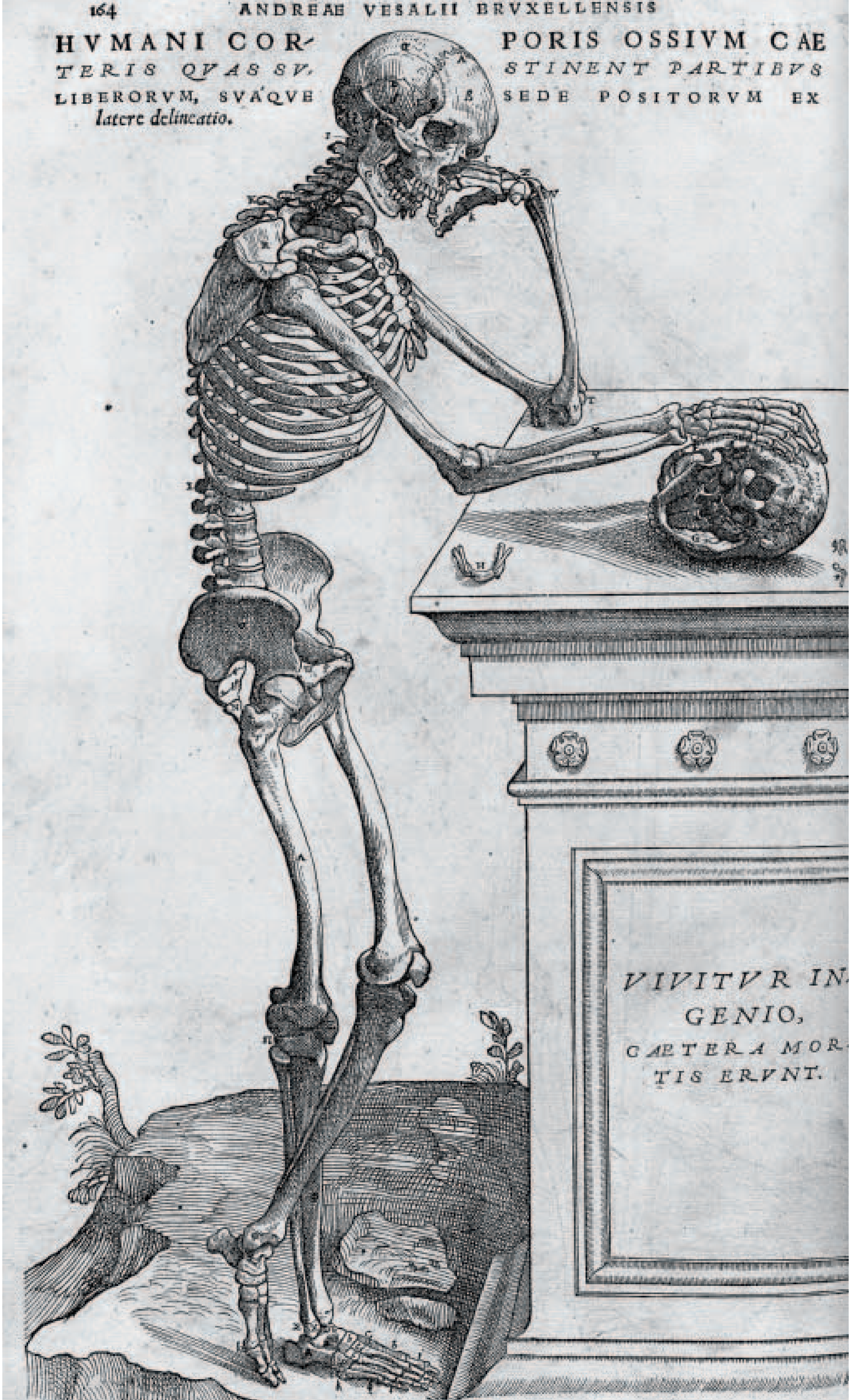
Interest in mummies as rare specimens for collections slowly developed during the 17th century. European demand for mummies grew enormously thanks to Napoleon's expeditions to Egypt (1798–1801) and the general fascination with Egypt which followed. Mummies were not merely displayed. "Unwrapping" shows were held, in which the organizers tried, in the most literal sense of the phrase, "to get to the heart of the matter". The driving forces behind such events were curiosity, a morbid fascination, and the hope of discovering precious artifacts. The mummified body itself was only the means to the end.

One of the first important steps towards scientific mummy research was made by Thomas Joseph Pettigrew, surgeon to the Duke of Kent. His book, *History of Egyptian Mummies*, documented the detailed observation of the unwrapping of a mummy for the first time. The beginning of the 20th century saw an increase in the serious scientific research of mummies, with attention focused on gaining insights into mummies as human beings. Interdisciplinary investigative programs were introduced, usually based on non-destructive methods of analysis, such as radiography. Modern mummy research had begun. At first, the only objects examined were Egyptian mummies, but that soon changed. Now both human and animal mummies, from all natural environments and cultural affiliations, are of scientific interest.

Impressive examples of this scientific interest include the internationally-renowned German Mummy Project, based at the Reiss-Engelhorn-Museen, and the international mummy exhibition. The Reiss-Engelhorn-Museen in Mannheim, Germany, were the first museums in the world to present a complete survey of the natural and cultural history of mummies. With over seventy mummified specimens from nearly each continent, the exhibition presented examples of every natural environment and many cultural affiliations associated with mummification. As the exhibition made apparent, modern mummy research is an interdisciplinary effort which makes use of many advanced methods of investigation and analysis. Through the cooperation of anthropologists, anatomists, physicians, chemists, physicists, biologists, geneticists and other specialists, the secrets of the mummies were extracted. For example, by using computed tomography, DNA analysis, drug and collagen isotope analysis, and radiometric dating, it is possible to obtain information about the individual's sex, lifespan, height, place of origin, illnesses, cause of death, diet, living environment, and type of mummification. At the present time, the most thoroughly studied mummy in the world is, incidentally, not from Egypt—it is "Ötzi, the Iceman" found in the Ötztal Alps in northern Italy.

Mummies are unique records of the past. By studying mummies it is possible to gather information that contributes greatly to our understanding of life in past ages and many cultures. Mummies are also the most fascinating visual metaphor for the dream of everlasting life.

Mummies—In Nature and Around the World



Skeleton in a landscape, with one elbow resting on a pedestal inscribed, *Vivitur ingenio, caetera mortis erunt* ("Genius lives on, all else is mortal"). On the pedestal lies a skull, which the skeleton holds in order to examine it. From: *De humani corporis fabrica libri septem Andreas Vesalius* (1514–1564).

Preceding pages
The Schwarzes Moor bog
in the Rhön hills.

From Flourishing Life to Dust— The Natural Cycle of Growth and Decay[1]

BURKHARD MADEA, JOHANNA PREUSS AND FRANK MUSSHOFF

Dying, Death, Intermediate Period, Early Signs of Decomposition

Postmortem processes leading to the decomposition of a cadaver begin immediately after the onset of death; the manner and circumstances of death may determine the sequence of the first signs of decay. For this reason, this chapter will begin with a few remarks on death and dying. Dying and death are continuous biological processes which were undefined for a long time. In his work on contemporary Roman law, the respected 19th century jurist Friedrich Carl von Savigny wrote that death was such an elementary and natural event that there was no need for a closer definition of its elements (Madea 2006a). It was not until the advent of machines that could take over failed circulatory or respiratory functions that the need arose for a legal definition of death, such as would protect a physician from judicial prosecution in a case involving the turning off of a life-support system.

1a Suicide by hanging. After hanging for several days, the body displays livor mortis in the lower extremities (stocking-shaped in the legs, glove-shaped in the lower arms and hands). Initial greenish discoloration of the belly.

1b Livor mortis of a body lying face down.

Today, the criteria for the onset of death are the irreversible cessation of respiratory or circulatory functions, or the determination of brain death following serious primary or secondary brain damage, where, in the case of brain death the functioning of the cerebrum, cerebellum and medulla oblongata has ceased (Madea 2006a). The diagnosis of brain death under intensive care conditions is given in only a fraction of the approximately 850,000 yearly deaths in Germany, namely in connection with the suspension of life-support systems or the removal of organs for transplantation purposes. In the great majority of cases individual death is attributed to the consequences following the irreversible cessation of respiratory and circulatory functions.

In many cases of death due to internal disease, the dying process manifests itself to observers through an increasing dysregulation of essential bodily functions in the patient, who does not consciously experience dying, at least during this stage. The dying phase itself is known as the "death throes", which, if they take time, are the unmistakable precursor to death. The term *facies hippocratica* describes the facial expression of the dying person: the nose is pale and pinched, the eyes and cheeks sunken, the complexion gray and pale, and the forehead clammy. In contrast to these slow, quasi-methodical cases where the drawn-out throes take hours or days, violent or sudden deaths from natural causes have quick or practically instantaneous end phases in which the person dies in a matter of minutes or seconds.

Respiratory and cardiac arrest lead to a complete loss of muscle tension, so that, contrary to popular misconception, the final sensations of dying cannot be seen in the expressions of the recently deceased. Photographs of the dead, and death masks, display relaxed facial features, as a rule, although the facial expression may also—as in living persons—manifest signs of protracted illness (such as the haggard, emaciated appearance of cancer patients).

Although irreversible respiratory and cardiac arrest is a criterion for clinical death, not every tissue and every cell in the body has died. A phase known as the supravital phase, or intermediary or interlethal period, commences, in which certain tissues survive despite the stop of all blood flow to the brain (Madea 1994; Madea 2002; Madea and Henssge 1991). During this phase, certain tissues will react to outside stimulus, much like those in a living body. Thus, striated skeletal muscle will react after death to mechanical or electrical stimuli, in individual cases up to twenty hours *postmortem*. The smooth muscles of the iris also react up to forty hours after death to medications which dilate or contract the pupils. These supravital reactions are today used in order to estimate the time of death of a body in cases of violent crime or unknown time or cause of death (Henssge/Madea 1988; Henssge *et al.* 2002; Madea 2006a; Madea 2006b). The term "biological death" is used when the cells in the body have died. In bradytrophic tissues this may occur up to 100 hours after death. Biological death is a totally irrelevant cut-off point in determining the time of death.

The biochemical basis for supravital reactions are the metabolic processes which continue to occur for some time after death, until either substrate deposits are exhausted or reaction-stopping conditions (fall in pH values) arise. Following irreversible respiratory and cardiac arrest, since the dissolved oxygen in tissues has been exhausted and there is no supply of fresh oxygen, anaerobic glycolysis becomes the essential energy-releasing reaction, a reaction which, however, yields only $^1/_{18}$ the amount of energy.

Sure indications of death, visibly and easily identifiable also by non-medical professionals, are livor mortis and rigor mortis, which were not recognized as definite signs of death until well into the 19th century (Henssge and Madea 1988; Henssge *et al.* 2002)

The first sure sign of death was considered to be the onset of putrefaction or the loss of electrical excitability of the skeletal muscles, since the reaction of muscles to mechanical or electrical stimulus was erroneously considered to be a sign of existing "vitality".

Livor mortis, the discoloration of the cadaver's skin (figs. 1a and 1b), comes about after circulation ceases in the dead body and the blood sinks by action of gravity to the lowest situated, "hanging" parts of the body. In a body lying on its back, this is the back itself, although the support points—the points of the body in direct contact with the underlying surface—are not affected, since the pressure from the surface is greater than hydrostatic pressure. Livor mortis sets in about twenty to thirty minutes after cardiac arrest and appears first as reddish discolored blotches which then coalesce. In the early *postmortem* period they disappear when light pressure is applied, or they can be shifted to different body parts by changing the position of the cadaver. As time continues, it becomes more difficult to make them disappear or to shift them.

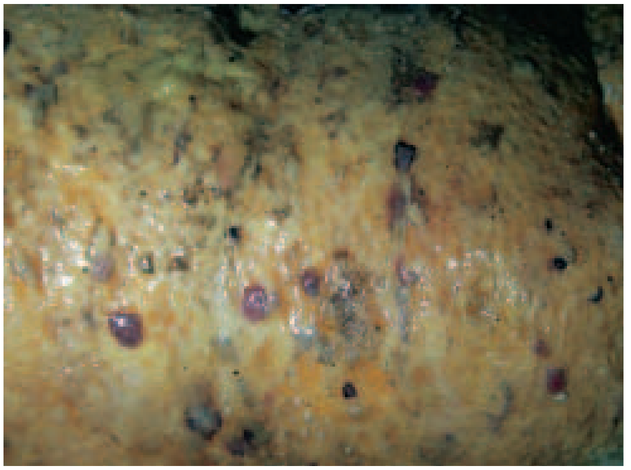
Muscles store glycogen, which following death is used to resynthesize adenosine triphosphate (ATP). When the glycogen is used up, there is a fall in ATP levels. ATP functions as a "softener" in the muscles by enabling the actin filaments and myosin filaments to slide into each other and allowing the release of the myosin heads from the actin filaments. In the absence of ATP, the actin and myosin filaments form an irreversible bond and the sliding mechanism gives way to a state of rigidity (fig. 2). Rigor mortis was not acknowledged as a sure sign of death until well into the 19th century, even though Shakespeare gave an accurate and detailed description of it (Shakespeare, Romeo and Juliet, Act IV, Scene 1):

> "Each part, deprived of supple government,
> Shall, stiff and stark and cold, appear like death"

The nature of the dying process is also illustrated by the amount of time it takes after death for rigor mortis to set in. At a normal environmental temperature (room temperature of 20°C/68°F), rigor mortis in the body of a person with average strength and diet sets in as a rule between three and four hours after death.

The old court physicians were already aware of factors which could influence the progress of rigor mortis, such as were summarized by the internist Adolph Kussmaul (1822–1902) in his study of rigor mortis from 1856 (Henssge and Madea 1988): "The more quickly an individual passes away, the stronger and longer lasting the rigor is under constant conditions, and typically the later

2 Lower legs extended against gravity through rigor mortis.



3 Bacteria causing change of pigment in the dermis of a drowned body.

its onset… The greater the adverse effects of the late illness on the nourishment of the muscles, the weaker and more brief the appearance of rigor and the quicker it usually appears. The more strongly an agent reduces the vitality of the muscle tissues, the more rapidly it stiffens. The cadaver of a physically strong person in surroundings of 2.5°C to 7.5°C (36.5°F to 45.5°F) will remain rigid for eight to ten or more days, while at 18.8°C to 30°C (66°F to 86°F) it will lose all trace of rigidity in four to six days."

Later Signs of Decomposition

Thanks to their time sequence, the early signs of decomposition in a cadaver (rigor mortis and livor mortis), along with the supravital reactions, are today instrumental in accurately determining the *postmortem* interval (i.e. the time elapsed since onset of death). Immediately following the early signs of decay there begin the later stages, which chronologically cannot be strictly separated, and which lead not only to the decomposition of the cadaver, but also in some cases to its preservation. Exogenous and endogenous factors contribute to the destruction and decomposition of a cadaver. Among endogenous factors are autolysis, putrefaction and decay, while exogenous factors include animal predation, exposure to the elements, and mechanical injury.

NOTE

Various dissimilar signs of advanced decay may appear simultaneously in a cadaver as a result of a change in surrounding conditions. If a cadaver is exposed by its position to separate environmental conditions (such as from lying in a roadside ditch, half-submerged in water, half-exposed to air) quite different processes of decay may occur simultaneously.

Autolysis (Self-digestion)

Autolysis is here defined as the destruction of an organ's structures through its own enzymes. Organs, such as the pancreas, which are already rich in enzymes in life are thus subject to very quick self-digestion after death. Under the right circumstances, for example when a cadaver is stored at a high temperature, only a few hours are needed to render a histological diagnosis of the organ impossible. Due to the effects of gastric acid, autolysis of the stomach lining occurs relatively quickly, which can lead to a complete softening of the stomach lining. The adrenal medulla is also destroyed quite rapidly. Since it takes some time following death for all energy-supplying processes to cease, there is also a collapse in the functioning of the cells' membranes or in the intracellular compartments, with a *postmortem* equalization of the concentration of substances which were unequally distributed in the different compartments during life. Therefore, there is an increase in potassium and a decrease in sodium and chloride concentrations in extracellular fluid after death. As a result of anaerobic glycosis, levels of lactic acid concentration rise while pH values fall. For this reason, the clinical-chemical tests which are of such great importance in diagnosing the progressive stages of illness in a living person are of only very limited use *postmortem*.

As a result of autolysis, the lysosomes discharge hydrolytic enzymes which are activated by the low pH value in the cytosol: acid phosphatase, acid ribonuclease, acid desoxyribonuclease, cathepsin, collagenase, acid triglyceride lipase, alpha and beta-glucosidases, glucuronidases, and many other enzymes. These play a decisive role in the self-destruction of cell structures. Autolytic processes also lead to a collapse of the skin's protective functions: anaerobic germs in the deeper skin layers are replaced by aerobic outer skin layers, and the skin's "acid mantle" becomes increasingly less effective (Krause 2004). This makes the skin more receptive to bacteria floating in the air. Pigment-producing bacteria, such as *Serratia marcescens*, may cause a typical red discoloration of the skin (fig. 3). Decisive factors in the chronological progress of autolytic processes are the inner milieu of the cadaver upon death, and the surrounding temperature. Autolysis eventually limits itself either through a lack of substrate or the deterioration, or proteolytic inactivation, of the enzymes themselves. As bacteria penetrate the tissues, autolysis is finally superseded by the processes of putrefaction and decomposition.

Immunohistological Testing for the Visualization of Proteins

Autolysis leads to structural decay at cellular and subcellular levels. This structural decay is also used in solving practical forensic problems, such as determining the duration of the *postmortem* interval (Madea 2005).

Immunohistological testing for the purpose of determining the time of death is based on the assumption that the tertiary structure of antigens undergoes *postmortem* changes as the *postmortem* interval lengthens, and that, due to protein denaturation, the presence of the antigen can no longer be detected through the appropriate antibodies. The appropriate tests for the immunohistochemical detection of various antigens have been developed for insulin, thyroglobulin and calcitonin. Thyroglobulin protein can always be found in the thyroid gland *postmortem* for up to five days, but never after a period of 13 days. A negative reaction therefore points to a period of over six days after death, while a positive reaction means a period of under twelve days. The beta cells of the pancreas always show a positive immune reaction to insulin up to twelve days *postmortem*, while for a period of over thirty days the reaction is always negative. This means that in those cases with a negative immune reaction the time of death is over twelve days earlier, and in those with a positive result the time is under 29 days. Calcitonin has always been found in the C cells of the thyroid gland for up to four days, but in no case was it present after the 13th day.

Of course, the immunohistochemical staining of cellular antigens gives only a very rough estimate of the time of death; nevertheless, in certain cases the conclusions regarding time of death derived from observing immune reactions may be very useful. In any case, it must be taken into account that a lack of reaction depends to a large extent on temperature (Madea 2005).

Putrefaction

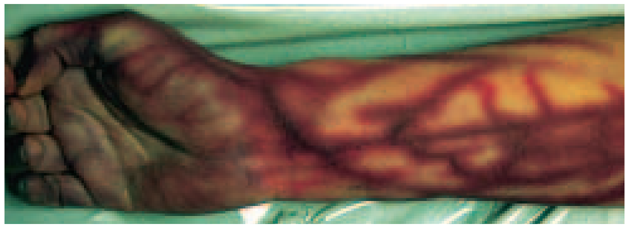
In contrast to autolysis, putrefaction is described as a "heterolytic" alkaline colliquative process on a reductive basis caused by bacteria, which as it progresses displays typical characteristics, both visual (bloating) and olfactory (foul ammoniacal odors), due to the build up of gases (hydrogen sulfide, hydrocarbons) and the release of ammonia. Parts which are particularly affected by bloating from gas accumulation are above all tissues with low turgor ("liquid" pressure from within), such as the eyelids, mouth, and tongue, which may become monstrously swollen (fig. 4). The abdomen may also swell extremely due to gas accumulation. The production of gas is the main reason drowned bodies soon float to the surface of water.

The abdominal wall takes on a greenish discoloration, the result of the buildup of sulfhemoglobin as oxygen is used up by intestinal bacteria (see also fig. 1, initial green discoloration of the belly). Since this requires oxygen, the green discoloration through sulfhemoglobin accumulation first appears on those parts of the body where the intestines lie closest to the abdominal wall, such as the lower right belly. The discoloration may then, however, expand to the entire surface of the body.

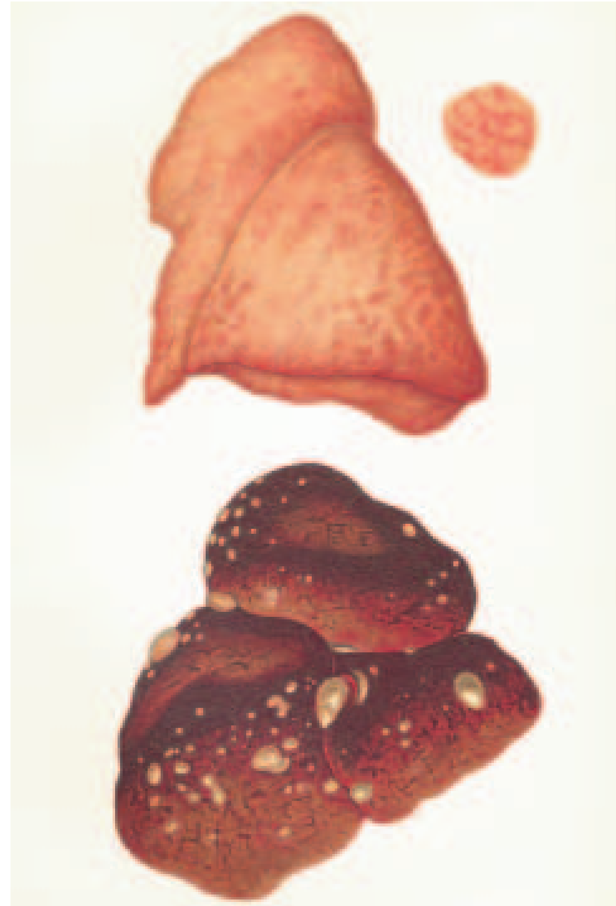
The spread of bacteria in the veins of subcutaneous fatty tissue and the hemolysis of red blood cells causes the venous "marbling" of the skin (fig. 5).

A further characteristic of putrefaction is the formation of putrefaction transudates (accumulations of putrefied fluids) which leak out of the dermis and may cause the epidermis to detach from the dermis. Such putrefactive blisters may grow to large dimensions, finally tearing through the epidermis, causing it to come off in shreds and exposing the dermis, which can very quickly dry out and become brown. In addition, during putrefaction the hair and nails become loose and can easily be dislodged. This looseness of hand and toenails and hair found in drowned bodies is a criterion for determining the their length of time in water (Madea, 2006b). In the course of putrefaction there is finally a liquefying

4 Gas accumulation and greenish discoloration in the face of a drowned body, along with several dried up reddish-brown patches on the chest where the epidermis has fallen off.



5 Venous marbling in an arm.



6 Top—A normal lung. Bottom—Lung affected by putrefaction, with dull red discoloration and formation of gas blisters.

of fatty tissues, which may then flow out of the body like butter or margarine when the skin is cut open, as well as the decomposition of the body's proteins (proteolysis). During proteolysis there is an accumulation of biogenic amines (putrescine, cadaverine, histamine, choline, etc.) as well as cadaveric alkaloids, referred to as ptomaine (cadaveric poisoning). Even though this ptomaine has exhibited muscarinic atropine-like effects in tests on animals, we cannot use the term ptomaine/cadaveric poisoning to say that it makes the area around a putrescent corpse "toxic". The health risks from corpses, the same as those from living people, come from infectious pathogens (tuberculosis, hepatitis, HIV), since these pathogens are able to survive the death of their host (the deceased person).

During bacterial proteolysis certain amino acids such as delta-aminovaleric acid or gamma-aminobutyric acid can be found in the brain and liver, which can be used to make a rough estimate of the time elapsed since the death of the body (Daldrup 1984).

Further symptoms arising from gas accumulation and gas bloating are the formation of so-called "foam" organs (fig. 6)—organs permeated with gas and macroscopically detectable cavities—as well as the discharge of putrefactive fluids from the mouth, nose, anus and genitals. In pregnant women, the pressure from putrefactive gas may cause the fetus to be expelled through the genitalia, a phenomenon known by the macabre term "coffin birth". While the early signs of decomposition can be used in making a rough estimate of the time of death, the sequence of symptoms of decay which depend on previously existing organ disease; length of dying; environmental conditions, especially surrounding temperature; bacterial infestation, and other factors, is so variable that there can be no conclusions drawn as to the time of death (Table 1), but only very approximate estimates. A rule of thumb which goes back to the Berlin forensic doctor Johann Ludwig Casper (1796–1864)—named Casper's Law, after him—says that one week in air equals two weeks in water equals eight weeks buried in the ground. Casper's Law thus places the decomposition process under different environmental conditions (air, water, earth) but does not allow for a concrete determination of time of death.

Estimating the time of death of a body exposed to air is difficult above all because of the considerable fluctuation in temperatures (between day and night). When the cadaver has been lying in water, however, the surrounding temperature remains relatively constant, so that the signs of decay present can be used to estimate roughly a "minimum water time".

All aspects of putrefaction—not only the visual, olfactory, and tactile, but also the auditory—are described by the French poet Charles Baudelaire in "Une charogne" (The decaying carcass) in *Les Fleurs du Mal*:

"The blow-flies were buzzing round that putrid belly,
From which came forth black battalions
Of maggots, which oozed out like a heavy liquid
All along those living tatters.
All this was descending and rising like a wave,
Or poured out with a crackling sound;
One would have said the body,
swollen with a vague breath,
Lived by multiplication.
And this world gave forth singular music,
Like running water or the wind,
Or the grain that winnowers with a rhythmic motion
Shake in their winnowing baskets."[2]

The Chemistry of Putrefaction

Putrefaction is a bacterial process which starts with the microbial flora of the skin and mucous membranes (Berg 1975; Berg 2004; Bonte 1978). Of particular importance in this process are clostridia and various types of proteus, whose flagellant motility enables them to spread quickly and actively through an organism. In experiments, a dissemination speed of 20 cm in 30 hours could be measured. Aerobic bacteria such as *E. coli* and *Staphylococcus* species have only a very limited ability to penetrate through cadaveric tissues.

By administering antibiotics while a patient is still alive *postmortem* putrefaction processes can be suppressed or delayed. When considering the breakdown of substrates, catabolic putrefying processes are best differentiated into protein, carbohydrate, and fat metabolic pathways. Proteolysis through proteases (enzymes which break down proteins) proceeds to breakdown products such as peptone and oligopeptide and finally to the approximately twenty amino acids found in human proteins. These are then either deaminated into their corresponding acids or decarboxylated into analogous amines, by which the end products ammonia and carbon dioxide are created. *Postmortem* increases in ammonia concentrations have been investigated as to their suitability in estimating time of death. Glutamic acid yields alpha-aminobutyric acid, gamma-aminobutyric acid and delta-aminovaleric acid, which likewise have been investigated in connection with their suitability in estimating time of death. The aromatic amino acids phenylalanine, tyrosine and tryptophan yield p-cresol, phenol, skatole and indole, which have been identified as olfactory components in putrefaction. Of particular significance for the odor of putrefaction, however, are the breakdown products of the sulfur-containing amino acids cystine, cysteine, and methionine (hydrogen sulfide, methyl mercaptan, and ethyl sulfide). Ornithine and lysine yield putrescine and cadaverine while leucine and isoleucine yield short-chain fatty acids.

Anaerobic glycolysis leads to the breakdown of carbohydrates. Through glycolysis, one glucose molecule yields two molecules of lactic acid. Various bacteria, among them clostridia, may, through alcohol fermentation, break down monosaccharides into alcohol, so that typical putrefactive alcohols are created in the cadaver.

Fats and lipids are broken down by hydrolases, esterases and catalases into their components. Long-chain, unbranched fatty acids, however, can only be broken down to a small extent through beta-oxidation, due to the lack of oxygen.

Putrefactive gas is composed of the volatile end products of bacterial catalysis: methane, carbon dioxide, hydrogen sulfide, ammonia, primary amines (cadaverine, putrescine, skatole, indole) and mercaptans. Using modern analytical methods, research today continues into the chemistry of putrefaction, in particular by an interdisciplinary work group at the Institute of Forensic Medicine at the University of Bern, Switzerland.

With the further development of imaging techniques (magnetic resonance spectroscopy), the *in corpore* measuring of putrefactive products has been made possible. Experiments on isolated sheep heads at a constant ambient temperature (21 ± 3°C/70°F) for 18 days have yielded reproducible changes in the concentration of known metabolites as well as the appearance of degradation products that have yet to be identified. Alto-

TABLE 1

Morphological changes in the putrefaction phase. Aboveground exposure at 20°C to 24°C (68°F–75°F) without insect infestation. According to Berg, 2004.

INDICATION	INTERVAL AFTER DEATH
Initial greenish discoloration on abdominal skin	1–2 days
Cutaneous venous marbling	2–4 days
Beginning of film-like slippage of the epidermis	5–6 days
Loss of pigmentation in the *stratum germinativum*	6–8 days
Putrefactive blisters and putrefactive transudates in the body cavities	8–14 days
Putrefactive emphysema in the *subcutis*	8–14 days
Bloating of abdominal cavities	8–14 days
Diffusion of all fluids, collapse of organs	usually not until months later
Beginning of mummifying dehydration of soft tissues	usually not until months later

Please note that this table gives only rough indications for the sequence of putrefaction in cadavers exposed above ground at a relatively narrow range of temperature. Numerous deviations are possible, depending on the body's build, the underlying surface, coverings, and terminal illness.

gether, 30 metabolites were identified in sheep brains, 19 of which displayed time responses. Thus, the neuronal marker N-acetylaspartate displays a rapid *postmortem* decrease in concentration and can be used to indicate a *postmortem* interval of under 70 hours. Butyrate and propionate show—as a result of bacterial metabolism—after 30 to 50 hours an increase in concentration which lasts up to about 400 hours *postmortem*. Using the metabolites acetate, alanine, trimethylamine, butyrate and propionate, times of death were calculated in each reading which correlated well with the actual time of death (correlation coefficient r = 0.93). Good correspondences between estimated and actual times of death have been shown for a *postmortem* interval of up to 250 hours (cited by Madea 2005). The *postmortem* degradation of the human brain is very similar to that of a sheep brain. With the magnetic resonance spectroscopic examination of degradation products in a cadaver brain we thus have a non-invasive method of detecting putrefactive products which enables longitudinal examinations with reproducible results (Madea 2005).

Preservation of Decomposing Bodies

With regards to the skin, the essential symptoms of putrefaction are hemolysis, transudation and gas accumulation. It is possible to preserve signs of putrefaction for a longer period of time under special storage conditions, for which it is of utmost importance that the packaging of the body or body parts is extremely airtight (Berg *et al.* 1981; Madea 1992; Schmitt *et al.* 1995).

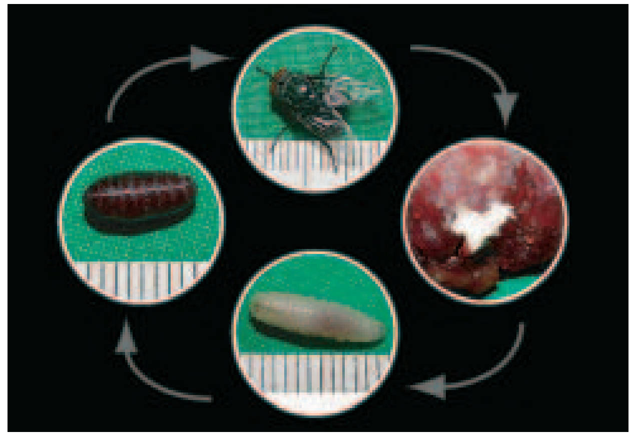
A case reported by Petersohn (Petersohn 1972) concerns a six-year-old boy whose body was found wrapped in a plastic bag under about 30 to 40 cm (12 to 16 in) of construction debris in the light well of a basement window, three and a half years after his disappearance. The excellent state of body preservation, including the maintenance of the form and color of all the inner organs, was attributed to the nearly airtight packaging of the cadaver in plastic foil. Berg (Berg *et al.* 1981) describes the case of a newborn child whose body, after being buried for ten years in a plastic wrap under the floor covering of an apartment building terrace, was found in a state of decomposition which would otherwise correspond to a period of six weeks. In this context, Berg and his team referred to the extraordinarily well preserved corpses of ancient China, whose conservation was attributed, among other factors, to their being hermetically submerged in a dark reddish-brown fluid.

Experimental investigation of the influence of vinyl materials on *postmortem* alterations in rabbit and mice cadavers kept in plastic bags of different air volumes (three liter/five pints, one liter/1¾ pints, no air) at room temperature yielded a clearly delayed decomposition of cadavers stored in plastic materials; the volume of air in the bag is clearly of great importance in the progression of decay (Madea 1994). In one particular case of a body which had been dismembered to hide evidence and the parts wrapped in plastic bags, the extremely good state of preservation after a period of two years allowed a positive dactyloscopic identification, despite epidermolysis (Madea 1994, fig. 7).

Along with the inhumation of the body parts in winter, a preservative factor in this case was considered to be the very airtight packing into plastic bags, which together with a physical covering clearly contributed to a delay in decomposition processes. In a different case of hiding evidence by dismemberment, in which the body parts had lain hidden in different districts of Cologne, Germany, over the unusually long period of seven years before discovery, their extraordinary state of preservation allowed each individual part to be assigned, through molecular biological evidence, to one person (Schmitt *et al.* 1995). After being hermetically sealed for seven years after the homicide, the section containing the chest wall even allowed for a determination of the cause of death (stab wounds to the chest, with two punctures of the heart).

Destruction of Corpses by Maggots

Maggots may contribute significantly to the destruction of a corpse (fig. 8). Flies may begin to lay eggs on the body in the period before death. Depending on surrounding conditions, egg deposits often occur in the nostrils and in the corners of the mouth and eyes. Egg deposits develop into maggots, then pupae, then empty pupal shells and adult flies. The development cycle lasts between three and five weeks, depending on species and temperature. Maggots produce enzymes which break down proteins and they feed on disintegrated soft tissues. In summer, it is possible for maggots to reduce an aboveground cadaver nearly completely to a skeleton within a few weeks. For the coroner, an additional problem is that eggs are frequently deposited in wounds to the skin while the subject is still alive, resulting in extensive destruction to the wounds and the loss of evidence of the cause of death (Madea 2006b).



7 Body parts found wrapped in garbage bags buried in the woods for two years. Despite the loss of epidermis, a dactyloscopic identification was possible on the hands.

8 Development cycle of the fly: egg mass, maggots, pupae and adult flies.

Decomposition

Decomposition, as distinct from putrefaction, is a dry, acidic process on an oxidative basis, which leads to the splitting-off of acids (H_2CO_3, H_3PO_4, H_2SO_4). Decomposition is accompanied by a rancid odor which is described as a musty or rotting smell. Very often there are colonies of mould (fig. 9).

The Chemistry of Decomposition

While putrefaction is a mainly anaerobic bacterial reduction process, decomposition is dominated by aerobic microbiological processes which may create pungent, rotten odors from the metabolic products of oxidation. In the course of putrefaction, if the superficial layers of the skin become permeable (such as when the skin is penetrated by maggots), oxygen from the air can penetrate into deeper layers of tissue so that here too an aerobic milieu dominates and anaerobic putrefactive processes are then superseded by aerobic decomposition processes. At the beginning of decomposition large patches of fungus also form on the skin and mucous membranes. At this point of the decomposition process the breakdown by beta-oxidation of the long-chain unbranched fatty acids accumulated during putrefaction can now continue, releasing carbon dioxide. Acetaldehyde, acetic acid and succinic acid are the end products of the oxidative breakdown of carbohydrates (Krause 2004).

Period up to Skeletonization

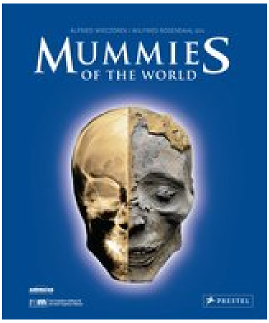
The period up to skeletonization varies greatly, depending on how the body is stored; this has already been expressed through Casper's Law, which says that a cadaver lying on the ground decomposes more quickly than one lying in water or underground, although the ratios Casper states are also certainly subject to numerous variations.

Cadavers lying on the surface of the ground are as a rule skeletonized within one year, and after two years the bones are essentially completely free of soft tissues. A considerable proportion of soft part reduction in the summer months is due to maggot infestation and animal predation. Under such conditions, a cadaver can be completely skeletonized within a few weeks (fig. 10).

In the case of a body lying underground, the time needed for skeletonization depends essentially on the composition of the soil. Under normal conditions, usually water-permeable, aerated soil at a depth between 1 and 2 m (3 ft 3 in to 6 ft 6 in), about five to seven years are needed until skeletonization is complete (Berg 2004; Fiedler *et al.* 2002; Gaedke 2004), although considerably longer periods are also possible. In warmer climates, the period of skeletonization is normally rather shorter. Results of exhumations in the past few years indicate, however, that even after burial periods of five to seven years some bodies, plus clothing, were often well preserved; in some cases the inner organs with the gastrointestinal tract were still intact. This has been of particular importance since, among other issues, the matter of poisoning and the route of poison ingestion has had to be determined (Käferstein *et al.* 1996; Madea 2006a).

9 Mould colonizing a cadaver.

UNVERKÄUFLICHE LESEPROBE



Alfried Wieczorek, Wilfried Rosendahl

Mummies of the World

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Prestel

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Dieser Begleitband zu einer lang erwarteten Ausstellungstournee in den USA, die 2010 eröffnet wird, stellt 70 Mumien aus verschiedensten Kulturen und Gegenden der Welt vor, darunter Mumien aus Asien, Ozeanien, Südamerika und Europa sowie aus dem Alten Ägypten. Gezeigt wird zudem die Bandbreite der Techniken, die unsere Vorfahren einsetzten, um die Körper ihrer Toten zu konservieren – nicht nur im Wüstensand, auch im Eis, grasbedeckten Mooren und unterirdischen Räumen. In fast 30 Aufsätzen werden die jüngsten Erkenntnisse auf dem Gebiet der forensischen Mumien-Forschung präsentiert. Mit herausragenden Fotografien und Illustrationen beleuchtet dieser Band die unausgesprochenen Geheimnisse der Mumien.