REVIEW ARTICLE

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Decomposition of buried corpses, with special reference to the formation of adipocere

Abstract The unrestrained decomposition of a corpse involves the consecutive processes of autolysis, putrefaction and decay. Ideally, decomposition is completed within the regular resting time (15–25 years) and leads to the entire skeletalisation of the corpse. Adipocere, a greyish fatty substance formed during decomposition, is regarded as a spontaneous inhibition of post-mortem changes; it makes the corpse almost entirely resistant to decomposition and makes it impossible to use the same graves again. This creates problems for local governments with regard to the generally growing demand for burial ground.

Apart from corpse-specific characteristics (e.g. sex, age, physique, cause of death), method of burial (e.g. material of the coffin, depth of grave, individual or mass grave, clothing) and time of burial, the conditions of the resting place (geology, topography, soil properties and frequency of use, air, water, and heat budget), in particular, have a special impact on adipocere formation. This study summarises the present knowledge on this phenomenon, combining results gained both in forensic medicine and in geosciences.

Introduction

In central Europe, the post-mortem changes in human corpses usually take place in the earth. Ideally, decomposition leads to the entire skeletalisation of corpses, which is usually achieved within the regular resting time (15–25 years). However, numerous publications can be

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found on subjects ranging from decomposition disturbances in graveyards to the development of adipocere, commonly known as grave wax. The latter represents the most frequent cause of the inhibition of post-mortem changes in interred corpses (Büchi and Willimann 2002). Adipocere formation leads to the conservation of corpses beyond their regular resting time and prevents the reuse of the graves (Weinzierl and Waldmann 2002). This creates problems for local governments with regard to the generally growing demand for burial ground. According to a survey carried out in the federal German state of 'Baden-Württemberg' in southern Germany, approximately 38% of all graveyards are affected (Graw and Haffner 2001). Wourtsakis (quoted in Fleige et al. 2002) assumed that as many as 30–40% of the cemeteries in 'Rheinland-Pfalz' are located in problem-prone areas. Considerable political and economic problems are obvious.

Adipocere has been extensively analysed in forensic science using tissue samples collected from corpses. However, the majority of publications are cause-orientated (Peterson 1972; Madea 1994; Schumann et al. 1995). Soils in which adipocere formation occurs have never been described in great detail. Corpses which have been interred for a similar length of time can still display varying degrees of decomposition. Therefore, more detailed information about the environmental conditions of the burial area is needed for the precise determination of the time of death. To date, few investigations outside forensic research are available. There have been a few studies dealing with post-mortem storage and decomposition of corpses in earth graves with respect to their potential ecological risk due to the possible accumulation of germs (Pacheco et al. 1991), heavy metals (Grenzius 1987), nutrients (Fleige et al. 2002), and xenobiotics (Urban 2002). No systematic surveys of soil-dependent reasons for the formation of adipocere have yet been carried out.

On the basis of this topical interest, the present review summarises the current knowledge of post-mortem changes with special reference to adipocere formation in

earth graves. For the first time, results from forensic medicine and geosciences are brought together and integrated, since the combined effort of these sciences is necessary in order to solve the problems likely to be encountered.

Post-mortem changes

Post-mortem changes have been dealt with extensively in previous publications (Evans 1963b; Coe 1973) and will thus not be referred to in detail here. Human decomposition (degradation) begins approximately 4 min after death (Vass 2001) and is characterised by different phases and processes. These can be distinguished functionally but it is not possible to attach a definite timescale to them (Graw et al. 2002). Shortly after death, enzymes occurring naturally in the body begin the degradation processes (*autolysis*). This leads to an increased permeability of the cell membrane and to a sanguineous–aqueous saturation of the tissue (*haemolysis*) and finally to the liquefaction of the soft tissue.

These processes allow the rapid expansion of the intestinal flora, thus leading to the acceleration of the decomposition. While the processes of *putrefaction*, such as the formation of hydrocarbons, ammonia compounds and biogenic amines, operate under strictly anaerobic conditions (Daldrup 1979), subsequent *decay* by bacteria and fungi is purely aerobic and, ideally, leads to the entire *skeletalisation* of the corpse (Berg et al. 1975; Urban 2002).

The time interval between time of death and final skeletalisation is governed by the environment in which these processes occur: While the processes of degradation on the soil surface, which is biologically highly active, usually reach completion within several weeks (Walcher 1937), the time required for the decomposition of interred bodies takes between 3 and 12 years under favourable conditions (Prokop 1966; Schoenen 2002). Under unfavourable conditions, the processes might require up to a hundred or even thousands of years before completion (Berg et al. 1975).

Spontaneous inhibition of post-mortem changes

There are a number of post-mortem processes in which the decomposition processes are dramatically reduced. These include (1) mummification under dry and airy conditions, (2) conservation in peatland under the influence of humic acids and oxygen deficiency and (3) the formation of adipocere. Since adipocere formation poses specific problems in graveyards, this review will focus on this phenomenon.

Formation of adipocere

Adipocere (adipo = fat, cere= wax) is formed by the alteration of the soft tissue of the corpse into a greyish-white, soft, cream-like substance, over time becoming an armour-like solid and resistant mass (Strassmann and Fantl 1926). Since the middle of the nineteenth century it has been known that this mass mainly includes palmitic and stearic acid (Gregory 1847; Goy and Wende 1922). Depending on the environment of the resting-place, adipocere-laden bodies can be observed after as little as 30–90 days after death (Zillner 1885; Mant and Furbank 1957; Dix and Graham 2000).

According to individual reports, the first comprehensive description of the phenomenon was undertaken in 1789 by Fourcoroy and Thouet on the occasion of extensive exhumations in Paris (quoted by Prokop and Göhler 1976). Although no final systematic investigations are currently available on the formation of adipocere, the essential processes are largely agreed upon. Through the *hydrolysis* of triglycerides into glycerine and free fatty acids, the neutral fats (storage fats) liquefy and penetrate into the surrounding tissue, such as muscle (Neureiter et al. 1940).

Action by bacterial enzymes leads to the transformation of unsaturated into saturated fatty acids. β-oxidation and hydration of the double bond of oleic acid leads to palmitic acid (Berg et al. 1975), hydrogenation of the double bond first leads to hydroxy-stearic acid, and subsequent dehydrogenisation to oxo-stearic acid (Takatori and Yamaoka 1977a, 1977b; Takatori et al. 1986, 1987; Gotouda et al. 1988). Both reactions lead to the elevation of the melting point of the metabolic products. While oleic acid has a relatively low melting point of 16°C, that of palmitic acid is 63°C and that of 10-hydroxy stearic acid is even higher (81°C). The mean environmental temperature in earth graves of central Europe is 3–16°C (Schoenen 2002). Thus, the fatty acids crystallise, which leads to solidification and hardening of tissue.

The reduced water solubility of the fatty acids explains why the basic shape of the corpses remains intact (Froentjes 1965). According to Bürger (1910), facial traits of adipocere-laden corpses can sometimes be observed even decades after burial. Apart from soft tissue, also eyes, genital organs and internal organs (brain, liver, heart, etc.) can be preserved (Krauland 1943; Evans 1962; Berg et al. 1975). The preservation of the internal organs depends on the stage of putrefaction at which the formation of adipocere begins (Evans 1963b; Froentjes 1965). Frequently, adipocere formation is also accompanied by an increase in the volume of the corpse (Froentjes 1965) and the development of 'goose bumps' arising through the fixation of the arrector pili muscles (Dix and Graham 2000).

While early investigations often believed in the *saponification* of the neutral fats with ammonia or calcium and magnesium (Voit 1888; Mueller 1940, 1953), more recent investigations do not regard this process as essential (Graw et al. 2002), even if adipocere

contains mainly calcium and fatty acids (Nanikawa et al. 1961; Nanikawa 1973). Saponification is mainly observed in adipocere found in water (Döring 1973).

The often-discussed theory that adipocere is formed from decomposing muscle tissue (*adiponeogenesis*) (Kratter 1880; Specht 1937) has proved to be wrong (Neureiter et al. 1940; Prokop 1976). Instead, adipocere formation in organs and tissue with little fat content is based on the translocation of the liquefied fat into decomposing tissue as a result of the pressure of the gases produced during putrefaction (*phanerosis*) (Strassmann and Fantl 1926).

Decomposition of adipocere

Although the results of some investigations dealing with the formation of adipocere in model experiments have been reported in the literature (Voit 1888; Harcken 1952; Reimann 1953; Mant and Furbank 1957), targeted investigations on the decomposition of adipocere have not yet been performed. Adipocere is not an end-product. Adipocere can be decomposed over a very long period of time (Harcken 1952). Evans (1963a) and Froentjes (1965) have reported on cases in which after 127 or 140 years, respectively, adipocere could still be found. This shows that adipocere-laden corpses are very resistant to decomposition in unchanging environments.

Similar to the formation of adipocere, its decomposition also largely depends on the environment of the resting place. Harcken (1952) assumed that decomposition is terminated sooner in water than in soils. According to Froentjes (1965) an aerobic environment is necessary for the decomposition of adipocere. This assumption is supported by reports on the alteration of adipocere after its translocation to the soil surface or into graves close to the surface in suitable soils (Evans 1963b; Prokop and Göhler 1976). From the sum formula employed for the degradation of stearic acid into carbon dioxide and water, 26 moles of oxygen are required to convert 1 mole of stearic acid. Expressed differently, the degradation of 1 kg stearic acid requires 2.92 kg oxygen ($\sim$10 m^3) (Schoenen 2002). It is assumed that, in particular, Grampositive bacteria such as *Bacillus* spp., *Cellulomonas* spp. and *Nocardia* spp. are involved in the decomposition of adipocere (Pfeiffer et al. 1998).

Factors which influence adipocere formation

Factors which act before burial

Pre-mortem conditions

So far, only a few, partially contradictory, studies are available on the decomposition processes of human bodies under different conditions (Mann et al. 1990). Empirical studies suggest that adipocere may not develop at all, even if the corpses are interred at locations with the same 'favourable' conditions. Bodies decompose differently, depending on specific features which are decisive for forming adipocere (Harcken 1952). Rodriguez and Bass (1985) suggest that in particular *body size and physique* are of importance. According to Zillner (1885), Harcken (1952) and (Mant 1987), thin individuals are less prone to developing adipocere than fatter corpses. Mann et al. (1990), however, could not confirm this.

It is regarded as certain that female bodies are more prone to developing adipocere than male bodies because of their, on average, higher fat content and different fat distribution (Evans 1963a; Froentjes 1965; Dix and Graham 2000). While Evans (1963b) did not see any relation between *age* and adipocere formation, Froentjes (1965) observed a growing tendency in the formation of adipocere with increasing age of the deceased. One could assume that the latter results from the degenerative old-age adiposity and the gelatinous transformation of fat tissue, which leads to an easier translocation of fat and thus might also favour adipocere formation (Reimann 1953).

Similar controversies are found with respect to adipocere formation in infants and adults. Morovic-Budak (1965) assumes a faster decomposition in infant bodies that died in their first year. According to Wieners (1938) and Harcken (1952) new-born babies are particularly prone to adipocere formation. On the basis of their relatively high proportion of fat, this seems plausible (Dix and Graham 2000).

Cause of death, intoxications

In general, bodies with open wounds (e.g. death due to stabbing) undergo faster decomposition than bodies without wounds (Willey and Heilmann 1987; Mann et al. 1990). Dix and Graham (2000) observed a preferential formation of adipocere in the areas of wounds. If a person dies as a result of bacterial or viral infection, post-mortem alterations are accelerated (Janaway 1987). With regard to the decomposition rate, Morovic-Budak (1965) was unable to observe a difference between natural and violent death. However, *antibiotics, drugs and poisons* (e.g. cyanide, strychnine) impede the decomposition processes (Panzer 1902; Selles 1957; Wagner 1960, 1961; Katte 1967; Schmidt 1969; Daldrup 1979; Geldmacher-von Mallinckrodt 1975a; Mann et al. 1990).

Time elapsing between death and burial

At room temperature, the decomposition processes begin as little as 36 h after death. At cold but not freezing temperatures, these processes usually begin after 4–7 days (Mant 1987). Consequently, the decomposition rate correlates with the storage temperature of the body and its duration before burial. At temperatures below −5°C, decomposition is prevented. Therefore, deceased persons are usually stored at +4°C (Weinzierl and Waldmann

2002). High temperature favours decomposition and prevents adipocere formation. The extent to which lower storage temperatures before interment have an effect on the microbial degradations in soil after burial is unclear.

Burial

In general, Casper's rule is used to describe the degree of degradation of a corpse: the degree of degradation of a corpse that has been lying on the soil surface for 1 week corresponds to that of a corpse that has been lying in water for 2 weeks or 6–8 weeks buried in soil (Dix and Graham 2000). Differences between the decomposition conditions in an earth grave and those on the surface are mostly related to (1) scavengers, (2) insect colonisation, and (3) temperature variations.

Buried corpses are usually safeguarded against *scavengers* when they are buried at a depth of 90 cm or below. Corpses on the earth surface are open to attack from scavengers, which leads to the destruction of soft tissue and to the acceleration of decomposition (Reed 1958; Hunger and Leopold 1978; Rodriguez and Bass 1983; Micozzi 1986; Henderson 1987). In addition, interment greatly reduces the colonisation of the corpse by *insects and microorganisms* (Vass et al. 1992). However, several investigations suggest that buried corpses might also be colonised by insects. Motter (1889) observed, for example, that a corpse which was buried 150 cm below the surface was colonised by mites, *Collembola*, *Phoridae* (in particular *Concera*, *Metopina*) and by some *Staphylinidae* species. It can be assumed that the storage conditions of the body before interment have a decisive influence on the intensity of insect colonisation on the corpse after interment.

In an investigation carried out by Evans (1963a), corpses which were buried in spring and summer frequently showed fewer signs of adipocere than those which were buried in autumn or winter. In contrast, the investigation by Mant (1987) showed that bodies which were buried during the summer months revealed the highest degree of degradation. Morovic-Budak (1965) observed a very low degree of degradation in corpses which were buried in winter. Lötterle et al. (1982) could not correlate the degree of degradation with the time of burial. According to Evans (1963b) the weather conditions at the time of burial, in particular fog and misty conditions, might influence adipocere formation.

It has often been discussed whether the *depth of the grave* might influence the decomposition processes (Rodriguez and Bass 1985; Micozzi 1991; Mant 1987). In an investigation carried out in a Dutch graveyard, Froentjes (1965) observed that corpses which were buried on top of each other showed a greater tendency to form adipocere than did corpses which lay in individual graves. In particular, the corpses which were found at the greatest depths (max. 250 cm) showed signs of adipocere. A disproportionately large number of adipocere-laden bodies were observed in mass graves (Mant 1987).

With regard to decomposition of the corpses, pine and spruce *coffins* seem to allow more rapid decomposition than oak coffins (Weinig 1958; Weinzierl and Waldmann 2002). Oak, as well as lead and zinc coffins, enhance the adipocere formation (Froentjes 1965; Henderson 1987). During the exhumation of 160 bodies, Morovic-Budak (1965) could not discover a significant correlation between decomposition and the material used for the coffins (metal, wood). Müller (1914) often observed adipocere-laden bodies in wooden coffins, the joints of which were lined with pitch, which rendered air and water circulation nearly impossible. However, he did not discover any signs of adipocere in coffins of which the lids were perforated with 6–10 cm thick wooden posts. This 'artificial' ventilation of the coffins accidentally originated during foundation work for the tombstones.

Many authors have reported on the *bedding* at the bottom of the coffin which usually consists of plant material (wood chips, straw). It is assumed that plant bedding favours the processes of decay but prevents adipocere formation (Evans 1963b; Cotton et al. 1987; Henderson 1987; Mant 1987; Vass et al. 1992). Mant (1987) examined a mass grave and found no adipocere on a corpse that was bedded on straw, but did so on corpses which were buried without straw. He suggested that this phenomenon might be caused by thermal insulation and the heat which is released as a result of the decomposition of plant material.

Many authors postulated that the *clothes* worn by the deceased person can delay post-mortem changes and even favour adipocere formation (Matthes 1903; Mant and Furbank 1957; Cotton et al. 1987; Mellen et al. 1993; Dix and Graham 2000). According to Mant (1987), the clothes keep insects away and also favour the absorption and storage of moisture. In this respect, Geldmacher-von Mallinckrodt (1975b) supposes that the number of bacteria therefore increases slowly; Berg et al. (1975) suggest that this observation correlates with the limited gas circulation. On the other hand, it is also possible that the latent heat flux through the continuous evapotranspiration due to the constant moisture film on the corpse favours adipocere formation (Willimann 1996). Aeschlimann (2002) assumes that clothing made of nylon, such as tights, uniforms, socks and shoes, largely impede decomposition processes.

Site-dependent factors

While the weather conditions before burial have a great influence on the decomposition rate (Weinig 1958), the corpse is subject to greater soil/grave-related influences after interment.

In general, the decomposition rate depends on the *climatic conditions* (Rodriguez and Bass 1983), such as amount of precipitation and temperature (Hunger and Leopold 1978; Mengede et al. 2001). Temperature governs microbial processes and thus also post-mortem changes (Mann et al. 1990). Nanikawa (1973) and

Takatori et al. (1986) suggest that the influence of bacteria, particularly *Clostridium perfringens*, and their enzymes (Tomita 1984), play a key role in the transformation of hydroxy fatty acids.

According to Henderson (1987) the decomposition rate varies with *geographical location and season*. Based on the seasonal course of temperature, one can assume that the degradation process is less intensive in the northern hemisphere between January and March than it is between July and September (Rodriguez and Bass 1983). Fast decomposition during spring and summer is attributed to more intensive insect activity (Kulshrestha and Chandra 1987).

While a corpse which is lying on the surface is subject to great variations in humidity and temperature (Henderson 1987), the temperature inside a grave is low and does not fluctuate greatly. The saturated and hydroxy fatty acids precipitate at low temperatures because their further degradation is prevented (Willimann 1996). There are, however, indications that adipocere formation is particularly enhanced in warmer surroundings (Bohne 1914; Mant and Furbank 1957; Simonsen 1977). Cotton et al. (1987) assume that, at first, higher temperatures are necessary for the bacteria to grow; whereas later the bacterial enzymes might still continue their activity at lower temperatures and cause the transformation of fatty acids. According to Schoenen (2002), it is unrealistic to expect differences in the degradability of protein, fat and polysaccharides to be independent of temperature. According to the latter author, low temperatures do not lead to adipocere formation. Investigations carried out by Micozzi (1986) show that frost–thawing cycles can have an influence on decomposition. He observed mainly aerobic degradation processes on frozen and subsequently thawed animal carcasses, while carcasses that did not undergo temperature shifts more often showed a tendency toward anaerobic degradation processes. These extreme temperature variations can, however, be ignored with respect to corpses buried at normal burial depths of >90 cm.

According to Weinig (1958), Willey and Heilmann (1987) and Reed (1958), *topography* (inclination, exposition) and *vegetation* of a burial site might also influence the decomposition rate. Generally, smaller insect populations are found on corpses buried in areas without tree cover than in forested areas (Reed 1958). In particular, conifers with deep-reaching roots enhance decomposition processes (Müller 1913). However, Krauland (1943) observed adipocere formation despite a high root density and explained this by the parent material of soils (loam-enriched moraine material over poorly permeable schist).

The most important characteristics of soils, which influence whether an area can be used as graveyard, are connected with the *parent material*. Adipocere-laden bodies could be found on loam-enriched moraine material (Müller 1914; Krauland 1943), periglacial regoliths (Fiedler et al. 2002; Steudt-Gaudich 2002), poorly permeable materials such as schist (Krauland 1943), marl and clay stones (Müller 1913, 1914).
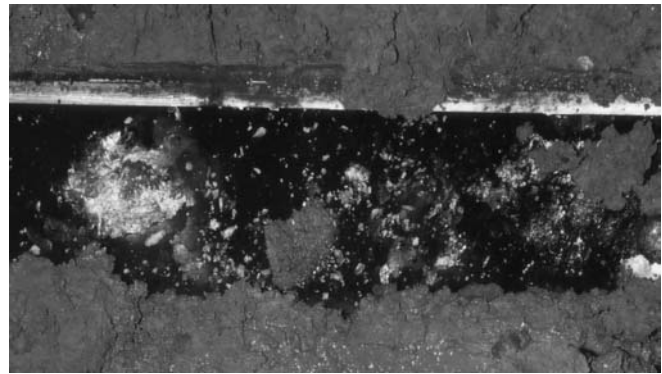
Fig. 1 Example of a wet earth grave (photo: M. Graw)

A recent investigation carried out in the federal German state of 'Baden-Württemberg' (southern Germany) shows that graveyards which are located on Jurassic (in particular Lower and Central Jurassic) and Triassic sediments (in particular Lower Triassic Red Sandstone) encounter degradation problems more frequently than do graveyards that are located on sediments of quaternary and tertiary periods (Graw and Haffner 2001; Fiedler et al. 2003). In an investigation from the eighteenth century (Thouret, quoted in Harcken 1952), it was mentioned that adipocere formation was frequently found in 'black-coloured' soils. One can assume that 'black colour' refers to soil evolved from clay and marl stones, which are naturally dark. Many authors agree that the soil is particularly important with regard to the decomposition rate (Rodriguez and Bass 1985), although the actual degradation process is primarily independent of soil (Berg and Specht 1958).

Experience has shown that bodies decompose differently within a given resting time and that this largely depends on the characteristics of the surrounding soil. Weinig (1958) differentiates between 'active' (= rapid decomposition) and 'inactive' (= slow decomposition) soils. 'Active' soils include a high portion of clay, 'less active' soils include unfertile soils (e.g. acid sand), 'hot' soils which lead to a fast decomposition include sandy and limy soils and those found on south-facing slopes.

Possible reasons for the reduced decomposition in soil including adipocere formation are the following: (1) *water saturation* (Zillner 1885), (2) *anaerobic conditions* (Neureiter et al. 1940; Mant 1987; Fiedler et al. 2002) and (3) *reduced gas circulation* (Schauenstein 1882; Müller 1914). Adipocere formation has mainly been observed in moist or waterlogged soils (examples are shown in Figs. 1 and 2) (Erman 1882; Okamoto 1903; Müller 1913; Evans 1963b; Sticht et al. 1981; Mant 1987), and soils with poor drainage (= clay and loamy enriched soils) (Kratter 1880; Krauland 1943; Berg et al. 1975; Raissi and Müller 1999; Schneckenberger 2002).

The majority of authors believe that moisture is absolutely necessary for adipocere to be formed (Berg et al. 1975; Vass et al. 1992). However, Mant (1987) and Müller (1913) have also observed adipocere formation in

Fig. 2 Corpses showing the uniform formation of adipocere in an earth grave (photo: M. Graw)

aerobic and dry surroundings. Therefore, these authors concluded that moisture was not an essential prerequisite for adipocere formation. Water is necessary for the general bacterial and enzymatic activities involved in adipocere formation; however, there seems to be enough water stored in the fatty tissue of the corpses (Janaway 1987). Insufficient gas circulation slows down post-mortem changes because the degrading bacteria die (Müller 1914; Schoenen 2002) due to oxygen deprivation, acidity, amines or other end-products which affect the pH or membrane functions.

To evaluate soils with respect to their potential use as a graveyard, the geological situation (e.g. stratification) (Schützenmeister 1972) and the size of the soil particles (i.e. texture) both play an important role (Keller 1963; Krumme 1964; Hofgeismar 1980; Lötterle et al. 1982; Schweier 1988). This physical soil parameter is the decisive factor of air, water and heat budget.

Adipocere formation was mainly observed in soils with a high proportion of fine particles (<6.3 μm), i.e. in clay-enriched soils (Krauland 1943). These soils have a large pore space, which is inversely proportional to its permeability. Thus they tend to retain moisture, which additionally reduces gas circulation, creates anaerobic conditions and slows down decomposition processes (Müller 1914; Schraps 1972; Lötterle et al. 1982; Schmierl 1982). Under these conditions, the growth of fungi is restricted. Fungi, in addition to microbes,

participate in the degradation processes (Janaway 1987). Consequently, it is recommended that sites with this kind of soils as well as groundwater-affected soils are not used as graveyards (Hausbrandt 1942; Weinig 1958; Schraps 1970; Gaedke 2000; Fleige et al. 2002).

On the other hand, soils with loamy and sandy texture seem to be very suitable for unrestricted decomposition (Schraps 1972). Hunger and Leopold (1978) and Bethell and Carver (1987) observed a virtually complete decomposition in soils of loamy-sand texture. Other authors regard sand texture (63–2,000 μm) as the best, due to its large proportion of macro-pores (Keller 1963; Lötterle et al. 1982). However, Hunger and Leopold (1978) also observed restricted post-mortem changes in acid and moist sandy soils. In addition, Lund (1964, quoted in Hunger and Leopold 1978) observed that insect colonisation might largely depend on the texture of the soil. Very few insects live below the surface of sandy soils, whereas loamy soils have a higher insect population.

The soil texture indirectly influences the *heat budget* of the soil. Since air does not conduct gas as well as water or mineral components, heat is exclusively conducted via the solid or fluid phases of the soil. Putrefaction is an exothermal process which can function as self-accelerating process because of the reduced thermal conductivity of the environment. This is the case when the corpse is surrounded by an insulating air space within the coffin. On the contrary, if the coffin is filled with water and/or decomposition fluids, the density of heat flux increases and leads to a lower post-mortem body temperature. Willimann (1996) as well as Büchi and Willimann (2002) clearly regard this phenomenon as the major cause for adipocere formation.

In addition to physical soil properties (Weinig 1958), *pH* (Berg and Specht 1958; Hunger and Leopold 1978; Micozzi 1991) and *redox conditions* (Lorke 1953; Lorke and Schmidt 1952a, 1952b; Schoenen 2002) might also influence adipocere formation. According to Mant (1987), there is not much evidence for the influence of pH. While Fleige et al. (2002) suggest that acid conditions prevent decomposition processes, Müller (1913) assumes that high clay and silt content as well as high lime content (pH>7) are responsible for adipocere formation. It is regarded as certain that anaerobic conditions, i.e. low reduction–oxidation potential, favour the formation of adipocere (Mant 1987). According to Harcken (1952) and Müller (1914), a high *salt content* of soils has a positive effect, since the hardening of the lipid armour is enhanced by the deposition of Ca^{2+}, Mg^{2+} and Na^+ ions (Reimann 1953; Nanikawa 1973; Rothschild et al. 1996).

Soils of similar genesis, properties and features can be integrated as a *soil type*. Consequently, the soil type is an important factor involved in decomposition processes (Rodriguez and Bass 1985). However, according to Mant (1987), the influence of the soil type is overestimated. He investigated corpses under similar conditions but different soil types and found virtually no differences. These authors did not provide any details on the type of soil

surrounding the bodies, so it is difficult to judge and generalise. In the majority of cases, the decision on the location of a graveyard is governed by the availability of areas and their ease of access. The characteristics of the soils are of little importance. As a result, many graveyards are set up under conditions which do not guarantee the complete skeletalisation of a human body within the regular resting time (Schmidt-Bartelt et al. 1990; Graw et al. 2002).

Anthropogeneous influences

Due to their special use, the soils of graveyards (Necrosols) are being anthropogeneously altered. The natural *structure* is being destroyed when the soil is dug up and technogeneous substrate inserted (e.g. fastening of tombstones) (Schneckenberger 2002; Fiedler et al. 2002). Thus, the natural water flow is hampered to such a degree that graves might function as 'watertraps' (Müller 1914; Killam 1990; Holland 1996). An already high water capacity (Grenzius 1987; Sukopp 1990) may be increased by watering the plants on the graves (Weinzierl and Waldmann 2002; Fleige et al. 2002). On the other hand, covering graves with compact stone slabs can also drastically alter the gas and water content of the soil (Fiedler and van de Sand 2001).

According to Bauer (1992), the *frequency of use* of the graves has a decisive influence on the decomposition rate. He observed that bones and slightly decayed parts of deceased humans were dug up when new graves were repeatedly prepared at the same sites.

The bottom of the grave is different from the soil around it with regard to chemistry, texture, moisture, density, amount of organic substances and pH (Rodriguez and Bass 1985; Killam 1990; Vass et al. 1992). During the decomposition, substances are released from the body to the surrounding soil (Weinig 1958; Rodriguez and Bass 1985), and substances from the environment are transported into the bones (Bethell and Carver 1987; Waldron 1987). The colour of the area in which a corpse was deposited is clearly different from that of the surrounding soil [also described as dark-coloured patches (Payne and King 1968), silhouettes or pseudomorphs (Bethell and Carver 1987)]. The humus that is generated remains at the bottom of the grave since animals like earthworms or moles are rarely present at this depth. According to Rubner et al. (1912) the accumulation of humus leads to the disruption of the decomposition processes of corpses that are subsequently buried at the same site. Humus accumulation due to decomposition leads to smaller pore volumes, the soil becomes less suitable for decay processes, since these are usually delayed, and later on leads to adipocere formation. The blockage of the pores might also favour the retention of water (Lautenschläger 1934). However, this observation cannot be generalised; graveyards from the Middle Ages are known to have been continuously reused without showing signs of problematic decomposition processes (Büchi and Willimann 2000). The latter is supported by Janaway (1987), who suggests the positive influence of frequently reused graves in that dormant microorganisms may intrude into the corpse and thus lead to faster decomposition.

Conclusions

It is difficult to give precise conditions under which the decomposition of corpses might be prevented, as virtually no systematic investigations are available and those opinions which do exist are partially contradictory. While the chemical processes involved in adipocere formation are largely understood, the causes of its formation have not been well investigated.

From scanning the literature it seems, that apart from individual characteristics of corpses (e.g. sex, weight, age, cause of death), there are other factors involved: mode of burial (depth, coffin, clothing); and in particular the properties of the resting place (parent material, soil texture, water, air and heat budget) all influence adipocere formation. While it is not possible to influence the sex, weight or age of corpses, other factors, such as the mode of burial or the cemetery location, could have a significant effect on the formation of adipocere. For example, in the last two decades clothing as well as bedding made of nylon or other synthetic fibres (which favour adipocere formation) have become less fashionable.

In addition, care has been taken to select soil types for burials in which decomposition can be expected to be completed within the given resting time. But which soil types can be classed as suitable? To date, no nation-wide standardised criteria are available with respect to setting up a cemetery which are both geologically and pedologically sound. It would be desirable to fill this gap, as the selection of appropriate burial sites can help avoid adipocere formation in a most economic and sustainable way. Appropriate burial places have to be chosen on the basis of suitable soil texture, redoxi-/hydromorphic features, bulk density, pore size distribution, and the rate of infiltration.

It remains to be asked what can be done with sites in which the occurrence of adipocere is common? A study of adipocere decomposition might prove useful although, to date, no such investigation has been performed. Consequently, sustainable rehabilitation measures are still missing. It seems that it is not only the formation of adipocere, but also its eventual decomposition, which largely depends on the conditions of the resting place. As a result, site-specific concepts will in future be necessary. The current problems can only be solved through the integration of forensic, geological, pedological and microbiological research.

References

Aeschlimann E (2002) Probleme mit der Erdbestattung. Friedhofs-kultur 92:24–26

Bauer F (1992) Von Tod und Bestattung in alter und neuer Zeit. Hist Z 254:1–31

Berg S, Specht W (1958) Untersuchungen zur Bestimmung der Liegezeit von Skelettteilen. Dtsch Z Gesamte Gerichtl Med 47:209–241

Berg S, Mueller B, Schleyer F (1975) Leichenveränderungen, Todeszeitbestimmung im frühpostmortalen Intervall: Leichen-zersetzung und -zerstörung. In: Mueller B (ed) Gerichtliche Medizin. Springer, Berlin Heidelberg New York, pp 45–106

Bethell PH, Carver MOH (1987) Detection and enhancement of decayed inhumations at Sutton Hoo. In: Boddington A, Garland AN, Janaway RC (eds) Death, decay and reconstruction: approaches to archaeology and forensic science. Manchester University Press, Manchester, pp 10–21

Bohne G (1914) Über Leichenerscheinungen. Vjschr Gerichtl Med 47:13–25

Büchi H, Willimann I (2002) Verdachtsfläche Friedhof: Umwelt-gefährdung durch Leichenzersetzung? Wasser Boden 54:20–24

Bürger (1910) Die Adipocirebildung und ihre gerichtlich-medi-zinische Bedeutung. Vjschr Gerichtl Med 39:172–182

Coe JI (1973) Postmortem chemistry: practical considerations and a review of literature. J Forensic Sci 19:13–32

Cotton GE, Aufderheide AC, Goldschmidt VG (1987) Preservation of human tissue immersed for five years in fresh water of known temperature. J Forensic Sci 4:1125–1130

Daldrup T (1979) Postmortaler Eiweisszerfall in menschlichen Organen: Reaktionen und zeitliche Zusammenhänge. PhD thesis, Rheinisch-Westfälische, Aachen

Dix J, Graham M (2000) Time of death, decomposition and identification: an atlas. CRC, Boca Raton, Fla.

Döring G (1973) Die chemischen Veränderungen des Leichen-lipids. PhD thesis, Göttingen

Erman (1882) Beitrag zur Kenntnis der Fettwachsbildung. Vjschr Gerichtl Med 37:51–65

Evans WE (1962) Some histological findings in spontaneously preserved bodies. Med Sci Law 2:145–164

Evans WE (1963a) Adipocere formation in a relatively dry environment. Med Sci Law 3:145–153

Evans WE (1963b) The chemistry of death. CC Thomas, Spring-field, Ill.

Fiedler S, Sand M van de (2001) Welche Bodeneigenschaften sind für eine Friedhofsnutzung von Bedeutung? Gemeinde 8:285–286

Fiedler S, Schneckenberger K, Graw M, Schmidt M, Schweinsberg F, Stahr K (2002) Bildung so genannter Fettwachsleichen in redoximorphen Nekrosolen: Beispiel St. Georgen. Wasser Boden 54:8–11

Fiedler S, Weinzierl W, Waldmann F, Graw M (2003) Problems of decomposition in cemetery soils: Evaluation of 'Baden-Würt-temberg' (Germany). Z Dtsch Geol Ges

Fleige H, Horn R, Blume H-P, Wetzel H (2002) Bodenkundliches Bewertungsverfahren zur Bestimmung des Eignungsgrades von Friedhöfen. Wasser Boden 54:31–39

Froentjes W (1965) Kurzer Bericht über die unvollständige Leichenzersetzung auf Friedhöfen und die Adipocirebildung. Dtsch Z Gesamte Gerichtl Med 56:205–207

Gaedke J (2000) Handbuch des Friedhofs- und Bestattungsrechts. Heymanns, Köln

Geldmacher-von Mallinckrodt M (1975a) Das Schicksal von Medikamenten und Giften im Organismus. In: Mueller B (ed) Gerichtliche Medizin. Springer, Berlin Heidelberg New York, pp 718–729

Geldmacher-von Mallinckrodt M (1975b) Postmortale Veränderun-gen. In: Mueller B (ed) Gerichtliche Medizin. Springer, Berlin Heidelberg New York, pp 730–733

Gotouda H, Takaton T, Terazawa K, Nagoa M, Tarao H (1988) The mechanism of experimental adipocere formation: hydration and dehydrogenation in microbial synthesis of hydroxy and oxo fatty acids. Forensic Sci Int 37:249–257

Goy S, Wende E (1922) Über zwei Leichenwachsuntersuchungen. Biochem Z 187:470–471

Graw M, Haffner H-T (2001) Studie zur Zersetzungsproblematik auf Friedhöfen in Baden-Württemberg. Gemeinde 8:284–285

Graw M, Schmidt M, Schneckenberger K, Fiedler S (2002) Degradation von Leichen: Fäulnis, Verwesung und Artefakt-bildung. Wasser Boden 54:16–19

Gregory W (1847) Ueber eine fette Substanz, von einem thierischen Körper herrührend. Justus Liebigs Ann Chem 56:362–364

Grenzius R (1987) Die Böden Berlins (West): Klassifizierung, Vergesellschaftung, ökologische Eigenschaften. PhD thesis, TU Berlin

Harcken W (1952) Fettwachs und Fettwachsbildung unter beson-derer Berücksichtigung des pH-Wertes. PhD thesis, Georg-August-Universität, Göttingen

Hausbrandt F (1942) Bemerkenswertes an einer 6 Jahre in einem Moortümpel gelegenen Fettwachsleiche (nach Mord durch Erdrosseln). Dtsch Z Gesamte Gerichtl Med 36:217–231

Henderson J (1987) Factors determining the state of preservation of human remains. In: Boddington A, Garland AN, Janaway RC (eds) Death, decay and reconstruction: approaches to archae-ology and forensic science. Manchester University Press, Manchester, pp 43–54

Hofgeismar EA (1980) Der Friedhof als Gemeinschaftsaufgabe. In: Evangelische Akademie von Kurhessen-Waldeck (ed) Der Friedhof als Gemeinschaftsaufgabe. Schlösschen, Schönburg, p 71

Holland K (1996) Stadtböden im Keuperland am Beispiel Stuttgarts. Hohenheimer Bodenkundliche Hefte 39

Hunger H, Leopold D (1978) Identification. Springer, Berlin Heidelberg New York

Janaway RC (1987) The preservation of organic materials in association with metal artefacts deposited in inhumation graves. In: Boddington A, Garland AN, Janaway RC (eds) Death, decay and reconstruction: approaches to archaeology and forensic science. Manchester University Press, Manchester, pp 127–141

Katte W (1967) Nachweis von Strychnin als Mordgift nach fünf Jahren Erdgrablagerung. Arch Kriminol 139:28–33

Keller G (1963) Über die Eignung norddeutscher Böden für die Erdbestattung. Z Dtsch Geol Ges 115:609–616

Killam E (1990) The detection of human remains. CC Thomas, Springfield, Ill.

Kratter J (1880) Studien über Adipocire. Z Biol 16:455–492

Krauland W (1943) Fettwachsbildungen unter ungewöhnlichen Bedingungen. Dtsch Z Gesamte Gerichtl Med 37:179–189

Krumme F (1964) Untersuchungen zum Flächenbedarf der Fried-höfe. PhD thesis, Hannover

Kulshrestha P, Chandra H (1987) Time since death: an entomo-logical study on corpses. Am J Forensic Med Pathol 8:233–238

Lautenschläger O (1934) Die Böden der Friedhöfe: mit besonderer Berücksichtigung des Zentralfriedhofes Danzig-Langfuhr. PhD thesis,TU der Freien Stadt, Danzig

Lorke D (1953) Die postmortale Wasserstoffionenkonzentration an der Oberfläche tierischer Organe. Dtsch Z Gesamte Gerichtl Med 42:167–172

Lorke D, Schmidt O (1952a) Beitrag zum postmortalen Abbau des Schwefels in Abhängigkeit von der Redoxlage: Die Bildung von Mercaptanen und Thioäthern. Dtsch Z Gerichtl Med 42:164–166

Lorke D, Schmidt O (1952b) Fäulnis und Verwesung im Exper-iment. Dtsch Z Gesamte Gerichtl Med 41:236–239

Lötterle J, Schmierl G, Schellmann B (1982) Einfluss der Bodenart auf die Leichendepomposition bei langen Liegezeiten. Beitr Gerichtl Med 40:197–201

Madea B (1994) Leichenzerstückelung mit ungewöhnlicher Kon-servierung der Leichenteile. Arch Kriminol 193:72–78

Mann RW, Bass WM, Lee Meadows BA (1990) Time since death and decomposition of the human body: variables and observa-

tions in case and experimental field studies. J Forensic Sci 35:103–111

Mant AK (1987) Knowledge acquired from post-war exhumations. In: Boddington A, Garland AN, Janaway RC (eds) Death, decay and reconstruction: approaches to archaeology and forensic science. Manchester University Press, Manchester, pp 65–78

Mant AK, Furbank R (1957) Adipocere: a review. J Forensic Med 4:18–35

Matthes X (1903) Zur Frage der Erdbestattung vom Standpunkt der öffentlichen Gesundheitspflege. Z Hyg Infektionskr 44:439–468

Mellen PFM, Lowry MA, Micozzi MS (1993) Experimental observations on adipocere formation. J Forensic Sci 38:91–93

Mengede R, Burghardt W, Bahmani M (2001) Langzeitversuch zur Bodenatmung auf einem Friedhof. Mitt Dtsch Bodenkdl Ges 96:531–532

Micozzi MS (1986) Experimental study of postmortem change under field conditions: effects of freezing, thawing, and mechanical injury. J Forensic Sci 31:953–961

Micozzi MS (1991) Postmortem change in human and animal remains: a systematic approach. CC Thomas, Springfield, Ill.

Morovic-Budak A (1965) Experiences in the process of putrefaction in corpses buried in earth. Med Sci Law 5:40–43

Motter MG (1889) A contribution to the study of the fauna of the grave: a study of one hundred and fifty disinterments, with some additional experimental observations. J N Y Entomol Soc 6:201–233

Mueller B (1940) Die Exhumierung. In: Mueller B (ed) Gerichtliche Medizin. Springer, Berlin Heidelberg New York, pp 186–189

Mueller B (1953) Gerichtliche Medizin. Springer, Berlin Heidelberg New York

Müller W (1913) Postmortale Dekomposition und Fettwachsbildung: Die Ausgrabungen auf dem Friedhof Hohe Promenade in Zürich. Leemann, Zürich

Müller W (1914) Physikalisch-chemische Bestimmung über die Entstehung und Vermeidung des Leichenwachses auf Friedhöfen: Das Prinzip der künstlichen Sargventilation. Arch Hyg 83:285–326

Nanikawa R (1973) Über die Bestandteile von natürlichen und experimentell hergestellten Leichenwachsen. Z Rechtsmed 72:194–202

Nanikawa R, Tawa N, Saito K (1961) Chemical studies on adipocere formation: re-evaluation of the saponification theory. Dtsch Z Gesamte Gerichtl Med 52:708–709

Neureiter F, Pietrusky F, Schütt E (1940) Handwörterbuch der Gerichtlichen Medizin, Springer. Berlin Heidelberg New York

Okamoto Y (1903) Ein Fall von einer sehr wohl erhaltenen Gräberadipocire. Vjschr Gerichtl Med 26:259–262

Pacheco A, Mendez JMB, Martins T, Hassuda S, Kimmelmann AA (1991) Cemeteries: a potential risk to groundwater. Water Sci Technol 24:97–104

Panzer T (1902) Beiträge zur Kenntniss von der Widerstandsfähigkeit der Pflanzenalkaloide gegen Fäulnis. Z Unters Nahr Genussm Gebrauchsgegenstände 5:8–10

Payne J, King E (1968) Arthropod succession and decomposition of buried pigs. Nature 219:1180–1181

Peterson F (1972) Rechtsmedizinische Feststellungen an einer 3 Jahre in Plastik gehüllten Kindsleiche. Beitr Gerichtl Med 29:351–358

Pfeiffer S, Milne S, Stevenson RM (1998) The natural decomposition of adicocere. J Forensic Sci 43:368–370

Prokop O (1966) Forensische Medizin. Volk und Gesundheit, Berlin

Prokop O, Göhler W (1976) Forensische Medizin. Fischer, Stuttgart,

Raissi F, Müller U (1999) Bodenkundliche Anforderungen an Anträge zur Erdbestattung. Niedersächs Landesamt Bodenforsch Hannover GeoFakten 4

Reed HB (1958) A study of dog carcass communities in Tennessee, with special reference to the insects. Am Midl Nat 59:213–245

Reimann W (1953) Zur Frage der frühzeitigen Leichenwachsbildung. Wiss Z Martin-Luther-Univ Halle-Wittenberg 3:459–466

Rodriguez WC, Bass WM (1983) Insect activity and its relationship to decay rates of human cadavers in East Tennessee. J Forensic Sci 28:423–430

Rodriguez WC, Bass WM (1985) Decomposition of buried bodies and methods that may aid in their location. J Forensic Sci 30:836–852

Rothschild MA, Schmidt V, Pedal I (1996) Leichenlipid: Unterschiedliche Entstehungsarten erschweren zusätzlich die Abschätzung der Leichenliegezeit. Arch Kriminol 197:165–174

Rubner M, Grate M, Ficker M (1912) Handbuch der Hygiene. S Hirzel, Leipzig

Schauenstein A (1882) Später auftretende Leichenveränderungen. In: Maschka J (ed) Handbuch der Gerichtlichen Medizin. Laupp'sche Buchhandlung, Tübingen, pp 385–429

Schmidt G (1969) Postmortale Veränderungen von Arzneistoffen und Giften in Organen und Körperflüssigkeiten einschliesslich Neubildung von Störsubstanzen. In: Preuss R (ed) Gadamers Lehrbuch der chemischen Toxikologie und Anleitung zur Ausmittelung der Gifte. Vandenhoeck Ruprecht, Göttingen, p 779

Schmidt-Bartelt D, Behnke R, Burghardt W (1990) Friedhöfe auf Löss und urban-industriell überprägten Substraten im Ruhrgebiet: Bodenmerkmale, Probleme und Lösungsansätze. Mitt Dtsch Bodenkdl Ges 61:131–134

Schmierl G (1982) Die Leichenzersetzung im Erdgrab aus verwaltungsrechtlicher, hygienischer, geologischer und rechtsmedizinischer Sicht. PhD thesis, Friedrich-Alexander Universität, Erlangen-Nürnberg

Schneckenberger K (2002) Charakterisierung zweier Nekrosole mit Leichenlipidbildung im Vergleich zu einem Referenzstandort sowie Ableitung möglicher ökologischer Konsequenzen. Thesis, Universität Hohenheim, Stuttgart

Schoenen D (2002) Wachsleichenbildung: ein mikrobielles Problem. Wasser Boden 54:12–15

Schraps WG (1970) Bodenkundliche Untersuchungen für die Anlage von Begräbnisplätzen. Z Dtsch Geol Ges 122:81–87

Schraps WC (1972) Die Bedeutung der Filtereigenschaften des Bodens für die Anlage von Friedhöfen. Mitt Dtsch Bodenkdl Ges 16:225–229

Schumann M, Barz J, Bonte W (1995) Leichenbeseitigung durch Einbetonieren und Versenken im Wasser. Arch Kriminol 195:18–26

Schützenmeister W (1972) Die geologischen Bedingungen für Friedhofsstandorte. Z Gesamte Hyg 18:87–90

Schweier G (1988) Totenberg- Friedhof und -Kapelle in Heidenheim. Stadtarchiv, Heidenheim

Selles M (1957) Die Leichenverwesung und ihre Verzögerung durch den Einfluss der Antibiotika. Dtsch Z Gesamte Gerichtl Med 46:518

Simonsen J (1977) Early formation of adipocere in temperate climate. Med Sci Law 17:53–55

Specht W (1937) Chemische Abbaureaktionen bei der Leichenzersetzung. Ergeb Allg Pathol 33:138–180

Steudt-Gaudich R (2002) Durchlässig, grundwasserfrei und sorptionsfähig? Friedhofsböden in NRW. Friedhofskultur 92:16–19

Sticht G, Ramme H, Dotzauer G (1981) Morphologische und toxikologische Befunde nach 17-jähriger Liegezeit einer Leiche. Beitr Gerichtl Med 39:177–183

Strassmann G, Fantl D (1926) Untersuchungen an einer Fettwachsleiche. Dtsch Z Gesamte Gerichtl Med 6:168–174

Sukopp H (1990) Stadtökologie. Das Beispiel Berlin. Dietrich Reimer, Berlin

Takatori T, Yamaoka A (1977a) The mechanism of adipocere formation. I. Identification and chemical properties of hydroxy fatty acids in adepocere. J Forensic Sci 9:63–73

Takatori T, Yamaoka A (1977b) The mechanism of adipocere formation. II. Separation and identification of oxo fatty acids in adipocere. J Forensic Sci 10:117–125

Takatori T, Ishiguro N, Tarrrrao H, Matsumiya H (1986) Microbial production of hydroxy and oxo fatty acids by several microor-

ganisms as a model of adipocere formation. Forensic Sci Int 32:5–11

Takatori T, Gotouda H, Terazawa K, Mizukami K, Nagao M (1987) The mechanism of experimental adipocere formation: substrate specificity on microbial production of hydroxy and oxo fatty acids. Forensic Sci Int 35:277–281

Tomita K (1984) On the production of hydroxy fatty acids and fatty acid oligomers in the course of adipocere formation. Jpn J Legal Med 38:257–272

Urban R (2002) Umweltbelastung, Bodenkontamination und Gesundheitsgefährdung bei Erdbestattungen? Wasser Boden 54:25–30

Vass AA (2001) Beyond the grave: understanding human decomposition. Microbiol Today 28:190–192

Vass AA, Bass WM, Wolt JD, Foss JE, Ammons JT (1992) Time since death determinations of human cadavers using soil solution. J Forensic Sci 37:1236–1253

Voit E (1888) Versuche über Adipocirebildung. Münch Med Wochenschr 35:518–519

Wagner H-J (1960) Einfluss der Antibiotika und Sulfonamide auf die Leichenfäulnis. Dtsch Z Gesamte Gerichtl Med 49:714–720

Wagner H-J (1961) Die Beeinflussung postmortaler physikalisch-chemischer Vorgänge durch Antibiotika und Sulfonamide. Dtsch Z Gesamte Gerichtl Med 51:572–581

Walcher K (1937) Die späteren Leichenveränderungen. Ergeb Allg Pathol 33:35–137

Waldron T (1987) The relative survival of the human skeleton: implications for palaeopathology. In: Boddington A, Garland AN, Janaway RC (eds) Decay and reconstruction: approaches to archaeology and forensic science. Manchester University Press, Manchester, pp 55–64

Weinig E (1958) Die Nachweisbarkeit von Giften in exhumierten Leichen. Dtsch Z Gesamte Gerichtl Med 47:397–416

Weinzierl W, Waldmann F (2002) Karte der potenziellen Problemstandorte für Erdbestattungen in Baden-Württemberg. Wasser Boden 54:4–7

Wieners F (1938) Ansichten über die Fettwachsbildung unter besonderer Berücksichtigung der modernen Anschauungen. PhD thesis, Westfälische Wilhelms-Universität, Münster

Willey P, Heilmann A (1987) Estimating time since death using plant roots and stems. J Forensic Sci 32:1264–1270

Willimann I (1996) Leichenzersetzung im Erdgrab: Zersetzungsstörungen—Hygiene—Massnahmen. Thesis, ETH, Zürich

Zillner E (1885) Zur Kenntnis des Leichenwachses. Vjschr Gerichtl Med 42:1–31