



Adipocere: What is known after over two centuries of research

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ABSTRACT

This paper reviews over two centuries of research focusing on various issues relating to adipocere. Adipocere is a crumbly, soap-like postmortem product that forms from soft tissue in a variety of environments. The timing of the formation and degradation of adipocere depends largely on the environmental circumstances. Once formed, adipocere can persist for hundreds of years, acting as a preservative. In this way, some define it as a process of mummification. This type of persistence can be useful in a forensic context as it can preserve evidence. Sustained interest in adipocere prompted many investigations into the composition and conditions of formation. More recent investigations, aided by technological advances, build upon the knowledge gained from prior studies as well as delve into the chemical composition of adipocere. This in turn provides new information on detection and documentation of constituent substances.

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1. Introduction

Adipocere represents a form of arrested decay of postmortem soft tissue. Various referred to as grave wax or corpse wax [1–4] this tenacious material has been documented in a variety of contexts and has served as the focus of considerable research. Through experimentation, case analysis and observation much has been learned about its external morphology, chemical composition, mechanisms of formation and the timing of its development and eventual degradation. Adipocere represents an important taphonomic phenomenon since it can lead to prolonged preservation of evidence, reveal environmental and constitutional factors that may be useful in forensic investigation and complicate evaluations of postmortem interval.

2. Definitions

Classically, adipocere has been defined by its morphological characteristics. Wetherill described it as the “fat of graveyards” [5, p. 1]. Stewart [6] and Forbes et al. [7,8] refer to it as a soft, whitish substance. Dix [9] presents it as a saponified, hard condition. Mellen et al. [1] describe its “waxy, grey consistency.” Haglund [10] notes that when fresh, adipocere can present a soft, greasy appearance. He notes that as it ages, it may take on hard and brittle characteristics. Haglund also notes that the terms adipocere and saponified tissue have been very loosely applied. Bereuter et al.

refer to it as the “fatty wax type of mummification” [2, p. 268]. For Yan et al. [11] adipocere represents a waxy or greasy decomposition product. Vass [12] presents it as saponification or the formation of soap from fat under high pH conditions. Forbes et al. [13] refer to it as “a grayish-white postmortem decomposition product that can vary in consistency from crumbly to paste-like.” O’Brien and Kuehner describe it as “completely saponified adipose tissue” [14, p.294]. Aufderheide defines it as a “crumbly, wax-like product that resists subsequent chemical change and thus tends to preserve the tissue’s gross morphology” [15, p.53].

As a result of recent research, definitions of adipocere increasingly include a chemical or histological component, especially in regard to early detection. Forbes et al. [7,8,16] and Cassar et al. [17] note that the presence of adipocere is marked by particular fatty acids. Tkocz et al. [18] reference histology, scanning electron microscope examination, biochemical studies and histological structure. Mellen et al. [1] discuss diagnosis by white-violet fluorescence under Wood’s lamp, melting point and assay for free fatty acids.

3. A process of mummification?

The literature presents varied discussion of the relationship of adipocere to more general processes of mummification. In a thorough discussion of processes of mummification and the complex terminology involved, Aufderheide [15] considers adipocere to represent a form of mummification resulting from chemical factors (as opposed to six other mechanisms of mummification). Evans [19] acknowledges the relationship between mummification and adipocere formation. He reports adipocere formation in some cases of natural and prepared mummies. Non-fatty tissues in

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adipoceros bodies are dry and dehydrated, and in that way, they compare with same type of tissue formed in mummification. Though Evans does not specifically describe adipocere formation as a process of mummification, he does explain that “the differentiation between mummification and adipocere formation can be less easily made than has been implied in the past” [19, p. 72–73]. In contrast, Makristathis et al. [20] draw a distinction between adipocere formation and mummification.

However, it is classified, all recognize that adipocere, like the unusual preservation of remains in peat bogs [21] and mummification through desiccation [15], represents an anomaly in the normal decomposition process. Although many factors may retard the process of decomposition [12,22–24], adipocere formation predictably will result in unusual preservation. Because of such preservation adipocere complicates estimation of postmortem interval [25].

4. History

According to den Dooren de Jong [26], as early as 1789, Fourcroy described adipocere and coined the term from the Latin words *adeps* (fat) and *cere* (wax). Fourcroy's work focused on human remains exhumed from the cemetery of the innocents in Paris [27]. He noted that in a three to five year old buried body some muscle was preserved within the adipocere formation whereas in remains buried longer even muscle could not be recognized. Fourcroy also noted that adipocere was concentrated in areas of the body with major fat deposits and that with time soft and wet adipocere became dry and brittle. He also related information from cemetery grave-diggers that typically adipocere was noted in remains interred for over three years. Fourcroy conducted experiments suggesting that adipocere represented a form of soap resulting from reactions of fat with ammonia. [26]

In 1860, Wetherill [5] provided a major review of adipocere and a report of his own research on formation. He noted in some Philadelphia cemeteries, remains with adipocere were found next to others completely skeletonized. He analyzed adipocere recovered from two humans, a sheep and an ox noting “mostly solid fatty acids, a little oleic acid and coally matter” [5, p. 7]. In particular he noted the presence of palmitic acid.

Wetherill [5] experimented with an animal heart buried in sand on December 8, 1853 and kept moist. In six months, fat deposits had changed to apparent adipocere. In one year extensive adipocere was present. This research and that summarized above suggested that the original fat of the body either decomposes or loses its glycerine and most of its oleic acid in conversion to adipocere. Key factors in this process were the abundance of fat and moisture.

In a Canadian study and major review article Ruttan and Marshall [28] summarized published studies and added their own chemical analysis to the growing corpus of information on adipocere. Their analysis of “hard, clean adipocere wax” revealed 68 percent palmitic acid with less than 10 percent stearic acid, oleic acid, hydroxy stearic acid, stearin, palmitin and other substances. Their 1917 conclusion was that “adipocere is the residue of the preexisting fats of animals...composed almost entirely of the insoluble saturated fatty acids left after the slow hydrolysis of the fats in wet ground...the insoluble hydroxy stearic acids which are so characteristic of adipocere are probably derived from a portion of the oleic acid in the original fat by hydration” [28, p. 327].

Chemical analysis of adipocere advanced in 1922 with Goy's [29] research in Germany. He also noted the decline in oleic acid and documented the increase in free fatty acids. In a follow-up German report, Krauland [30] noted adipocere formation on terrestrial remains, describing slate deposits allowing moisture

accumulation as a key factor. Krauland [30] describes a recovered pregnant woman with adipocere formation within which a fetus, also with adipocere formation was found.

Working in London, Mant and Furbank [31] noted that fat throughout the body potentially may become hydrolysed and hydrogenated. They also made the key observation that the body itself contains sufficient water to promote adipocere formation. They suggested that a damp environment was more conducive to adipocere formation than either a very dry one or submersion in water. They noted that bodies with clothing presented more rapid and complete adipocere formation than those without. They observed that bacteria (bacterial enzymes), especially *Clostridium* were essential for adipocere formation. They found anaerobic conditions to be conducive but not essential.

Mant and Furbank also noted that “as there are many degrees of hydrolysis and hydrogenation, the presence of adipocere is not necessarily obvious to the naked eye in the early stages of its formation and its presence could only be ascertained by analysis” [31, p. 32]. This observation set the stage for later chemical definitions of the presence of adipocere. Their call for additional highly specialized biochemical research was also prophetic.

In 1961 den Dooren de Jong [26] provided a major review article, summarizing history of research to that point. His review was prompted by the findings that in Dutch cemeteries (also reflected in the German literature) when exhumations were attempted after a 10 year postmortem interval, more than half of the individuals were not completely decomposed. His lengthy and complex analysis suggested that “the formation of adipocere is a process occurring under virtually anaerobic conditions in which human fat is converted into a complex of saturated fatty acids by a great variety of bacterial species occurring in and on the decomposing body” [26, p. 361].

In 1963 Evans [32] presents another timely synthesis and adds information on the importance of context. Of 109 exhumations conducted of remains buried between 100 and 200 years in dry vault environments, 50 percent presented adipocere formation. Like Fourcroy before him, Evans noted muscle preservation in addition to adipocere formation. Adipocere was more common in females (62.2 percent) than in males (45.4 percent). No strong correlation was noted with age at death or the number of days prior to inhumation.

Subsequent to Evans' work in 1963 [32], a robust literature has formed related to adipocere research including key reviews by Takatori [33], Fiedler and Graw [34] and Aufderheide [15]. Knowledge also has been advanced by numerous case reports [10,35–44] and research, especially on chemical composition.

5. Chemical analysis

Chemical research since 1963 has concentrated on detection of additional components of adipocere, methodological advancement and improved precision in quantification. In 1977 Takatori and Yamaoka [45,46] reported on the separation and identification of two kinds of oxo fatty acids found within adipocere as well as the identification and chemical properties of hydroxy fatty acids. They noted that hydroxy fatty acids comprise 3–20 percent of total fatty acids and that two hydroxy fatty acids play important roles. They followed up these studies by reporting in 1979 the separation and identification of 9-chloro-10-methoxy (9-methoxy-10-chloro) hexadecanoic and octadecanoic acid in adipocere [47].

In 1983, Takatori et al. [48] identified 10-hydroxy-12-octadecenoic acid in adipocere. Experimental work was conducted on substrate specificity relating to the microbial production of hydroxy and oxo fatty acids [49] as well as hydration and dehydration factors [50].

In 1992, Evershed [51] presented the chemical composition of human adipocere preserved within a bog. This study noted that adipocere formed within this context was similar to that formed in other environments. Also in 1992, Vass et al. [52] published their study of how volatile fatty acids in the soil can be used to estimate the postmortem interval. Chemical analysis of the soil beneath seven cadavers documented that propionic, butyric and valeric acids were useful for time since death estimation. These acids are distinct from those found within adipocere. Note also more recent studies by Vass and colleagues on this topic [12,25,53] noting how adipocere formation complicates the estimation of the postmortem interval.

Adachi et al. [54] compared the composition of adipocere with a control of fresh subcutaneous fat noting two hydroxy fatty acids that were unique to adipocere. They noted the presence of epicoprostanol in adipocere (coprostanol being the major metabolite of cholesterol produced in the intestine by bacterial microflora). They further noted that the ratio of epicoprostanol to cholesterol increased with time since death and might prove to be useful in estimating postmortem interval in adipocere cases.

In 2000, Stuart et al. [55] argued that diffuse reflectance infrared spectroscopy could be useful to recognize types of fatty acids present in adipocere. In 2001, Takatori [33] provided a review article summarizing research conducted by that time calling attention to melting points of key fatty acids and the role of microbial conversion factors.

Detection of adipocere in grave soils is important in cases in which remains with adipocere may have been removed through clandestine activity and in evaluations of burial environments conducive to adipocere formation. Forbes et al. [56] demonstrated that gas chromatography–mass spectrometry (GC/MS) may prove useful in such research. In a study conducted in the Black Forest of Germany, Fiedler et al. [3] compared soils in graves with adipocere to those from a non-cemetery area. Adipocere soils contained lower pH, lower calcium and higher phosphorus, organic carbon and cadavarine as well as lower bacterial activity. Fiedler et al. suggested that the calcium was bound in adipocere and that phosphorus had migrated from the body into the soil [3]. Algarra et al. [57] and Cassar et al. [17] also discuss methodology to identify fatty acids in soils.

Forbes et al. [13] conducted a chemical study of adipocere formation in pig cadavers in Western Australia. They employed GC/MS as well as Fourier transform infrared spectroscopy (FTIR) to detect the saturated fatty acids myristic, palmitic, stearic and 10-hydroxy stearic acid and the unsaturated fatty acids of palmitoleic, oleic and lanoleic acid, as well as to document triglycerides and calcium salts of fatty acids. The study provided key information on the transformation of adipose tissue in pigs to adipocere. Adipocere formation was more advanced on the actual pig remains than within associated soils. Yan et al. [11], Gill-King [58], and Takatori [59] also found the composition of adipocere to be of hydroxy fatty acids and salts of fatty acids in addition to being primarily a mixture of fatty acids, mainly palmitic and stearic acids.

In 2008 Notter [4] and colleagues introduced solid-phase extraction in combination with GC/MS for detection of free fatty acids in adipocere. In 2009 they used this technique to compare fatty acids between humans and pigs [60]. This research is relevant since others have used pig decomposition and adipocere formation as a model to interpret these processes in humans. “The analysis was conducted in total ion scan mode and identified those fatty acids known to comprise adipocere. The saturated fatty acids considered were myristic, palmitic, stearic, and 10-hydroxy stearic acid. The unsaturated fatty acids, palmitoleic, oleic, and linoleic acid were also considered because of their occasional presence in low concentrations” [4, p. 75]. They found that

differences between pigs and humans affect the timing of adipose tissue decomposition. They also detected differences in the amount of sodium, potassium, calcium and magnesium.

In a recent chemical study of adipocere formation in a cold water environment, Forbes et al. [61] employed infrared spectroscopy (diffuse reflectance spectroscopy). Using porcine remains in Lake Ontario, Canada submerged at depths ranging from 10 to 30 feet, they documented the decline of triglycerides and increase of unsaturated and saturated fatty acids, salts of fatty acids and hydroxy fatty acids. They found that although depth was not a factor, adipocere formation was diminished in colder temperatures.

6. Timing of formation

Through research and case experience, much has been learned about the context of adipocere formation. Although typically regarded as a product of a damp environment [62], adipocere can form in a variety of contexts, including dry environments [58] and water submersion [9,14,61,63,64] even cold sea water [65]. Remains can include all ages, both sexes and both embalmed and unembalmed remains [66], although most common in individuals with high body fat and within individuals in areas of high body fat [67]. Moisture appears to represent an important factor in formation [58,68] but the source can be from the environment or from the body itself [66].

Burial in clay soils or other types [69] that retain moisture can promote formation [70,71]. Experiments by Forbes et al. [16] suggested that adipocere can form in various soil types, but is accelerated in sandy and silty soils with temperature and moisture content important variables [14]. The presence of clothing with water absorbing capability [72] appears to favor formation [1,7,66,73] although formation can be slowed with remains buried in coffins [7] or protected with plastic [7]. Although general environment represents a factor in formation, the microenvironment in immediate proximity to the remains is critical [74]. Considerable variation can occur among individuals deposited within the same general environment [5,6]. Experimental research with pig adipose tissue suggests that key factors in adipocere formation include mildly alkaline pH, warm temperature [1], anaerobic conditions and adequate moisture [8]. In contrast, cold temperature [1], lime and aerobic conditions can inhibit formation [8]. Postmortem presence of bacteria, especially *Clostridium*, promotes formation [12]. Within soil environments, adipocere formation and detection is influenced by soil characteristics, burial environment, soil pH, temperature, moisture and oxygen content [57]. Adipocere formation appears to advance slower in soils than directly on remains [68] and reflects many factors in addition to postmortem interval [68].

As noted above the timing of formation of adipocere is highly variable and influenced by many factors. Stewart [6] suggests that formation can begin only a few days after death but becomes apparent morphologically after about three months. In another general discussion of adipocere, Fisher [64] notes that it may form in as few as three months but extensive conversion usually requires five or six months.

In their experiments with pig cadavers, Yan et al. [11] noted beginning formation in only a few hours after death. Advanced formation required several weeks. In a related experimental study using human adipose tissue, Mellen et al. [1] found formation required between two and three months in warm tap water but longer in cold water. Cold water experiments in Lake Ontario, Canada by Forbes et al. [61] suggested initial formation after about one month.

In an experimental study of human cadavers in Tennessee, Vass et al. [52] note adipocere beginning formation on day 38 with

remains deposited in the spring and first detected adipocere on day 91 within a winter/spring deposit. Working at the same facility, Rodriguez and Bass [75] report traces of adipocere formation on an individual buried at a depth of one foot after 2.5 months, moderate adipocere after six months at a depth of two feet, and extensive adipocere after one year at a depth of four feet.

In their study of 15 cadavers recovered at different times in cold sea water over 433 days from a sunken Belgian cargo ship, Kahana et al. [65] found adipocere formation as early as 38 days. In Missouri fresh water lakes, slight adipocere formation was detected on a cadaver missing four months and slight to moderate formation on an individual missing six months [9].

7. Persistence

For many years, general discussions of adipocere have recognized its extraordinary longevity once fully formed [6,62–64,76]. Fründ and Schoen [77] note adipocere formation in a German cadaver after 35 years. Manhein [73] reports preservation of adipocere 122 years after death in a study of a Louisiana coffin burial. Adipocere survived on frozen remains found within a retreating glacier in northwestern British Columbia, Canada dating back between 150 and 330 years [78]. In Denmark, adipocere was found within skulls with an antiquity of 440 to 740 years. Adipocere was found on child remains dating from the Late Roman era 1600 years ago near Mainz Germany [38].

Perhaps the record for adipocere persistence originates from the Tyrolean Iceman. These Late Neolithic remains recovered in 1991 from the Tyrolean Alps date from between 3350 and 3100 BC [2]. Chemical analysis suggested some exposure to water [79] and possible adipocere formation on the inner side of skin, associated with other forms of preservation [2,35].

8. Factors in degradation

Although adipocere represents extremely tenacious material resistant to degradation, eventually even it will break down leading to skeletonization [6]. Fisher suggests that adipocere can persist for “months or years” [64, p. 21]. In a German experimental study, Fründ and Schoenen [77] found that adipocere degraded in less than 10 years with exposure to air and soil microbiota. They suggest that degradation of adipocere is accelerated with exposure to air, moisture and fungal growth. In another laboratory study, Pfeiffer et al. [80] found that adipocere degraded with the presence of gram positive bacteria.

9. Preservation of evidence

Since adipocere represents unusual preservation of soft tissues, it can contribute to the retention of evidence related to those tissues. In the extreme, advanced adipocere can maintain the form of the body offering evidence of external morphology that can contribute to recognition and thus personal identification. Such soft tissue preservation also can preserve evidence of injury or lack thereof and thus contribute to interpretations of foul play.

As noted by Stewart [6] adipocere formation can protect the evidence for possible forceful strangulation. Dutra [81] reports a case of adipocere formation in the neck area of a young woman. A fractured hyoid was found within the adipocere suggesting that strangulation had taken place. Sydney Smith reports two similar cases [82,83] in which fractured hyoids were found in remains with adipocere formation. In both cases, adipocere was found on the broken ends of the hyoid fragments suggesting the fracture had occurred prior to adipocere formation.

Adipocere formation also can lead to retention of toxicological evidence. Inoue et al. [84] report a Japanese case study in which

toluene was detected in remains preserved by adipocere. In this case a 24 year old male was found dead within a car submerged in a river for about three months. Adipocere preservation facilitated autopsy which revealed the toluene as well as diatoms in the lung, liver and kidney suggesting death by drowning. The toluene levels were thought to be toxic but not lethal and likely due to the individual sniffing paint thinner.

10. Summary

Much has been learned about the “fat of graveyards” since Fourcroy’s 1789 descriptions of the remains from the Paris cemetery. The classic morphological definitions of a crumbly, wax-like product have now been supplemented with chemical definitions reflecting advances in methodology as well as new knowledge of the chemical products unique to adipocere. Although the literature presents some confusion regarding how to classify it in relation to other forms of preservation, the prevailing view is that it represents a chemical form of mummification.

The history of adipocere investigation reveals an early and sustained interest in its chemical composition and factors leading to its formation. These investigations have been greatly augmented by technological advances facilitating detection and documentation of constituent substances, as well as innovative experimental research designed to elucidate complicating factors.

The literature reveals that adipocere can form in a variety of environments, both terrestrial and aquatic. Favorable factors include presence of body fat, moisture, mildly alkaline pH, warm temperature, anaerobic conditions and presence of appropriate bacteria. The initial stages of adipocere can present relatively soon after death but more advanced visible formation requires weeks. Once formed, adipocere can persist for many years and has been suggested to be present in the 5000 year old iceman recovered from the Tyrolean Alps. Research suggests that aerobic conditions and the presence of gram-positive bacteria are conducive to the degradation of fully formed adipocere but that this process under ideal conditions may still take months or years.

Although adipocere has been considered a nuisance by some interested in more rapid decomposition, it also has resulted in long term preservation of morphological characteristics of the individual and evidence for cause and manner of death. Its presence has complicated attempts to estimate postmortem interval.

Much has been learned about adipocere but key challenges remain. The estimation of postmortem interval of remains with adipocere represents one of these. Extensive chemical research has revealed key factors in adipocere formation. Similar research may indicate how chemical changes within adipocere can be used to estimate time since death or perhaps time since initial formation. This and other research problems likely will continue to attract innovative experiments aimed at understanding more of the decomposition product adipocere.

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