forensic sciences

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Preliminary Taphonomical Comparison of the Decomposition Process in Simple Burials, Traditional Tombs and Aerated Tombs in an Urban Cemetery in Northern Italy

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Abstract: In densely populated countries like Italy, cremation is promoted for the final disposition of the dead. However, many families still choose inhumation or entombment. In ordinary (traditional) tombs, bodies skeletonize slowly and partially, and often need a second disposal after the exhumation. The aim of this study was to experimentally test the functionality of a new type of tomb, defined as "aerated". Aerated tombs feature an aerating system, absorbing materials and a purifying filter, which collectively maintain ventilation, process putrefactive fluids and gases and neutralize odors. In an experimental cemetery area with pristine soil, limbs of piglets were wrapped in cotton sheets and were either inhumed, placed in ordinary tombs or placed in aerated tombs. Following exhumation after planned time intervals (1, 3, 6, 9, 12, 18, 24 months), all samples were macro- and microscopically examined. The inhumed samples were completely skeletonized by 9 months after burial, and after 12 months showed initial bioerosion in bone Haversian canals. The traditionally entombed samples developed progressive adipocere formation, whereas the samples disposed in aerated tombs became mummified. Despite this outcome, aerated tombs represent a more energy-effective, environmentally-friendly and economical choice when compared to ordinary tombs. A mummified body is lighter and drier than a body entombed traditionally and, as such, it is easier to exhume and quicker to cremate. Overall, in the absence of alternative burials, aerated tombs are more suitable than ordinary tombs for the final disposition of the dead in cemeteries with limited space. The results of this experiment add to the knowledge of taphonomical processes in temperate climates and urban environments, potentially benefitting the forensic and medico-legal community.

Keywords: post-mortem interval (PMI); cremation; exhumation; skeletonization; mummification; necrosols

Citation: Guareschi, E.E.; Magni, P.A. Preliminary Taphonomical Comparison of the Decomposition Process in Simple Burials, Traditional Tombs and Aerated Tombs in an Urban Cemetery in Northern Italy. *Forensic Sci.* **2022**, *2*, 505–515. https://doi.org/10.3390/forensicsci2030037

Academic Editors: Pier Matteo Barone, Rosa Maria Di Maggio, Alastair Ruffell and Laurance Donnelly

Received: 17 June 2022
Accepted: 15 July 2022
Published: 19 July 2022

1. Introduction

In densely populated countries, where the space available for cemeteries is limited, cremation is actively promoted for the final disposition of the dead. In Italy, cremation has been constantly increasing in the last 20 years, from 10% in 2007 [1] to 33.22% in 2020 [2]. This trend has also been accelerated by the need of handling a large number of deceased in a short period of time, due to the COVID-19 pandemic [3–5]. However, many families still choose inhumation (burial in the ground), or entombment (placement in a tomb or mausoleum), for practical reasons (e.g., the logistics of the crematorium), tribal traditions or religious and cultural beliefs. In a 2019 estimate for the Italian territory, this resulted in 18.82% of inhumations and 50.50% of entombments [2]. In order to maximize the space available in existing cemeteries, the Italian law requires periodic exhumations after 10 to 20 years, depending on the location [6]. However, while inhumed bodies can reach complete skeletonization in such time, allowing an easy relocation of the skeletal remains to ossuaries, after the same amount of time entombed bodies are generally not ready to be transferred. Even after 40 years since entombment, these remains can be still found only partially skeletonized, partially articulated and immersed in putrefactive sludge [7], with possibly extensive adipocere of soft tissues and corification of the skin layers [8]. In these cases, a further disposal of the body is required, either by cremation or inhumation, before the transfer to the ossuary. This practice is associated with sensitive issues, such as the cost of a second disposal, the necessity of space in cemeteries and the distress of the families involved [7]. In the last 20 years, the entombment in a new type of tomb defined as "aerated" [9,10] has been proposed as an alternative to inhumation or to the ordinary (traditional and sealed) entombment, with the aim of promoting the rapid skeletonization of the body, minimizing public health hazards and lowering the costs of further disposals, while respecting the established exhumation turnover.

Aerated tombs can be newly built or adapted from ordinary tombs. Through an aerating system with a purifying filter, these tombs achieve the double purpose of maintaining the ventilation within the tomb and of processing the putrefactive fluids and gases separately. This system targets the two main disadvantages of sealed tombs: (1) the ineffective skeletonization of bodies due to lack of ventilation; and (2) the leakage of fluids and gases during decomposition, which promotes the formation of adipocere [11]. In aerated tombs, fluids are absorbed by Enzisalm® (Ceabis), a biodegrading biological powder placed on the bottom of the coffin. Enzisalm® is composed of microorganisms and their specific nutrients, and promotes decomposition by metabolizing organic matter. Furthermore, Hydro-Gel® (Ceabis), another powder with gelifying and biocide action, is placed in the plastic collecting tray under the coffin, to absorb fluids and neutralize odors. Gases generated by decomposition are purified by an activated carbon filter. The structure of an aerated tomb is outlined in Figure 1. The first countries legalizing the use of aerated tombs in cemeteries were France, with the regulation NF P 98-049:1994 [12] and Spain, with the Decree 2263/1974 (20 July) and autonomous regulations [13]. In the Italian region where this study was conducted (Emilia Romagna, north of Italy), aerated tombs were legalized in 2006 [14].

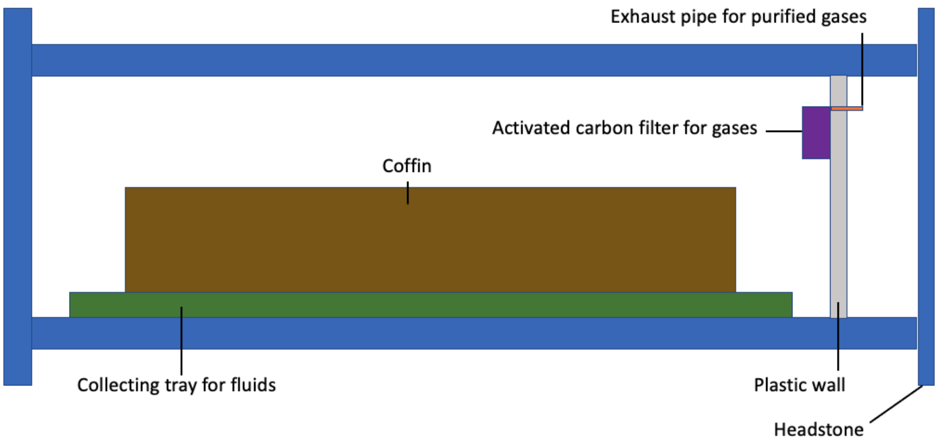

Figure 1. Structural outline of an aerated tomb. Enzisalm® (Ceabis) is placed on the bottom of the coffin to absorb decomposition fluids. Hydro-Gel® (Ceabis) is placed in the collecting tray under the coffin to absorb fluids and neutralize odors. Decomposition gases are purified by the activated carbon filter (top right).

The aim of this study, carried out between 2011 and 2013 in Parma, Italy, was to test the safety and the functionality of aerated tombs for the first time, by characterizing the associated decomposition process and by comparing the decomposition rate with the one observed in inhumations and ordinary tombs in the environment of a northern Italian cemetery. Aerated tombs have been in use for about 20 years in the cemeteries of a few European countries, such as Italy, France and Spain, with the aim of achieving a more efficient, faster and cleaner decomposition of bodies. However, the aimed results have never been tested by research. The obtained results provide important information regarding the human decomposition process and the taphonomy in cemetery settings. Beside the main scope of testing aerated tombs, the obtained data will benefit forensic sciences by adding clues to the estimation of the time since death (Post-Mortem Interval, PMI) and the modification of bodies after death in medico-legal investigations regarding exhumed bodies and illegal burials [15,16].

2. Materials and Methods

The experiment took place between February 2011 and February 2013 in the cemetery "La Villetta" in Parma (northern Italy, 44°79′00″ N 10°31′43″ W), in a fenced area where the soil had never been previously used for burials. The fencing was necessary to prevent the accidental trespassing of the public. The use of cemetery areas for scientific studies was in accordance with the Italian legislation [6]. According to the Köppen-Geiger climate classification, the climate of Parma is Cfa, that is temperate, humid and with hot summers. The mean annual temperature is 13.70 °C (56.66 °F) and precipitation is 888.00 mm (34.96 in).

For the purpose of the experiment, lower limbs of swines (*Sus scrofa domesticus* Erxleben, n = 21, weighing between 420 g to 1430 g) deceased by natural causes in a local pig farm were used. In Italy, the current legislation does not allow the use of human cadavers for experimental purposes, and swines are considered the best proxy to human bodies for taphonomical studies [17]. Each limb was wrapped in biodegradable sheets (cotton) to mimic the presence of clothes [18]. In order to replicate inhumation, limb samples (n = 7) were individually placed in small pinewood coffins buried in the ground at a depth of 1.5 m; ordinary entombment was instead replicated by individually placing the samples (n = 7) in small zinc coffins, which were then sealed inside a stone tomb. The remaining samples (n = 7) were individually placed in small wooden coffins, which were then lined inside an aerated tomb, complete of all its components. The limited space available for the experiment in a public urban cemetery required the use of limbs, instead of complete bodies, and the allocation of a relatively small number of samples.

One sample for each of the disposal types was exhumed at planned time intervals of 1, 3, 6, 9, 12, 18 and 24 months, and codified as I (inhumation), OT (ordinary tomb) and AT (aerated tomb). Macroscopical parameters such as weight loss and an empirical estimation of decomposition were assessed at the time of exhumation. Microscopical analyses, such as microbiology on soft tissues, and histology on bone, were also performed at the time of exhumation. Microbiology was conducted in three different types of culture media, i.e., in atmosphere of CO_2 at 37 °C for aerobic bacteria growth, in anaerobiosis at 37 °C for anaerobic bacteria growth, and in incubation at 25 °C for 10 days for yeasts, molds and fungal growth [19,20]. The staining techniques applied to histology on bone were Haematoxylin-Eosin, PAS (periodic-reactive Schiff acid) and Gomori-Grocott [21]. Each sample was observed and analyzed for the presence of insects and other arthropods, following the approved guidelines for collection and storage of necrophagous fauna available in the forensic entomology literature [22,23].

3. Data Analysis

Data obtained from the three types of sample disposals were subjected to statistical multivariate analysis. Contingency tables considered the type of disposal of the samples (inhumation, entombment in an ordinary tomb, entombment in an aerated tomb) and the outcome of decomposition (skeletonization, adipocere, mummification) over time (1, 3, 6, 9, 12, 18 and 24 months). The level of significance was set at $p < 0.05$. Calculations were performed using IBM® SPSS® Statistics 28 statistical analysis software.

4. Results

At the macroscopical observation, the inhumed samples followed the stages of putrefaction, that is, the typical pattern of decomposition. All the seven buried samples were completely skeletonized and disarticulated within 9 months since their deposition in the soil. On the contrary, the samples in both the ordinary and aerated tombs consistently maintained their overall morphology over time, until the last exhumation after 24 months. Traditionally entombed samples retained the moisture of soft tissues and showed the progressive formation of adipocere. In aerated tombs, samples shrank in size and became dry. The results of macroscopical observations are summarized in Table 1 and Figure 2.

Table 1. Results of the macroscopical observations: weight of each sample at the time of disposal (February 2011) and at the time of exhumation (after 1, 3, 6, 9, 12, 18 and 24 months), with the percentage of weight loss starting from 100%. Samples which had lost all soft tissues (complete skeletonization) were assigned a "0" weight value. Weights have been rounded to the closest whole number.

Type of Disposal	Period of Disposal (Months)	Weight at the Time of Disposal (g)	Weight at the Time of Exhumation (g)	Weight Loss (%) [a]
Inhumation (I)	1	770	716	93
	3	1430	1100	77
	6	770	390	51
	9	650	0 [b]	100 [b]
	12	780	0 [b]	100 [b]
	18	750	0 [b]	100 [b]
	24	1040	0 [b]	100 [b]
Ordinary tomb (OT)	1	490	486	99
	3	1320	1180	89
	6	730	570	78
	9	730	500	68
	12	700	420	60
	18	930	450	48
	24	1380	650	47
Aerated tomb (AT)	1	570	544	95
	3	600	465	78
	6	500	330	66
	9	420	133	32
	12	650	146	22
	18	1160	214	18
	24	1060	160	15

[a] Starting from 100% at the time of disposal. [b] Completely skeletonized samples were assigned a "0" weight value.

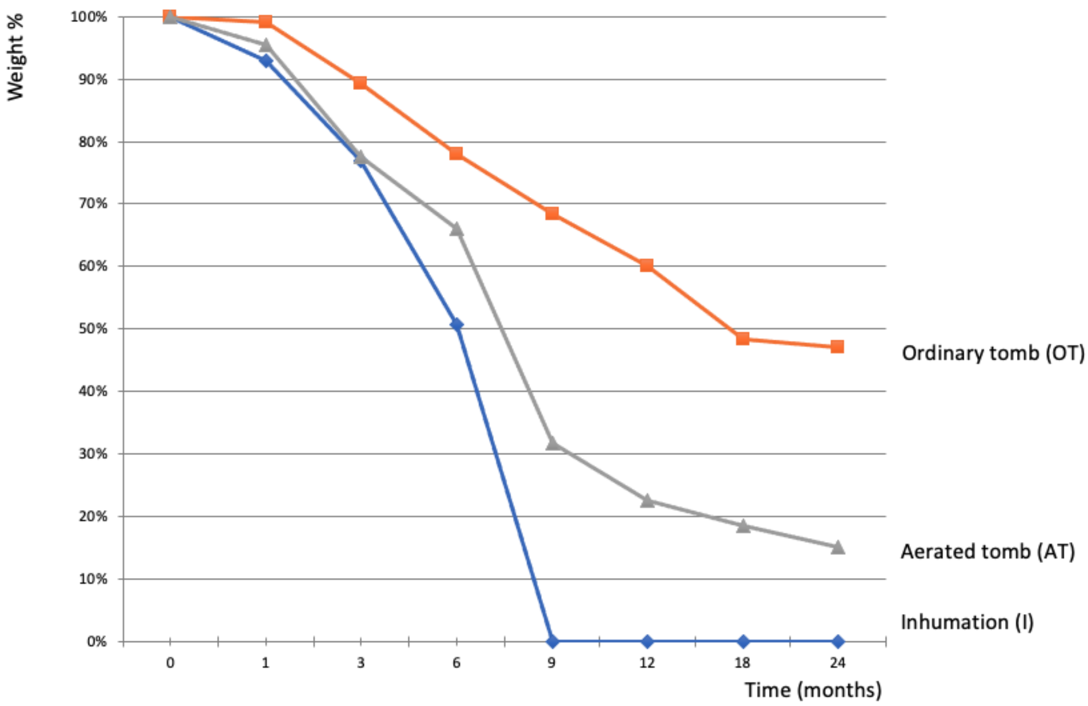

Figure 2. Decrease of the samples' weight over time, following the loss of soft tissues until the complete skeletonization. The buried samples were completely skeletonized within 9 months and were assigned a "0" weight value. The samples placed in ordinary tombs lost 48% and 47% of their initial weight in 18 and 24 months, respectively. The samples placed in aerated tombs showed a loss of about one-third of their initial weight (34%) in 6 months, and slightly more than two-thirds (68%) by 9 months.

Overall, in this quantitative, observational, longitudinal and prospective research, performed in an artificial setting, the statistical analysis of numerical data supported the hypothesis that aerated tombs were more functional than ordinary tombs for the decomposition of bodies in cemeteries. A total of 100% of the buried samples were completely skeletonized within 9 months after burial. In 18 and 24 months the samples placed in ordinary tombs only lost 48% and 47%, respectively, of their initial weight, showing a stabilization of the decomposition process from 18 months after the disposal onward. In 6 months, the samples placed in aerated tombs showed a loss of about one-third of the initial weight (34%), which reached slightly more than two-thirds (68%) by 9 months.

The microbiological analyses performed on soft tissues revealed a consistent presence of aerobic and anaerobic bacteria, with only anaerobic bacterial species (*Clostridium* spp.) present in ordinary entombments after 6 months. In all types of disposals (100%), the colonization by fungi and yeasts appeared to decrease over time, while molds increased. Bone histology confirmed the fast decomposition of soft tissues in inhumed samples, with preservation of bone microstructure and patterns of initial bioerosion in Haversian canals after 12 months. Bioerosion was not detected in bone samples from either ordinary or aerated tombs where, conversely, soft tissues such as bone marrow, connective and striated muscle remained visible throughout the whole duration of the experiment (24 months). Samples from aerated tombs exhibited a better microstructural preservation, with a clearer characterization of cells. The detailed results of microbiological and histological analyses are summarized in Table 2.

Table 2. Details of the results of microbiological analyses on soft tissues and bone histology.

Type of Disposal	Period of Disposal (months)	Presence of Bacteria [a]	Presence of Fungi [b]	Bone Preservation	Soft Tissue Preservation
Inhumation (I)	1	AnB	F, M, Y	Preserved	Residues of bone marrow
	3	AB/AnB	F, M, Y	Preserved	No
	6	AB/AnB	None	Preserved	No
	9	AB/AnB	F, M, Y	Preserved	No
	12	AB/AnB	F, M, Y	Bioerosion (Haversian canals)	No
	18	AB/AnB	Molds	Bioerosion (Haversian canals)	Rare remnants of bone marrow and cartilage
	24	AB/AnB	Molds	Bioerosion (Haversian canals)	Rare remnants of bone marrow and cartilage
Ordinary tomb (OT)	1	AB/AnB	F, M, Y	Preserved	Residues of bone marrow
	3	AB/AnB	F, M, Y	Preserved	Rare residues of bone marrow
	6	AnB	None	Preserved	Rare residues of bone marrow
	9	AnB (*Clostridium* spp.)	None	Preserved	Rare residues of bone marrow
	12	AnB (*Clostridium* spp.)	Molds, yeasts	Preserved	Rare residues of bone marrow
	18	AnB	Molds	Preserved	No
	24	AnB (*Clostridium* spp.)	Molds	Preserved	No
Aerated tomb (AT)	1	AB/AnB	F, M, Y	Preserved	Remnants of bone marrow, connective and striated muscular tissue
	3	AB/AnB	F, M, Y	Preserved	Rare remnants of bone marrow, connective and striated muscular tissue
	6	AB/AnB	Molds	Preserved	Rare remnants of bone marrow, connective and striated muscular tissue
	9	AB/AnB	None	Preserved	Rare remnants of bone marrow, connective and striated muscular tissue
	12	AB/AnB (*Bacillus* spp., *Coccus* spp.)	Molds	Preserved	Rare remnants of bone marrow, connective and striate muscular tissue
	18	AB/AnB	Molds	Preserved	Rare remnants of bone marrow, connective and striated muscular tissue
	24	AB/AnB	Fungi, molds	Preserved	Rare remnants of bone marrow, connective and striated muscular tissue

[a] aerobic bacteria (AB) and anaerobic bacteria (AnB), [b] fungi (F), molds (M), yeasts (Y).

With regards to the entomological analyses, while at least specimens of coffin flies (Diptera: Phoridae), house flies (Diptera: Muscidae), beetles and mites typically present in tombs and burial environments were expected [24,25], negative results were obtained both at a macroscopical and microscopical observation.

5. Discussion

This study tested for the first time the safety and the functionality of aerated tombs, in comparison with inhumations and ordinary entombments. The results obtained are of interest for cemetery management purposes, but can also be useful for forensic investigations involving the estimation of the PMI of buried and entombed remains in urban cemetery settings. This research demonstrates that the decomposition process in aerated tombs leads to the mummification of the experimental samples. Progressive stages of the mummification process were identified and linked to the increasing amount of time passed since the start of the observations. The continuous drying, and the consequent shrinking, of the samples was generated by the presence of air, an essential and defining feature of aerated tombs, which promoted both the efficient evaporation of fluids and the colonization by diverse bacterial species, aerobic and anaerobic, which persisted throughout the experiment. The rapid loss of moisture and weight experienced by the samples continued until 12 months (78%), after which it slowed down and stabilized. The stabilization of the decomposition process is a typical characteristic of the mummification process [8,26–28]. In fact, samples that spent 12 and 24 months in the aerated tombs lost 82% and 85% of their initial weight, respectively. Having reached close-to-complete mummification, the last aerated tomb sample showed, at 24 months, scattered remnants of soft tissues attached to bone, such as bone marrow, connective and striated muscle, which microstructure was recognizable histologically and allowed the occasional clear identification of cells.

In accordance with previous studies [7,29–31], inhumation, notoriously associated with the drainage of water and fluids, the access of scavengers and the availability of oxygen [32,33], was confirmed as the environment characterized by the fastest decomposition, with complete skeletonization and disarticulation of the sample by 9 months after burial. The high aerobic and anaerobic microbiological activity promoted the fast breakdown of organic matter, and was also supported by the identification of initial patterns of bioerosion [34–36] in bone Haversian canals from 12 months onwards. In similar accordance with previous studies [7,11,37], entombment in ordinary tombs reaffirmed the trend towards the pervasive formation of adipocere, with no microstructure of soft tissues histologically recognizable after 12 months. Contrarily to both inhumation and aerated tombs, ordinary tombs feature a double coffin and act as closed systems, with virtually no exchange with the external environment, and create a humid microclimate that, in the absence of evaporation, causes slow weight loss. In fact, 48% and 47% of the initial samples' weight were still present after 18 and 24 months, respectively. Finally, the consumption of air oxygen within 6 months led to the disappearance of fungi and aerobic bacterial species, thus only anaerobic bacterial species were detected.

Around the world, inhumation is still the most traditional of the post-mortem disposals [38,39], although presenting multiple disadvantages and being arguably eco-friendly. The requirements of a coffin with linings to accommodate the body, the purchase of a land plot and the need of funerary services (e.g., for the handling of the coffin) make it expensive. Moreover, cemetery land space is needed and potentially noxious substances, such as embalming chemicals, metals, cytotoxic drugs and infectious agents are left to seep into the ground for years [40–42]. This translates into the creation of necrosols, a type of urban soil [43,44], characterized by distinctive structure, stratigraphy and geochemistry. Necrosols present an increase in the contents of organic carbon, total nitrogen, phosphorus (defined as an indicator of anthropogenic impact) [45,46] and Zn, which can persist for thousands of years [47], and all concur in the production of an alkaline trend. Litter from grave artefacts, such as hardwood, nails, textiles and concrete, is widespread, and scattered human bones are easily found in necrosols [47–49]. This poses a threat to public health by the potential contamination of water sources, and makes any requalification of the urban spaces (e.g., parks) difficult [40,50]. Environmentally wise alternatives to inhumation or entombment are "green-burial" methods, such as water cremation [39,51] and human-composting, also known as natural organic reduction [52–54]. The environmental impact of these burials is much lighter than the traditional cremation by incineration [55] and achieves a final transformation of the body in a very short time (from 4 h in water cremation to 30 days in human composting), saving costs and space when compared to traditional cremation. Nowadays, green burials are available in an extremely limited number of countries, such as the US, Australia and South Africa.

When cremation is not the choice, either of the deceased (e.g., in their will) or of grieving families, green burials are not available and inhumation is not feasible, usually for the shortage of space in cemeteries, aerated tombs are a valid alternative to ordinary tombs for the final disposition of the dead. Despite the apparent favoring of mummification, aerated tombs represent a more energy-effective, environmentally-friendly and economical choice when compared to ordinary tombs. This study proves that, at the time of exhumation, the mummified body retrieved from an aerated tomb is comparatively lighter and drier than a traditionally entombed body, which often turns to adipocere. The exhumation of a mummified body is more hygienic and practical, the exhumations turnover can be more frequent, and the following cremation process requires less energy, with an overall decreased impact on the environment. Furthermore, it is highly likely that a mummified body exhumed from an aerated tomb in the context of a medicolegal investigation, e.g., for a posthumous identification, could yield usable genetic material, such as nuclear and/or mitochondrial DNA [56–58].

6. Conclusions

Preliminary comparison between different type of tombs shows that aerated tombs achieve better results than ordinary tombs in the decomposition of bodies. As a consequence, aerated tombs allow more frequent, practical and hygienic exhumations, as well as faster post-exhumation cremations. However, due to the limited numbers of samples, a variation of the obtained results can be reasonably expected if the experiment is repeated on a larger scale.

In countries affected by the shortage of space in, and for, urban cemeteries, a growing issue that requires careful management due to the sensitive nature of the topic, aerated tombs should be preferred to ordinary tombs when inhumation, cremation by incineration or other alternative final dispositions of the dead are not feasible.

7. Limitations of the Study and Future Directions

This study originated by research initially aimed to achieve a technical report to address a sensitive issue, associated with moral, ethical, financial, social and political implications. Hence, the small space allocated for the setup of an experimental area inside the public urban cemetery grounds limited the number of replicas. Moreover, the microbiological analyses were preliminary, and solely aimed to detect aerobic and/or anaerobic species. Finally, technical refinements of aerated tombs that might potentially overcome the mummification trend were not discussed, as they would fall beyond the journal's forensic topic. From a taphonomic point of view, the mummification of bodies in aerated tombs could be reduced or eliminated with the aid of further studies (e.g., prospective and longitudinal on bodies disposed in aerated tombs in the present, with an established exhumation interval), by refining the deposition procedures (e.g., optimizing the added amount of biodegrading biological powder) and by improving the technology of the tomb structure. Future studies should consider larger experimental areas, as well as cemeteries in other locations, to compare the efficiency of aerated tombs in different climates.

Author Contributions: Conceptualization, Investigation, Methodology, Data Curation, Writing—Original Draft Preparation, E.E.G.; Methodology, Data Curation, Writing—Review and Editing, P.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: No funds were received to perform and publish this research.

Institutional Review Board Statement: Ethical review and approval were waived for this study due to the absence of any specific requirement in the Italian legislation at the time of the study (2011–2013).

Informed Consent Statement: Not applicable.

Data Availability Statement: Not required at the time of the study (2011–2013). However, the authors declare that no animal was sacrificed for this study.

Acknowledgments: The authors wish to thank Paola Colla, then President of ADE S.p.A., and the cemetery director, Roberto Burchielli, for authorizing the study on the cemetery premises. The authors also wish to acknowledge the professional contributions of microbiologist Laura Zerbini, forensic pathologist Franklyn R.W. Van de Goot, Giuseppe Battistini and the operational staff of the cemetery "La Villetta" in Parma, Italy.

Conflicts of Interest: The authors declare that they have no conflict of interests.

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