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Contributions to the Forensic Anthropological and Taphonomic Study of Skeletal Remains

SUMMARY OF THE DOCTORAL THESIS

Doctoral Supervisor:
PROF. UNIV. DR. CURCĂ GEORGE-CRISTIAN

PhD Candidate:
UDRIȘTIOIU LARISA-ADELA

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INTRODUCTION

Death does not end the biological history of the body, but rather initiates a complex sequence of transformations through which tissues are modified, destroyed, preserved, or redistributed under the influence of the environment. In the case of skeletal remains, these transformations acquire particular significance, as bone and teeth often represent the last structures retaining useful information about the individual to whom they belonged. In this regard, taphonomy becomes essential for understanding human remains, as it enables differentiation between what belongs to the organism itself, what reflects the circumstances of death, and what was subsequently produced by postmortem processes. The motivation for choosing this topic arose from the concrete difficulties encountered in forensic practice when skeletal material is profoundly altered and consists of small fragments. Following an analysis of forensic anthropology cases over a ten-year period, I found that, in such situations, anthropological examination cannot be separated from taphonomic analysis. Moreover, laboratory methods are indispensable to forensic evaluation, bringing non-destructive investigations to the forefront. Considering the complex cases encountered at the national level, this thesis also acquired a specific focus on the chemical taphonomy of cadaveric remains. In a forensic context, interest in chemical taphonomy is justified by situations in which caustic or corrosive agents are used to destroy, alter, or conceal a corpse. Following an extensive review of the literature, I found that the impact of this research direction is even greater given that the scientific literature dedicated to the criminal use of caustic and corrosive substances remains limited and heterogeneous. At the same time, the public and cultural representation of this criminal method is virtually unlimited, being encountered from prose to animated films. Although this represents an extreme method of cadaver alteration, I formulated the hypothesis that the means by which it may be carried out could be accessible to almost anyone. In this regard, I conducted two experimental forensic studies in which hard tissues and teeth occupied a central place, as they are the most resistant structures of the body and, at the same time, among the most important sources of forensic information. Nevertheless, I found that exposure to strong chemical agents profoundly modifies both the macroscopic appearance and the microstructure and composition of these tissues. In addition, in such contexts, the absence of obvious destruction does not exclude chemical alteration, and preservation of the general shape does not guarantee the preservation of biological or traumatological information. In the first stage, I evaluated the changes produced by widely commercially available caustic and corrosive substances, not intended for professional use, on 59 fragments of pig ribs with soft tissues still present, over a period of two months. In addition, traumatic lesions were produced on the rib fragments using an axe and a ceramic knife. The selected solutions contained hydrochloric acid, sulfuric acid, a combination of the two acids, sodium hypochlorite, and caustic soda. The methods used in this study included photographically documented macroscopic analysis, XRF examination, radiological assessment, and serological investigations using anti-species sera. Considering the partial results observed dynamically for the sulfuric acid solution, larger samples were also included in the study; these were subsequently reduced to infracentimetric fragments. Each solution produced specific effects, including effects on the persistence of traumatic lesions; among them, the most destructive effect was observed in the case of sulfuric acid. For the second study, I used the same substances over a 48-hour period, each applied to one human tooth. Considering the rapid destructive effect of the solution containing sulfuric acid and the fact that the tooth became unusable for the intended investigations, this sample was excluded from the study. The remaining teeth were subjected to morphometric analysis, mass determination, stereomicroscopic evaluation, SEM-EDX analysis, preparation of ground dental sections, and assessment by optical microscopy and stereomicroscopy. These methods allowed an extensive characterization of the changes produced, as well as the formulation of hypotheses regarding patterns that may occur in such taphonomic contexts.In relation to the experimental pilot studies described above, some of the investigations mentioned were also applied in a real case submitted for forensic anthropological expertise, presented at the end of this thesis. In that case, the suspicion of homicide involving a six-year-old child was raised following forensic anthroposcopic analysis and was subsequently confirmed and refined through a series of investigations and expert assessments, including micro-CT, analysis of bone diagenesis, XRF analysis, traceological examination, genetic analysis, and psychiatric assessment of the suspect. Therefore, the present research aims to contribute to the understanding of the ways in which skeletal remains are influenced by taphonomic processes. The integration of macroscopic examination with complementary methods allows a more rigorous characterization of the observed changes and supports the differentiation between postmortem alterations and lesions of forensic significance. Thus, this thesis seeks to strengthen a perspective in which taphonomy is not merely a descriptive stage, but a central interpretative framework of forensic anthropological expertise.

I. GENERAL BACKGROUND AND STATE OF THE ART

1. FORENSIC ANTHROPOLOGICAL AND TAPHONOMIC FRAMEWORK

1.1 The Origins and Evolution of Taphonomy

In 1940, the Soviet paleontologist Ivan Antipovich Yefremov, also known as Ivan Efremov, introduced the concept of "taphonomy" as a new branch of paleontology, deriving the term from the Greek words *taphos* ("burial") and *nomos* ("law"). His central idea was that fossils do not represent biological reality in the sense of "as it was," but rather a record filtered through numerous processes, including death, transport, disarticulation, burial, alteration, and differential preservation. Therefore, in order to correctly interpret a fossil assemblage, it was first necessary to understand how that assemblage had formed (J.A. Efremov, 1940). Subsequently, the concept expanded, demonstrating that these processes not only alter or reduce information, but may also provide important additional data, such as rodent gnawing marks, fractures, or other modifications with interpretative value. Later, taphonomy came to be understood as the study of all processes that transform organisms after death and influence the condition, distribution, and significance of the recovered remains. In addition, anthropologist Lee Lyman argued that human interventions on organic remains, such as dismemberment, may also form part of the taphonomic history of an assemblage(Lee Lyman, 2010). It is essential to note that numerous principles derived from paleontology and archaeology have direct applicability in forensic anthropology, particularly in estimating the postmortem interval, reconstructing the environment and circumstances in which cadaveric remains evolved, clarifying the sequence of postmortem events, and differentiating traumatic injuries from changes produced by other taphonomic factors (Ubelaker, 1996).

1.2. Interdisciplinary Methods for the Physicochemical Investigation of Skeletal Remains in a Forensic Context

The investigation of skeletal remains in a forensic context requires an interdisciplinary approach, in which classical anthropological methods are complemented by taphonomic analysis and modern physicochemical techniques. These methods may be classified as follows:

1.Anthropological methods: macroscopic and osteological examination, determination of the biological profile, analysis of lesions, and assessment of individualizing features;

2.Taphonomic methods: evaluation of the recovery context, assessment of postmortem modifications, and differentiation between taphonomic alterations and traumatic injuries;

3.Physicochemical methods: microscopic and histological techniques, SEM-EDX, XRF, FTIR/Raman spectroscopy, micro-CT and other imaging methods, residue analysis, and assessment of structural and compositional changes.

Among these, the taphonomic methods used in the investigation of skeletal remains essentially pursue three major objectives: documenting and interpreting the recovery context, describing and assessing postmortem modifications, and differentiating them from traumatic injuries of forensic significance. In modern forensic anthropology practice, the value of taphonomic analysis derives precisely from its ability to integrate field data, the morphological signatures of postmortem alteration, and the principles of differential diagnosis, in order to reconstruct as accurately as possible the postmortem history of human remains (Dirkmaat et al., 2008; Dirkmaat & Cabo, 2016; Sorg, 2019). A particularly important role is played by the differential diagnosis between taphonomic alterations and traumatic injuries, which represents one of the most challenging issues in forensic anthropology practice.

Residue analysis and the assessment of structural and compositional changes represent the area in which these methods converge most clearly. Histology can reveal microcracks, bioerosion, altered collagen, and remodeling (Andronowski et al., 2018); SEM-EDX can identify metallic particles, gunshot residue, tool marks, and microcontamination (Stefano et al., 2022); XRF can characterize elemental distribution and detect metals or chemical anomalies (Manhas et al., 2025); FTIR and Raman spectroscopy can assess crystallinity, collagen preservation, and mineral-to-organic ratios (Tamara et al., 2023); while micro-CT can document internal microarchitecture, fracture pathways, and three-dimensional structural transformations (Franchetti et al., 2022).

Used in isolation, each of these methods has important limitations; when applied in an integrated manner, however, they allow a much more rigorous characterization of the ways in which bone has been modified by the environment, diagenesis, chemical agents, or trauma. For this reason, recent literature emphasizes that the future of forensic investigation of skeletal remains does not lie in a single “decisive” technique, but rather in a multimodal approach, in which morphological, histological, imaging, and compositional data are correlated to support an interpretation that is as robust and reproducible as possible.

2. CHEMICAL TAPHONOMY OF HUMAN REMAINS AND THE CONDITIONS FOR THE DISSOLUTION OF CADAVERIC REMAINS

The importance of the aforementioned methods becomes even greater in situations in which skeletal remains have been subjected to particular taphonomic conditions, such as the action of corrosive or caustic substances, in which case simple morphological examination may be insufficient for understanding the mechanisms of alteration.

2.1. General Considerations

I conducted a systematic search of the literature on this topic and found that the scientific literature remains limited, requiring the search to be extended beyond academic sources to so-called "grey literature" and simple Google searches. This search did not identify any review on the subject; therefore, a scoping review was conducted following the PRISMA structure for scoping reviews. A total of 83 papers addressing the alteration of cadaveric remains using caustic and corrosive substances were included. The review included experimental studies on human tissues, including teeth, studies on animal tissues, case reports, and cases identified in the media (Udriştioiu et al., 2025a).

2.2. Biological Substrate and Susceptibility to Chemical Alteration

Understanding the chemical dissolution of the corpse requires, first and foremost, an understanding of the substrate on which corrosive agents act. For example, cortical bone and trabecular bone do not react identically, as differences in density and specific surface area influence both the rate and pattern of alteration (Boskey, 2013; Dorozhkin, 2009; Feng, 2009). In the case of teeth, resistance is even greater, but not uniform (Salazar et al., 2025; Thurzo et al., 2022).

2.3. General Chemical Mechanisms of Postmortem Alteration

The available data show that these processes are simultaneously influenced by extrinsic factors, such as weather, soil, and humidity, and intrinsic factors, such as sex, age, and the individual characteristics of bone (Falgayrac et al., 2022).

From a chemical perspective, the alteration of hard tissues may follow several pathways: acid demineralization, alkaline hydrolysis of the organic matrix, oxidation, mineral recrystallization, and contamination or ionic exchange with the surrounding environment (Falgayrac et al., 2022). This complexity explains why, in many cases, there is no single "signature" sufficient for interpretation and why conclusions must be formulated by correlating morphology, composition, and the recovery context (Udriştioiu et al., 2025a).

2.4. Chemical Conditions Involved in the Dissolution of Cadaveric Remains

The action of acidic environments can be explained by their capacity to dissolve the mineral phase of bone and teeth. In practice, this means that acids can produce softening, with increased elasticity, thinning, mass loss, surface erosion, structural collapse, and, subsequently, compromise histological analysis and morphological interpretation (Guendalina et al., 2021). Recent experimental forensic literature shows that NaOH can aggressively dissolve soft tissues, with marked exothermic reactions, and can structurally and compositionally modify hard tissues, even though bone and teeth may sometimes remain macroscopically more recognizable than in concentrated acidic environments (Feirstein et al., 2025).

2.5. Taphonomic Changes Induced by Chemical Dissolution

Histology can reveal the compromise of bone architecture, bioerosion, collagen alterations, and microcracks (Sluis et al., 2025); SEM-EDX can document surface topography and exogenous residues (Stefano et al., 2022); XRF allows the assessment of elemental distribution (Gomes et al., 2024); FTIR and Raman spectroscopy provide information on phosphates, carbonates, collagen, and the degree of crystallinity (Tamara et al., 2023); and micro-CT enables the non-destructive evaluation of internal microstructure and fracture pathways (Falgayrac et al., 2022). In recent literature, ATR-FTIR has been described as a relatively rapid and accessible method for assessing the preservation state and DNA preservation potential of bones and teeth (Tamara et al., 2023), while Raman spectroscopy has proven useful for monitoring early molecular changes induced by diagenesis and for PMI-related research (Falgayrac et al., 2022). In addition, in the evaluation of teeth, ground dental sections may provide essential information (Udriştioiu & Andrei, 2026).

2.6. Forensic Value and Interpretative Limitations

The chemical taphonomy of human remains shows that the dissolution of a corpse is not a uniform phenomenon, but rather the result of the interaction between tissue composition, the chemical properties of the agent used, concentration, exposure time, temperature, the quantity of the substance, and the exposure environment (Guendalina et al., 2021; Udriştioiu et al., 2025a).

II. PERSONAL CONTRIBUTIONS

3. HYPOTHESIS AND OBJECTIVES

3.1. Hypothesis

The present research is based on the premise that an integrated forensic anthropological and taphonomic approach to skeletal remains allows a better understanding and interpretation of postmortem modifications, including those produced by the action of chemical agents, thereby contributing to the increased evidentiary value of the examination of bone and dental remains in forensic practice.

3.2. General Objective

The general objective of the thesis is to contribute to the development of a framework for the forensic anthropological and taphonomic analysis of skeletal remains, through the investigation of modifications observed in laboratory practice, experimental studies on bone and teeth, and the use of relevant forensic casework.

3.3. Specific Objectives

1. To conduct a retrospective analysis of cases from the forensic anthropology laboratory, in order to highlight the main types of taphonomic modifications encountered in current practice and their relevance for forensic anthropological expertise.

2. To conduct an experimental study on animal bone fragments using chemical substances commercially available in Romania, with the aim of identifying morphological and taphonomic patterns useful for forensic interpretation.

3. To conduct an experimental study on human teeth using chemical substances commercially available in Romania, in order to evaluate the macro- and microscopic changes induced by the same types of substances and to assess their value in the investigation of skeletal and dental remains.

4. To present and analyze forensic casework relevant to the research topic, with the aim of illustrating the practical applicability of anthropological and taphonomic data in a forensic context.

4. FORENSIC ANTHROPOLOGY IN BUCHAREST: THE EXPERIENCE OF THE LAST DECADE

4.1. Introduction

4.2. Materials and Methods

In the context of the need to explore the taphonomic conditions practically encountered in forensic anthropology in Bucharest, I conducted a retrospective study of completed and issued osteology cases registered within the Forensic Anthropology Laboratory of the “Mina Minovici” National Institute of Legal Medicine, between January 1, 2011, and December 31, 2020.

The cases were chronologically classified according to the date on which the skeletal material was discovered and were subsequently grouped by season. The cases were also distributed according to the county of origin and the location where the remains were recovered. The recovery site was classified into general categories, such as aquatic environment, field, sewer, landfill, soil/ground, riverbank, mountain area, building, or other locations. The skeletal material received was classified into the following categories: complete skeleton, incomplete skeleton, skull, long bones, short/flat bones, or various combinations thereof, according to the classification proposed by Baliso et al. (Baliso et al., 2019). The investigative data included information regarding objects discovered together with the remains, such as identity documents, clothing, or jewelry, as well as data regarding a possible missing person: date of disappearance, date of birth or age, stature, dental status, presence of prostheses or osteosynthesis materials, and possible pre-existing pathologies. The biological profile included the estimation of sex, age at death, and stature, after confirmation of the human origin of the analyzed material, together with the postmortem interval. Based on these data, the cases were classified as being of forensic or historical/archaeological interest. For each case, the presence of traumatic lesions, pathological changes, osteosynthesis materials, dental prostheses, or other relevant particularities was recorded.

The collected data were analyzed using IBM SPSS Statistics, version 25, and Microsoft Excel 2019. The statistical analysis included the calculation of frequencies and percentages, contingency tables, descriptive statistics, the chi-square test, and the t-test. The threshold for statistical significance was set at $p \leq 0.05$.

4.3. Results

A total of 309 cases were analyzed. The annual mean was 30.9 cases, with a maximum in 2012, when 43 cases were recorded, and a minimum in 2020, with 18 cases.

Bucharest and Ilfov County accounted for the highest number of cases, namely 65/309 cases, representing 21% of the total. These were followed by Tulcea County, with 29 cases, Gorj County, with 26 cases, and Prahova County, with 21 cases.

Most cases were discovered during the first half of the year.

Most skeletal remains were identified during excavation activities, accounting for 106/309 cases. Other frequent contexts included discoveries in fields, in 50 cases, and in mountain/forest areas, in 42 cases.

Most cases involved incomplete skeletons, namely 265 cases; in 2.6% of all cases, the skeletal material submitted was not of human origin.

In 78 cases, the investigative authorities provided data regarding missing persons.

The estimated postmortem interval ranged from approximately one week to over 100 years.

CT investigations were requested in one case, micro-CT and XRF analyses in two cases, and isotopic analysis in one case; in two cases, suspicion was raised that the skeletal material may have come into contact with caustic or corrosive substances.

Perimortem traumatic lesions were documented in 25 cases, antemortem traumatic lesions were observed in 33 cases, while postmortem lesions were the most frequent, being recorded in 202 cases.

4.4. Discussion

4.5. Conclusions

The study aimed to provide an integrated overview of the Bucharest experience in forensic osteological evaluation, with emphasis on the relationship between the biological profile, the recovery context, and the forensic interpretation of cases.

The results show that the interpretation of skeletal material cannot be limited to the establishment of the biological profile, but must integrate the recovery context, taphonomic modifications, traumatic lesions, individualizing features, and available antemortem data. The recovery site significantly influenced the patterns of preservation and postmortem alteration, with lesions produced by excavation, animal activity, plant roots, or other postmortem interventions being frequently observed.

In addition to highlighting the essential role of anthropological expertise, the study emphasized the need to include complementary investigations in the routine practice of this type of expert assessment.

5. FORENSIC EXPERIMENTAL STUDY ON TISSUE DEGRADATION AND TRACE IDENTIFICATION

5.1. Introduction

Our study was conducted with the aim of identifying the information that may be provided by small tissue fragments previously subjected to treatment with caustic and corrosive substances, as part of a broader forensic study (Udriștioiu et al., 2025b, 2026a).

5.2. Materials and Methods

A total of 60 rib fragments were prepared for inclusion in the study. However, as one rib fragment had been contaminated with metal prior to inclusion, it was excluded; consequently, 59 samples were used in the actual research. The soft tissues, referring to the intercostal muscles, were not removed. Lesions were produced on each rib using the two instruments selected following the feasibility study: an axe and a ceramic knife. The total study period was empirically established at two months. During this time, the samples were continuously analyzed through macroscopic photography and, at predefined time intervals and according to the macroscopic results obtained, rib fragments were collected for serological and XRF analyses. Macroscopic photographic documentation was performed according to a standardized protocol, using a Sony Alpha A7C camera equipped with a 90 mm macro lens. For the serological investigations, anti-species serum was purchased: anti-pig precipitating serum, an in vitro diagnostic medical device produced by the "Cantacuzino" National Medico-Military Institute for Research and Development. XRF and radiographic analyses were performed at the National Institute for Laser, Plasma and Radiation Physics. The XRF measurements were carried out using a Tomo-Analytic instrument built in-house (Dobrea et al., 2011), which integrates the micro-XRF method. To allow reliable comparison of the spectra obtained from different samples, the data were normalized against the calcium peak, centered at 3.69 keV.

5.3. Results

5.3.1. Macroscopic results (Udriștioiu et al., 2025)

Table 5.3. Main results obtained during the macroscopic evaluation of rib fragments immersed in the selected solutions

Solution	Soft tissue evolution	Bone changes	General appearance	Final observation
Caustic Soda	Detachment, saponification,	Cortical detachment,	Pink-reddish, friable	Complete fragmentation,

	gelatinous appearance, subsequently greenish discoloration	emaciation, crumbling		with only traces of deep lesions remaining
Promax-DF	“Soaked” appearance, brown discoloration, whitish cauliflower-like deposits	Accentuated lesions, exposure of marrow	Elastic, dry, granular, with a tendency toward fragmentation	Lesions still visible, with a tendency toward fragmentation toward the end
Misavan	Yellowish appearance, viscous transformation, subsequently pasty consistency	Bone exposure, yellowish appearance	Oily, with a tendency toward disintegration	Structureless paste, advanced disintegration; lesions no longer detectable
Promax-CAÎ	Whitening, followed by complete detachment and cleaning of the margins	Cortical exfoliation, whitish bone	Matte, firm, with clearly visible bone pattern	Bone tissue preserved, but subjected to exfoliation; lesions evident
Dizol	Liquefaction, complete loss of soft tissues	Blurring of lesions, dissolution	Brown-violet, friable, pasty	Loss of bone architecture; lesions no longer detectable

5.3.2. Effects of Dizol on Larger Samples

Based on the observed effects of Dizol on the tissues, we decided to evaluate its effects on larger samples: a fragment from the proximal extremity of a bovine femur, a pig foot fragment, and a distal segment of a porcine limb. The progression toward dissolution was recorded until day 11 for the pig foot, day 17 for the distal porcine limb segment, and day 33 for the bovine fragment.

5.3.3. Evolution of Rib Fragments During Drying at Room Temperature

It was also possible to observe the evolution of the rib fragments at room temperature during the drying process. For caustic soda, the most notable change was the tendency of the samples to transform into a white, chalky powder, with a marked tendency toward disintegration and crumbling. In the case of Promax-DF, during drying, the samples acquired increased consistency on palpation; the external surface had a greasy appearance, and the samples could be manually fragmented when slightly increased pressure was applied. The Dizol samples maintained a wet appearance throughout the observation period and were crumbly on palpation. The Misavan samples showed decreased consistency, with disintegration during handling. In the case of Promax-CAÎ, the samples had increased consistency on palpation, with "accentuation" of the lesions.

5.3.4. Results of XRF Measurements at the Lesion Level

In the samples exposed to caustic soda, the axe-induced lesions revealed the presence of Fe only during the first days, up to day 4. In the samples exposed to Misavan, metallic elements were detected for both instruments only during the first days, up to day 6 for the ceramic knife and up to day 4 for the axe. In the samples exposed to Promax-DF, elemental detection persisted until the end of the experiment for both instruments. In the samples exposed to Dizol, no metallic elements were detected. In the samples exposed to Promax-CAÎ, the axe-induced lesions revealed the presence of Fe only during the first days, up to day 4 (Udriștioiu et al., 2025b).

5.3.5. Results of Species Identification

In the samples exposed to caustic soda and Misavan, species identification remained possible until the end of the experiment. In the samples exposed to Promax-DF and Dizol, all results were negative. In the samples exposed to Promax-CAÎ, species identification was possible only on the first day and was no longer possible thereafter (Udriștioiu et al., 2025b).

5.4. Discussion

The reality of trauma, or the presence of traumatic lesions, represents one of the most important issues in forensic medicine. The ceramic knife produced the most striking results among the analyzed samples. Results involving the use of a ceramic knife have also been reported in other studies, particularly through SEM-EDX analysis (Porta et al., 2016).

Regarding the macroscopic evolution of the analyzed samples, correlated with the XRF and serological results, caustic soda, the only caustic substance tested, produced effects considered to be among the most destructive. The use of this substance in forensic anthropology practice is not new (Cunha & Ubelaker, 2020; Steadman et al., 2006). A different evolution was observed in the fragments cut with the axe, where the lesions, being deeper, remained visible for a longer period of time compared with those produced by the ceramic knife, namely 59 days versus 45 days.

Considering the entire evolution of these samples, it may be stated that destruction progressed from the exterior toward the interior, and soda-induced saponification was evident.

The fastest and most striking results were obtained for the Dizol solution. In practice, the duration of the experiment was nine days, with no difference observed between the samples with lesions produced by the ceramic knife and those produced by the axe.

In the case of Misavan, this substance, corresponding to hydrochloric acid, acted much more markedly on bone tissue than on soft tissues, the latter possibly exerting a protective effect on the bone.

For the Promax-DF solution, no differentiated evolution was observed between the lesions produced by the ceramic knife and those produced by the axe. Although the hydrochloric acid concentration was higher than in the case of the Misavan solution, its action on bone tissue was by far less significant. In addition, we considered that the number of lesions played an important role, as in the case of the lesions produced by the ceramic knife, more interlesional alterations were observed between the deeper lesions.

For the Promax-CAÎ solution, alterations of the samples were observed, although they were considerably less destructive than those described above. Specifically, changes were noted at the level of the soft tissues, which initially showed color changes, namely a salmon-like appearance of the muscle tissue and a lighter white appearance of the adipose tissue.

5.5. Conclusions

The results obtained highlight that the tested caustic and corrosive substances produce different changes in soft tissues, bone tissue, and traces associated with traumatic lesions, depending on their chemical composition, mechanism of action, and duration of exposure. Although all substances caused visible alterations of the samples, the degree of destruction, the speed of action, and the impact on subsequent investigations differed, supporting the importance of comparative evaluation of these agents in a forensic context.

6. CHEMICAL TRACES IN HUMAN DENTAL TISSUES: A FORENSIC PILOT STUDY

6.1. Introduction

As mentioned in the previous chapter, the use of caustic or corrosive substances for criminal purposes is not a novel phenomenon, but rather a less frequently encountered form of cadaver alteration. Among these effects, particular importance is attached to their action on some of the most resistant structures of the human body: the teeth (Udriștioiu et al., 2026a).

6.2. Materials and Methods

A total of five extracted human mandibular molars were included in the analysis and immersed in the solutions used in the previous study. Five teeth were used as experimental samples and were designated as S1 – Misavan, S2 – Promax CAÎ, S3 – Promax DF, S4 – Caustic Soda, and S5 – Dizol, while one tooth served as the control sample and was designated as S0. Each tooth was placed in a separate container containing 10 mL of experimental solution, ensuring complete immersion of the dental structure. The total duration of the experiment was 48 hours. The pH of the solutions used was determined both before the dental samples were introduced and at the end of the 48-hour experimental period.

The teeth were subjected to morphometric analysis in order to establish the initial dimensional parameters of each tooth. Subsequently, these parameters were monitored successively throughout the experiment at 0, 1, 3, 6, 12, 18, 24, 36, and 48 hours, using an S_Cal EVO Basic Sylvac precision caliper, Switzerland. Each experimental tooth, designated S1–S5, was weighed at predefined intervals: 0, 1, 3, 6, 12, 18, 24, 36, and 48 hours.

The morphological changes occurring on the external dental surfaces were documented by stereomicroscopic examination at the same experimental time points used for mass determination, with particular attention to changes at the enamel and root levels. After completion of the immersion period in the solutions, namely 48 hours, the external morphology of the dental tissues was examined by scanning electron microscopy (SEM). This was accompanied by analysis of the elemental mineral composition of the dental surfaces using energy-dispersive X-ray spectroscopy (EDX). After SEM-EDX analysis, all teeth were sectioned for evaluation of the deeper structures by optical microscopy.

6.3. Results

N.N. Although the teeth were immersed in the previously mentioned solutions, the tooth immersed in Dizol (S5) was rapidly altered by the solution, as was also observed in the case of the rib fragments. Its consistency would no longer have allowed the planned analyses to be performed, namely SEM-EDX and ground dental sections; therefore, the decision was made to continue the experiment without this solution.

Summary of Macro-/Stereomicroscopic Investigations, Mass Change, SEM-EDX Findings, Ground Sections, and Main Forensic Implications (Udriștioiu et al., 2026a)

S0 – Control Sample

Sample S0, used as the control, showed no mass change after 48 hours. Macroscopically and stereomicroscopically, both crown and root morphology were preserved, with normal enamel and cementum appearance. SEM-EDX examination revealed a preserved microstructure and a heterogeneous reference elemental profile, without a pattern suggestive of chemical alteration. Ground dental sections showed normal dental tissue morphology, with identifiable enamel, dentine, cementum, Retzius striae, dentinal tubules, and cementocyte lacunae. Therefore, S0 represents the reference pattern for comparison and highlights that normal dental tissues may display intrinsic structural and elemental heterogeneity.

S1 – Hydrochloric Acid-Based Descaler / HCl 5–15%

Sample S1, exposed to a hydrochloric acid-based descaler, showed a 44.79% decrease in mass after 48 hours. Macroscopically and stereomicroscopically, extensive enamel loss was observed, particularly near the cementoenamel junction, with exposed dentine, a matte/chalky-white appearance of the enamel, and pronounced alteration of both crown and root structures. SEM-EDX examination revealed marked acid-induced structural disorganization, residual enamel microcracks, coronal dentine disorganization, and collapse of the root surface, associated with heterogeneous Ca/P depletion, particularly at the root level. Ground dental sections confirmed altered crown and root morphology, with irregular enamel, loss of Retzius striae, reduction of dentinal tubules/odontoblastic processes, and blurring of cementum lacunae. This pattern is compatible with severe mineral-acid damage, but also shows that the dental substrate, although altered, may remain recognizable after 48 hours.

S2 – Sodium Hypochlorite-Based Bleach / NaOCl 1–5%

Sample S2, exposed to 1–5% sodium hypochlorite, showed no mass change during immersion. Macroscopically and stereomicroscopically, the general morphology of the crown was preserved, with the enamel remaining glossy, while root changes were observed predominantly apically, including widening of the apices and a matte/opaque appearance of the cementum. SEM-EDX revealed a predominantly superficial and heterogeneous alteration, with discrete coronal micropitting, root microcracking, increased roughness, and lamellar fragmentation. The mineral phase was largely preserved, with limited compositional disturbances. Ground dental sections showed minimal involvement of the coronal hard tissues, but apical root changes, including widening of the apices, reduction of odontoblastic processes, increased dentine transparency, and absence of cementum lacunae. This pattern indicates that chemical exposure may be present even when the general morphology is preserved, suggesting an oxidative-proteolytic action rather than true acid demineralization.

S3 – Mixed Acid Descaler / HCl 15–30% + H_2SO_4 1–5%

Sample S3, exposed to a mixed acid descaler containing HCl 15–30% and H_2SO_4 1–5%, showed the greatest mass loss, namely 52.45% after 48 hours. Macroscopically and stereomicroscopically, this was the most severely altered sample, characterized by rapid loss of normal appearance, almost complete enamel loss, exposed dentine, marked substance loss, and the presence of root deposits. SEM-EDX revealed severe surface collapse and disorganization, residual lamellar, pliable, or porous structures, almost complete Ca/P depletion in the coronal areas, and deposits or sulfur signals in the apical regions. Ground dental sections showed the most pronounced coronal changes, with a residual island of enamel, altered enamel with tufts and lamellae, externally demineralized secondary cementum, and loss of identifiable lacunae. This was the most destructive pattern in the series and supports corrosive exposure to a mixed acid, while also demonstrating that analyzable residual material may persist even under conditions of severe morphological obliteration.

S4 – Sodium Hydroxide / NaOH

Sample S4, exposed to sodium hydroxide, showed a 2.94% increase in mass after 48 hours. Macroscopically and stereomicroscopically, substance loss was limited, the crown being largely preserved and showing increased gloss, while the root surface was covered by a compact deposit, especially apically. SEM-EDX examination revealed heterogeneous coronal alteration, with micropitting and granular irregularity, as well as an adherent lamellar/plate-like root layer. The persistence of sodium and the increased Ca/P pattern were compatible with a calcium-rich secondary deposit. Ground dental sections showed limited coronal alteration, relatively preserved root histology, cellular cementum with lacunae, and the formed deposit may have acted as a protective layer. This pattern is more suggestive of exposure to a strong alkali than to acidic corrosion, and the association between preserved general morphology and surface deposits may retain useful diagnostic information

6.4. Discussion

For S0, SEM-EDX examination showed, overall, a well-preserved structural architecture, without signs of chemical etching, cracks, or surface degradation.

Exposure of tooth S1 to 5–15% hydrochloric acid for 48 hours produced a progressive pattern of degradation, dependent on the type of dental tissue involved. At the enamel level, the changes were dominated by advanced demineralization, loss of prismatic architecture, and persistence of a residual mineral scaffold. At the level of coronal dentine, the damage was more complex, involving both dissolution of the mineral component and degradation of the organic matrix, together with collapse of the tubular architecture. The most severe changes were observed in the root and apical dentine, where demineralization was almost complete and the surface was replaced by an amorphous, fibrillar, organic-dominant substrate.

These results support a staged model of HCl-induced degradation: initially, enamel demineralization with partial preservation of a residual mineral framework; subsequently, combined mineral and organic damage of the coronal dentine; and, in advanced stages, profound demineralization and structural collapse of the root and apical dentine. This differentiated response highlights the variable resistance of dental tissues to acid exposure and provides a useful morphological and compositional reference for the forensic interpretation of teeth exposed to corrosive environments.

The macroscopic, SEM, and EDX evaluation of tooth S2 indicates a superficially distributed and uneven pattern of alteration induced by exposure to sodium hypochlorite. The tooth preserved its general morphology, without global destruction or major substance loss, but showed discrete to moderate surface changes, such as reduced gloss, increased opacity, blurring of occlusal details, and a whitish-chalky appearance of the root. Overall, 1–5% NaOCl did not produce diffuse acid demineralization or extensive destruction of the tooth, but rather a predominantly superficial alkaline-oxidative alteration. The mineral phase remained largely preserved, while the changes mainly affected the surface microstructure, with more pronounced focal involvement at the coronal level and more diffuse structural changes at the root level.

S3 did not merely reflect simple demineralization, but rather a process of massive acid corrosion, characterized by almost complete destruction of the superficial mineral phase, structural collapse, and the appearance of secondary reaction products, especially at the root level. This profile differentiates the mixed acid solution from substances with predominantly superficial or alkaline-oxidative effects and provides useful morphological and compositional landmarks for the forensic interpretation of teeth exposed to strongly acidic corrosive environments.

Exposure of tooth S4 to sodium hydroxide for 48 hours produced a spatially variable pattern of alteration, different from the acid corrosion observed in the samples exposed to HCl or to mixed acidic solutions. At the enamel level, the effects were predominantly superficial and uneven, consisting of diffuse micropitting, granular texture, and local variations in elemental composition. These changes are compatible with heterogeneous alkaline etching, without uniform mineral loss and without the formation of a thick secondary layer at the coronal level.

At the root level, the process was dominated by the formation of a whitish, adherent secondary mineral deposit, visible macroscopically and confirmed by SEM-EDX. This layer displayed a lamellar, cracked, and partially exfoliative morphology, while its composition — reduced phosphorus, increased oxygen, a high Ca/P ratio, and the presence of sodium — indicates the formation of calcium-rich secondary precipitates, probably calcium hydroxide and/or calcium carbonate. The deposit was more compact and continuous in the middle root region, whereas at the apical level it became more fragile, discontinuous, and partially detached, with areas of exposed dental substrate.

Overall, the results indicate that exposure to NaOH does not produce a simple uniform dissolution of dental tissues, but rather a dynamic, spatially variable process involving superficial alteration, calcium release, secondary mineral reprecipitation, and progressive structural reorganization. The final increase in mass of sample S4 may be explained by the accumulation of these secondary mineral deposits on the root surface. In this experimental model, the deposition phenomenon appears to have exceeded the net loss of dental material, thereby explaining the weight increase observed after exposure.

This differentiation is forensically relevant because it shows that exposure to corrosive or caustic substances does not produce a single universal pattern of dental destruction. Recent forensic studies emphasize that the diagnosis of alterations produced by corrosive substances requires a multidisciplinary approach, while microscopy, SEM, EDX, micro-CT, and XRF may provide complementary information in cases of chemical destruction of tissues (Udriştioiu et al., 2025a; Udriștioiu et al., 2025b). In this context, the results of the present study support the usefulness of combining macroscopic observation with SEM-EDX analysis in order to identify differential patterns: acid-demineralizing, acid-related with secondary precipitation, oxidative-proteolytic, and alkaline with secondary mineral deposition.

Among the limitations of our study, we mention the small sample size, the fact that the immersed teeth had been extracted and were therefore not protected by the mandible or surrounding soft tissues, and the experimental protocol itself, in which the teeth were removed, washed with water, immersed, and re-immersed. In addition, SEM evaluation was performed separately on each tooth before contact with the solutions. These aspects may be further developed in future research, together with improved characterization using histological methods (Sluis et al., 2025b) and a more detailed SEM analysis of the examined samples.

Another limitation is that SEM-EDX investigations were not performed on the sectioned teeth, unlike in other studies (Kuntze et al., 2021b), where this approach allowed a more in-depth evaluation of internal structures and supported the conclusion that there is a relationship between acid molarity and the degree of dentine demineralization.

6.5. Conclusions

This study, which integrates this evaluation approach for the first time, combining stereomicroscopy, SEM-EDX, and ground dental sections, shows that commercially available corrosive and caustic agents produce distinct patterns of dental alteration after 48 hours of exposure. HCl caused progressive acid demineralization; the mixed HCl/H_2SO_4 solution produced severe corrosion associated with sulfur-rich secondary deposits; NaOCl generated predominantly superficial oxidative-proteolytic alterations, with relative preservation of the mineral phase; and NaOH induced superficial alkaline changes associated with calcium-rich secondary precipitates at the root level.

The data obtained confirm that chemically altered teeth should not be interpreted solely in terms of complete dissolution or morphological preservation. The type of agent involved may be suggested by correlating morphological changes with the elemental profile, particularly Ca/P variations, the presence of Cl, S, or Na, and the existence of secondary deposits. The control sample demonstrated that natural regional heterogeneity and superficial organic or environmental deposits may influence EDX profiles. For this reason, forensic interpretation must always correlate tissue type, surface morphology, and elemental composition.

Overall, SEM-EDX represents a useful complementary method for documenting and differentiating chemically induced dental alterations; however, confirmation of secondary reaction products requires additional methods, such as FTIR, Raman spectroscopy, or XRD.

The study showed that a multidisciplinary evaluation is necessary for the adequate characterization of such cases, as the methods used are complementary.

7. CASE REPORT INVOLVING THE ANALYSIS OF FORENSIC TAPHONOMIC FACTORS

7.1. Case History

In December 2006, a mother and her five-year-old daughter disappeared under mysterious circumstances after a meeting with the child's father, following a difficult divorce. They were listed as missing at both national and international levels, but no results were obtained. In 2021, after the woman's former husband and the child's father was reported to the police for another offence, the possibility that he may have killed his former wife and daughter was raised, considering his dominant behavior and the fact that, in his yard, there was a plot of land where pink and white roses had been planted, and where he used to go to pray and light candles. In light of these new statements, the police went to the suspect's residence, where they identified the rose bush that had been mentioned, with small candles hanging from it. Excavations were carried out beneath the rose bush and, at a depth of 45 cm, the skeletonized body of a child was found. The body was dressed in several layers of clothing, and an icon was found in the thoracic region (Udriștioiu et al., 2026b).

7.2. Results

The clothing items containing the skeletal elements, particularly those corresponding to the trunk region, each presented, in the upper third of the left half of the anterior surface, nine linear defects measuring 1–3 cm in length, with smooth margins. In four of these defects, corresponding defects with similar morphology were also identified on the posterior surface of the clothing items. Each anterior defect was aligned along the same trajectory as its corresponding posterior defect. The experiment showed that one of the four plastic rods connecting an anterior defect with its corresponding posterior defect came into contact with the left sixth rib.

The complete skeletal material was present, with the note that the cranial bones had to be reconstructed from 21 fragments, considering the improper exhumation maneuvers. In addition, the left sixth rib was fractured along the scapular line, with perfectly apposable margins. The left eighth rib was reconstructed from two partially apposable fragments; along the scapular line, three areas of incomplete sectioning were identified, partially detached, with regular, sharp margins, of the same color as the rest of the bone fragment. Two of these had an oblique direction, from superior and medial, while the third was relatively perpendicular, all supporting a perimortem mechanism of production.

Considering the macroscopic characteristics of the rib lesions, micro-CT analysis of the rib ends was considered useful. This allowed a much more detailed assessment of the previously mentioned features and, in addition, may allow quantitative analysis of knife marks on bone. Macrophotographic examination and micro-CT analysis of the rib fragment indicated postmortem changes in bone architecture, expressed by increased cortical porosity and discrete remodeling/alteration of the trabecular network.

Furthermore, the analytical spectrum also included XRF analysis of the sectioned ends, which revealed the presence of Fe and Zn, in addition to Ca. A forensic trace analysis was performed in order to clarify the circumstances of the victim's death. The assessment was based on both textile analysis and skeletal evidence, including additional investigations of the injured bones. From the submitted skeletal material, a femoral fragment was collected and analyzed, establishing a father–daughter relationship with a probability of 99.9999%.

7.3. Discussion

The particularity of the case lay both in the suspect's behavior and in the manner in which the body was concealed: the burial of the victim in his own yard, associated with the lighting of candles and the maintenance of vegetation above the burial site, had important significance for the interpretation of the case, especially in the context of local funerary practices. The examination of the victim's clothing played an essential role in the reconstruction of events. The clothing also provided indications regarding the season in which death occurred, consistent with the time of the child's disappearance. In this context, clothing analysis was not only valuable for identifying biological traces, but also contributed directly to the reconstruction of the dynamics of the assault. The case highlights the usefulness of modern methods, such as micro-CT, XRF, and macrophotography, in the investigation of trauma on degraded skeletal material, even though access to such techniques remains limited in current forensic practice in Romania. These methods allowed clarification of essential aspects regarding the injury mechanism, the perimortem nature of the trauma, and the postmortem condition of the bone. The assessment of the postmortem interval was also supported by structural bone changes, such as increased porosity, although the case could not benefit from forensic entomological analysis.

The corroboration of investigative data, clothing defects, skeletal lesions, and complementary investigations allowed the outline of a clear case of homicide, despite the difficulties generated by concealment of the body and the prolonged postmortem interval.

8. CONCLUSIONS AND PERSONAL CONTRIBUTION

8.1. Conclusions

Taphonomy developed as a branch of paleontology and was subsequently adopted by other fields, including forensic medicine, being understood as the study of all processes that transform organisms after death. In a forensic sense, this also includes changes that may result from human interventions on skeletal remains.

In contemporary forensic anthropology, the reference literature consistently shows that taphonomic analysis does not represent a secondary stage, but an essential level of forensic evaluation, being directly involved in estimating the postmortem interval, reconstructing the deposition environment, ordering the sequence of postmortem events, and differentiating between genuine lesions and “pseudolesions.”

Forensic taphonomy has applied numerous principles derived from paleontology and archaeology; however, rapid progress has been achieved through interdisciplinary methods for the physicochemical investigation of skeletal remains, including microscopic and histological methods, SEM-EDX, XRF, FTIR/Raman spectroscopy, micro-CT and other imaging methods, residue analysis, and the assessment of structural and compositional changes. For this reason, recent literature emphasizes that the future of forensic investigation of skeletal remains does not lie in a single “decisive” technique, but in a multimodal approach, in which morphological, histological, imaging, and compositional data are correlated in order to support an interpretation that is as robust and reproducible as possible.

In a particular taphonomic context, such as situations in which skeletal remains have been subjected to the action of corrosive or caustic substances, the importance of the aforementioned methods becomes even greater, especially since such scenarios have been used to alter, destroy, or conceal cadaveric identity.

Following the documented analysis of the postmortem effects of these substances, I found that, although this method of concealing a corpse has a history and has been popularized in the media, the scientific literature dedicated to the subject remains limited and heterogeneous. The available data show that the effects of these substances on tissues cannot be interpreted simplistically by referring exclusively to the idea of complete dissolution, but must be analyzed according to the nature of the chemical agent, concentration, duration of exposure, type of affected tissue, environmental conditions, and the specific manner of contact with the biological substrate.

In this context, the present research supports the need for an integrated forensic approach, in which macroscopic examination is complemented by physicochemical, imaging, microscopic, and biological methods. Cases in which exposure to caustic or corrosive substances is suspected are difficult to classify using conventional methods, because chemical alterations may mimic, mask, or modify traumatic lesions, influence the taphonomic appearance of the remains, and compromise both identification and reconstruction of the circumstances of death. Therefore, the diagnosis of these changes should not be based exclusively on the external appearance of the samples, but on the correlation of all available data.

The analysis of forensic osteological casework demonstrated that the interpretation of skeletal material necessarily requires integration of the recovery context and taphonomic modifications. The recovery location has a major influence on the state of preservation and the pattern of postmortem alteration, as skeletal material submitted for examination, depending on its origin, recovered from the ground, from fields, from mountain or forest areas, from aquatic environments, or from dwellings, presents different patterns of dispersal, degradation, and modification. At the same time, postmortem lesions produced by excavation, animal activity, root action, autopsy sectioning, or other anthropogenic interventions may significantly complicate forensic interpretation.

8.2. Personal Contributions

The experimental results obtained on soft and hard tissues with traumatic lesions confirmed that caustic and corrosive substances do not produce a uniform effect, but generate distinct alteration profiles. Sulfuric acid had the most aggressive destructive effect, with rapid damage to soft and bone tissues, loss of sample consistency, and compromise of morphological, biological, and physicochemical assessment. Caustic soda produced significant destruction through an alkaline mechanism, associated with an exothermic reaction, saponification phenomena, and progressive bone degradation from the cortex toward the cancellous bone. Hydrochloric acid had a slower but progressive action, predominantly through impregnation, decalcification, and gradual loss of bone consistency, with preservation of some visible lesions due to the less significant effect on soft tissues. Hypochlorite showed the least destructive effect on bone, behaving rather as a cleaning agent, with relative preservation of the bone cortex, but with impairment of species identification and detectability of certain traces (Chapter 5).

An important aspect resulting from the experiment is that pre-existing lesions may represent preferential penetration areas for the substance, accelerating local degradation and modifying the appearance of lesion margins. Furthermore, the value of XRF investigations proved to be dependent on the timing of examination and on the type of substance used: in the case of highly destructive agents, the detection window for metallic residues is reduced, whereas in better-preserved samples, metallic elements may persist until the end of the experiment (Chapter 5).

The experimental study on teeth complemented these observations and demonstrated that dental tissues, although among the most resistant structures of the human body, present different responses to chemical exposure. By combining stereomicroscopy, SEM-EDX, and the examination of ground dental sections, the research highlighted differential alteration patterns, depending on the dominant chemical mechanism. HCl produced progressive acid demineralization, with more severe involvement of root and apical dentine than enamel, the latter partially preserving a residual mineral scaffold. The mixed HCl/H_2SO_4 solution caused the most severe corrosive dental changes, with extensive loss of the mineral phase, structural collapse, and the appearance of sulfur-rich secondary deposits, especially at the root level. NaOCl produced predominantly superficial oxidative-proteolytic alterations, with relative preservation of the mineral phase, while NaOH generated a particular pattern characterized by coronal micropitting and calcium-rich secondary deposits at the root level (Chapter 6).

These results show that chemically altered teeth should not be interpreted exclusively in terms of macroscopic preservation or destruction. A tooth may remain recognizable in its general shape while presenting profound microstructural and elemental compositional changes. At the same time, some substances may produce not only material loss, but also secondary deposits, which significantly modifies the interpretation of elemental ratios, especially Ca/P. Thus, the reduction of calcium and phosphorus, the presence of chlorine, sulfur, or sodium, and the occurrence of secondary deposits may have orientative value regarding the type of agent involved, but do not allow, in isolation, a definitive identification of reaction products. SEM-EDX proves to be a useful complementary method for documenting and differentiating chemically induced dental alterations; however, its semi-quantitative nature requires caution. The crystallochemical confirmation of secondary deposits requires additional methods, such as FTIR, Raman spectroscopy, or XRD (Chapter 6).

These experimental studies are also affected by several limitations, such as the use of small rib fragments with part of the soft tissues still present; the small size of the dental sample; the fact that the time until complete destruction was not evaluated; and the absence of genetic identification methods, among others.

In order to further investigate the effects of corrosive substances, future studies are needed to broaden the spectrum of substances used, for example nitric acid; expand the type of material analyzed, including skeletal remains; use accelerators; study protective factors; and improve analytical methods, for example by including ICP-MS. The integration of these methods increases the possibility of recognizing chemical alterations, differentiating them from ordinary taphonomic changes, preserving traumatological information, and supporting the identification process.

The final chapter presents how investigations such as micro-CT and XRF genuinely improved the management of a forensic case and contributed to revealing a homicide, transforming the skeletonized remains of a child from vestiges of death into objective witnesses of judicial truth (Chapter 7).

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