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Original article

INTERMENT INTERVALS OF SKELETAL REMAINS FROM UDHRUH FORTRESS, JORDAN: ATR-FTIR ANALYSIS OF TOOTH DENTIN

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Abstract:
Archaeological evidence suggests that Roman forts along the Limes Arabicus, a defensive frontier in the Roman Empire, buried their dead in communal burial pits, indicating a deviation from traditional Roman burial practices. This study comprises 10 permanent second lower molars from the 2008 and 2009 excavations at Udhruh Fortress, most likely Late Roman, to estimate the intervals between internments and understand such a practice. The method of the study relies on measuring the extent of francolite incorporation in dentin phosphate apatite [I_{1096}/I_{1035}] using Attenuated Total Reflectance-Fourier Transform Infrared spectroscopy (ATR-FTIR), which increases with the post-depositional time. The results showed two separate internment intervals, where the former is likely associated with the abandonment of the fortress and the second with its reoccupation, mostly in later phases. The continuous use of Udhruh Fortress indicates that it remained a refuge for local communities as they faced various sociopolitical challenges. However, evidence of reoccupation during the Islamic period suggests a need for further research to fully understand the historical context of this burial practice.

1. Introduction

Studying the burial practices in Roman forts provides a valuable understanding of the sociopolitical dynamics of existing legionnaires and inhabitants. Through the analysis of diverse disposal techniques and funeral customs, scholars identified consistent trends in the treatment of deceased soldiers across different geographical areas of the Roman Empire [1], but not along the *Limes Arabicus* in Arabia. This analysis not only sheds light on the logistical challenges of disposing of deceased soldiers but also deepens our understanding of how Roman perspectives on death and remembrance evolved to accommodate military settings [2]. The disposal of deceased Roman soldiers was not consistent [3]. Roman soldiers were usually buried in unmarked mass graves [4,5], though occasional cremations did occur [6], often with minimal ceremonial rites [1]. Soldiers who did not die in battle were frequently buried in individual graves marked with stones, particularly during the Late Roman period [7], while those who died in minor battles or combat might be returned to their camp or fort for burial [2,8]. Fort burials were not uncommon during the Late Roman period in Jordan, where several burials were recovered from Lejjun, Udhruh, and 'Ain Gharandal forts in southern Jordan [9-11]. The 2008 and 2009 excavations near the eastern wall of Udhruh Fortress revealed a burial pit [12], identified later to have a minimum of 10 individuals, figs. (1-a & b).

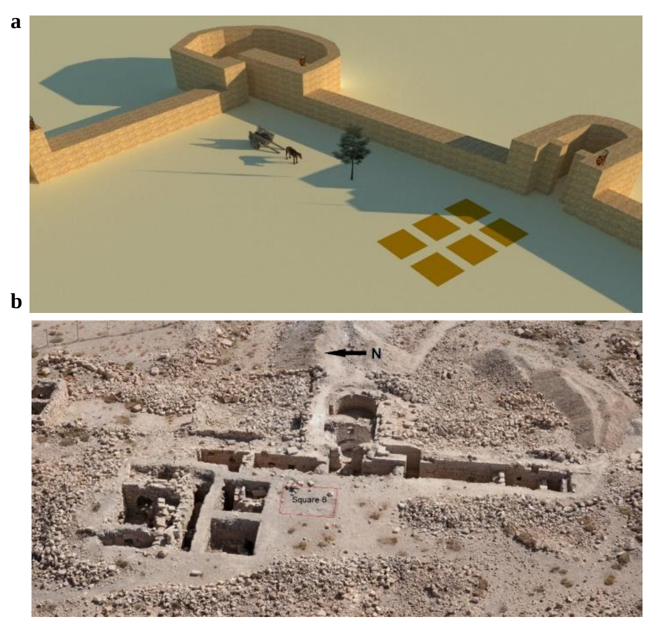

Figure (1) **a.** a 3D model of the eastern wall of Udhruh Fortress showing the grids where the cist burial was found (*©Abdulla Al-Shorman*), **b.** an aerial photograph of the eastern wall of Udhruh Fortress showing the pit burial marked by 'Square 6'.

The skeletons were dated to the Late Roman period based on the associated coins and pottery. The strontium isotope analysis of dental enamel from the individuals buried in the pit showed that they were local to the Udhruh region- either local legionnaires recruited by the Roman army or local people who inhabited the site in the aftermath of desertion [13]. Recruited local legionnaires were still subject to the authority of the Roman Empire and had to abide by the prevailing cultural norms, including funerary rituals, and thus strongly suggest a Late Roman burial. Additionally, pit burials of commingled individuals were not reported from Byzantine and Islamic sites in Jordan yet. Still, it was challenging to establish a chronological resolution between interments, which would have clarified the periodicity of inhabitation of the fortress as well as burial practices. Radiocarbon dating was not conducted at this time because the spacing in interment intervals would have been shorter than the standard error of radiocarbon dating (± 50 years [14]). Additionally, the Roman legionnaires occupied the fortress for a brief period, making it challenging to achieve a high level of chronological precision among the interments. Fluorine dating is more cost-effective and time-efficient compared to radiocarbon dating. Additionally, it has the potential to generate a more precise chronology, with the ability to determine spans of 20 years in certain cases, surpassing the traditional capabilities of radiocarbon dating [15]. The main goal of this study is to determine the interment intervals among the recovered skeletons by estimating the amount of francolite accumulation in tooth dentin using ATR-FTIR analysis. This method has a relatively better chronological resolution than radiocarbon dating, as diagenesis starts just after the exposure of bones to the surrounding burial soil. The second goal is to contextualize the findings of the study to previous knowledge on Roman army burial practices and existence along the *Limes Arabicus* of the eastern frontier. *Limitations of the study*, despite the valuable insights gained from this study, several limitations must be acknowledged. The primary challenge was the unstratified and commingled nature of the skeletal remains, which hindered precise osteological analysis of the individuals buried at Udhruh Fortress. The brevity of Roman occupation at Udhruh Fortress complicates the chronological precision of the interments, as the short period of occupation might result in less pronounced differences in francolite levels. Moreover, the presence of potential reoccupation during later periods introduces uncertainty regarding the exact timeline of the Islamic burials, making it challenging to elaborate on the subsequent historical phases. These factors collectively emphasize the need for more tooth samples for complementary dating techniques and more comprehensive contextual analysis to refine the understanding of burial practices and the historical dynamics of Roman fort sites in the region.

1.1. *Francolite in archaeological bones*

Fluorine enters the bones and teeth in burials, replacing the (OH) group in hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], yielding a new mineral called fluorapatite or francolite [$Ca_{10}(PO_4)_6F_2$], which is chemically more stable [16,17]. Given the consistency of this process, bones and teeth from the same burial should contain the same amount of fluorine if deposited at the same time [18]. In other words, under the same burial and environmental conditions, the fluorine concentration in bones and teeth increases over time [19,20]. ATR-FTIR spectroscopy can detect such incorporation in the apatite of bones and teeth, where francolite occurs as a shoulder peak at ~ 1096 cm^{-1} which is part of the phosphate asymmetric stretching v_3 (PO_4) at 1035 cm^{-1} [21-23]. ATR-FTIR spectroscopy has been utilized to gather both qualitative and quantitative data on the composition of fossil bones and teeth, as well as to study bone diagenesis, including the incorporation of francolite [24-26]. Earlier research has employed the ratio of the Amide I band at 1660 cm^{-1} to the phosphate band at 1035 cm^{-1} to estimate collagen degradation and thus burial duration [23,27]. However, to accurately estimate the francolite content in sampled teeth, scholars select the same tooth type to ensure similar densities [15,28] and the same depositional environment or burial [29,30]. In bioarchaeology, the most used methods for determining fluoride content in bones are FTIR spectroscopy and Ion-Selective Electrode (ISE) [31]. FTIR spectroscopy is a non-destructive technique that identifies and quantifies functional groups in a sample by measuring infrared radiation absorption, which is then plotted as a spectrum [30,32]. The presence of fluoride in a sample is indicated by an absorption peak at around 1096 cm^{-1} [33-36] inaccuracies in fluorine measurements by removing fluoride ions from the bone environment. This results in a measured concentration that is lower than the actual amount [37], making ISE less preferable as a relative dating technique. Adjusting measurement results to account for phosphate ion content can yield more accurate and reliable data [29]. Therefore, this study uses ATR-FTIR to calculate the fluoride and phosphate content using the net fluoride content equation (A) as proposed by Kasiri [37] as follows:

$$A = \frac{F\%}{PO_4^{3-}\%} = \frac{I_{1096}}{I_{1035}}, \textit{ where I is the area under the peak.}$$

1.2. *Udhruh Fortress*

Udhruh Fortress was built in AD 303-304 by the Roman *Legion VI Ferrata* [38], which was previously stationed at Humayma Fort [39]. The fortress was constructed to protect the eastern frontier in Arabia against roaming Saracens [40] and was supported by the temporary military camp of Tell Abara, located 2 km to the east [41,42]. Its architecture resembles other forts along the *Limes Arabicus*, such as Humayma [43,44] and el-Lejjun [45]. The Roman occupation of Udhruh Fortress lasted until AD 324. After a brief abandonment, it was reinhabited by local people during the subsequent Byzantine and Islamic periods [39]. The brevity of occupation at the fortress during the Late Roman period did not cause any significant shifts in the cultural or demographic makeup of the local inhabitants. Instead, the Romans opted to relocate locals outside, as noted by Killick [46]. This strategic decision maintained the local population nearby, thereby facilitating economic advantages for the fortress. Ensuring a continuous provision of daily necessities was necessary, as evidenced by archaeological discoveries revealing substantial agricultural activity in Wadi Udhruh, east of the fortress [10].

2. Materials and methods

The study comprises 10 teeth from Udhruh Fortress in southern Jordan that were dated to the Late Roman period based on the recovered coins and pottery assemblages. The sampled teeth are permanent second lower molars, which ensures that each tooth belongs to a different individual. The teeth were loose (not in occlusion) and in good preservation condition. Sexing and aging of the teeth could not be established at this time. The samples were cleaned manually to remove the surface dirt using a surgical blade, then ultrasonically in a water bath, and let dry overnight. Each tooth was embedded in epoxy and cut vertically using a diamond saw at a low speed. The surface of the section was polished to a smooth and even surface to ensure precise attachment to the sample holder in the ATR-FTIR spectroscope. The middle part of the root was scanned, and the ATR-FTIR spectra were collected using the *Nicolet iS50FT-IR spectroscope*, fig. (2-a). The scanning used an absorbance mode of 16 scans at a resolution of 4 cm^{-1} in a range of 4000-400 cm^{-1}. An atmospheric correction was applied to remove the contribution of the atmospheric background. A resin spectrum was obtained and then subtracted from the dentin spectra to eliminate the effect of resin pen-etration if present. The spectrum of each tooth (from 1250-820 cm^{-1}) was analyzed separately after baseline correction. Fourier self-deconvolution was then performed to enhance the resolution and extract more information at a wavelength of 1096 cm^{-1} (francolite) and 1035 cm^{-1} (phosphate group) [35]. Because the more incorporation of francolite in teeth postmortem, the wider the $v_3 (PO_4)$ peak in hydroxyapatite [47], the study uses the ratio of the area under the francolite peak/the area under the phosphate peak (I_{1096}/I_{1035}) to calculate the relative incorporation of francolite in dentin's hydroxy-apatite, fig. (2-b).

a

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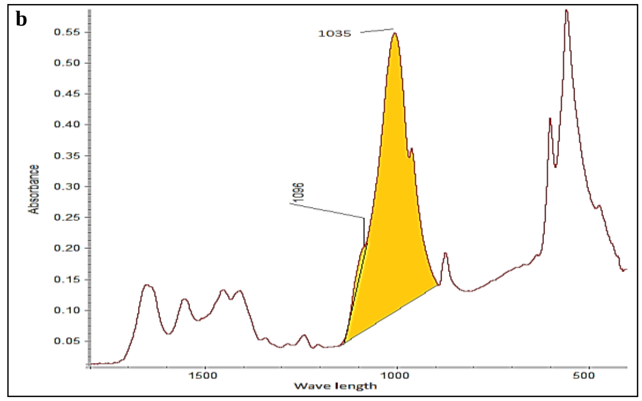

Figure (2) **a.** longitudinal section of a tooth sample embedded in resin showing the area of FTIR scanning, **b.** sample 104 showing the area under phosphate peak at 1035 cm^{-1} with francolite as a shoulder peak at 1096 cm^{-1}.

3. Results

The results of I_{1096}, I_{1035}, and I_{1096}/I_{1035} are shown in tab. (1) below. The values of I_{1096}/I_{1035} are clustered into two distinct groups (A and B), reflecting two periods of interment, fig. (3). The analysis of variance between the two groups asserts a statistically significant difference between their means [F (1.9) =187.83, P= 7.74E-07]. The two groups show a stat-istically significant difference in their means, indicating that the observed variation is not likely due to random chance. Specifically, the F-statistic is 187.83, which measures the ratio of variation between the groups to variation within the groups. The F values (1.9), represent the degrees of freedom: "1" corresponds to the number of groups minus one (in this case, two groups - 1 = 1), and "9" corresponds to the total number of observations minus the number of groups. The p-value is 7.74E-07 (or 0.000000774), meaning there is an extremely low probability that the difference in means occurred by chance. Therefore, the results strongly support the fact that the two groups have significantly different means. The mean and standard deviation of I_{1096}/I_{1035} values in Groups A and B are 0.0121 ± 0.001 and 0.004 ± 0.0008 respectively, which indicates that the teeth in Group B had less francolite and were interred in a later period compared to Group A. In addition, the low standard deviation in Group B indicates more homogeneity and thus shorter interment intervals compared to the individuals in Group A, who were mostly buried over longer spaced intervals.

Table (1) I_{1096}/I_{1035} values for the sampled teeth from Udhruh Fortress.

Sample no.	Group	Francolite (I_{1096})	Phosphate (I_{1035})	I_{1096}/I_{1035}
105		0.0180	6.81	0.0026
101		0.0150	3.56	0.0042
102	B	0.0150	3.56	0.0042
100		0.0062	1.37	0.0045
107		0.0100	2.06	0.0049
104		0.0560	5.35	0.0105
108		0.1100	8.85	0.0124
109	A	0.1100	8.85	0.0124
110		0.6000	47.88	0.0125
103		0.1330	10.12	0.0131

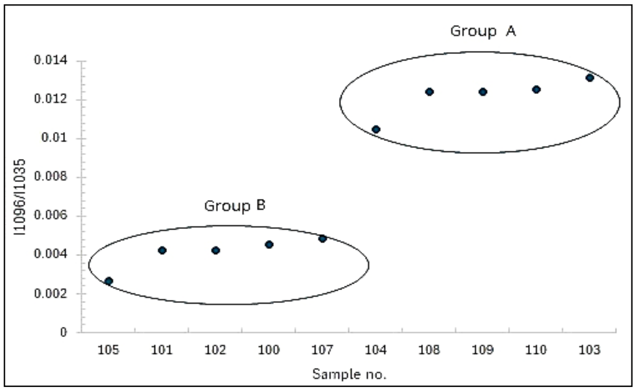

Figure (3) a plot of I_{1096}/I_{1035} of Udhruh Fortress tooth dentine samples.

4. Discussion

Although the Roman burial practices in Jordan are well documented [48], little is known about the burial practices of the Roman legionnaires, particularly after the establishment of the *Limes Arabicus* in the late second century AD. However, while a few sources mentioned instances of Roman soldier burials from Jordan [49-52], none of them was reported from forts. This study provides new evidence on Roman fort burial practices. The results of the study clearly indicate that the deceased at Udhruh fortress were buried in two different periods. The interments in the first period (Group A) were practiced over a relatively longer period, while the second period (Group B) witnessed interments over a shorter period. Group B suggests a hasty and informal burial practice (see [2,53], which could have been triggered by insufficient time to carry out formal burial practices. In addition, this practice was observed at 'Ayn Gharandal Fort, located 60 km southwest of Udhruh Fortress. Here, several skeletal remains were discovered in cist burials along the fort's curtain walls [11]. A similar burial was also found in the fort of Lejjun, suggesting a lack of military discipline and authority [9]. It is probable that a political event prompted the hasty burials at these forts [54], as represented by Group B. This incident might have been associated with the fall of the *Limes Arabicus* starting in the fourth century AD, as Emperor Constantinople directed his attention to more pressing events in the West [9]. There is evidence to suggest that Udhruh Fortress underwent reoccupation in later periods, but this negates the possibility that individuals from Group B were interred during later phases of the fortress's occupation, as they were dated as Late Roman skeletons. The only Islamic skeleton (although debatable) from Udhruh Fortress belongs to a 2-year-old child that was found in another locality [55]. Excavations at many similar fortresses in the region revealed Islamic skeletons; for example, ‘Ain Gharandal Fort revealed a child skeleton, where the orientation of the skeleton, the stratigraphy, and the results of carbon dating provide strong evidence to support a Late Islamic date [56]. The Late Roman Qasr Hallabat *Castellum* in eastern Jordan also revealed six Late Islamic skeletons recovered from a sealed cistern inside. These skeletons exhibited multiple cranial fractures, interpreted as inflicted by blunt force objects, indicating that the manner of death was homicide [57]. The pattern of the fractures, the edges of the fractures (non-sharp and not angular), irregularity along fracture lines, the fracture's lighter color, and that the fractures extended beyond the cranial sutures suggest postmortem fractures, mostly disposed of in the cistern as dry bones. However, the cases here represent a Late Islamic reuse and secondary disposal. Furthermore, the smaller courtyard of Castellum does not permit or provide space for burials, and thus suggests a primary burial outside Qasr Hallabat *Castellum*, which also questions the date of the recovered skeletal materials, fig. (4). However, the burial practices of Roman soldiers in the eastern provinces serve as a testament to the dynamic interactions between Roman military traditions and local cultural practices. The archaeological evidence underscores a complex narrative of cultural exchange and adaptation, where Roman customs were both imposed and integrated with indigenous traditions, leading to a rich tapestry of burial practices that reflect the multifaceted identities of these communities [58,59]. The pattern of hasty burials in the Late Roman period of Udhruh Fortress's occupation highlights the forts' enduring strategic and perhaps symbolic importance. The recurring use for burials during the Late Roman period indicates that Udhruh Fortress retained its relevance for inhabitants facing various crises. This stresses the need for more precise dating techniques and contextual analysis to understand the historical layers of occupation and the sociopolitical dynamics that led to the hasty interments in Roman fortresses not only during the Roman period, but also the periods that followed.

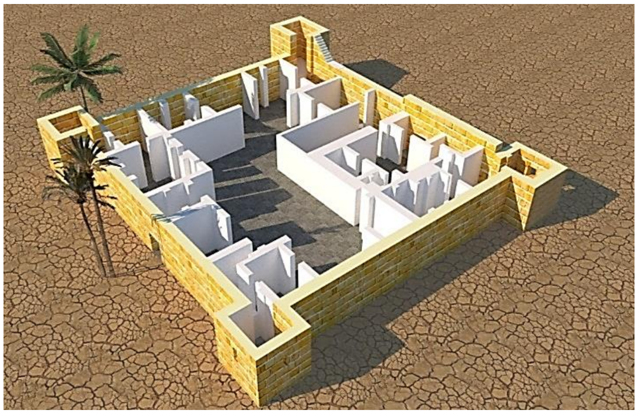

Figure (4) a 3D model of Qasr Hallabat showing a small courtyard. Drawn (© *Abdulla Al-Shorman*).

5. Conclusions

This study contributes to the understanding of Roman army burial practices in Jordan, particularly within the context of Roman forts. By analyzing the I_{1096}/I_{1035} values from Udhruh Fortress, this research uncovers two distinct periods of interment, characterized by significant differences in francolite content and thus burial practices. Group B, with lower I_{1096}/I_{1035} values and greater homogeneity, indicates shorter interment intervals and a later burial period compared to Group A. Group B experienced hasty and informal burials, likely due to pressing circumstances, such as military or political events, possibly linked to the decline of the Limes Arabicus in the fourth century AD. The comparison with similar burial practices at 'Ayn Gharandal and Lejjun forts supports this argument. However, the potential reoccupation of Udhruh Fortress during the later periods introduces complexities regarding the exact dating of other interments. These findings highlight the need for further research to definitively date the skeletal remains and fully understand the historical context of the burial practices at Udhruh Fortress.

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