Preliminary soilwater conductivity analysis to date clandestine burials of homicide victims

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Abstract

This study reports on a new geoscientific method to estimate the post-burial interval (PBI) and potential post-mortem interval (PMI) date of homicide victims in clandestine graves by measuring decomposition fluid conductivities. Establishing PBI/PMI dates may be critical for forensic investigators to establish time-lines to link or indeed rule out suspects to a crime. Regular in situ soilwater analysis from a simulated clandestine grave (which contained a domestic buried pig carcass) in a semi-rural environment had significantly elevated conductivity measurements when compared to background values. A temporal rapid increase of the conductivity of burial fluids was observed until one-year post-burial, after this values slowly increased until two years (end of the current study period). Conversion of x-axis from post-burial days to ‘accumulated degree days’ (ADDs) corrected for both local temperature variations and associated depth of burial and resulted in an improved fit for multiple linear regression analyses. ADD correction also allowed comparison with a previous conductivity grave study on a different site with a different soil type and environment; this showed comparable results with a similar trend observed. A separate simulated discovered burial had a conductivity estimated PBI date that showed 12% error from its actual burial date. Research is also applicable in examining illegal animal burials; time of burial and waste deposition. Further research is required to extend the monitoring period, to use human cadavers and to repeat this with other soil types and depositional environments.

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1. Introduction

The use of geoscientific techniques in forensic investigations is broadly divided into laboratory- and field-based [1]. Field-based geoscientists have been employed to locate homicide victim’s graves, weapons and other buried or concealed objects using a variety of techniques. The search methods include remote sensing [2,3], cadaver dogs [4], methane [5] and soil probes [6,7], near-surface geophysics, which includes metal detectors [8–10], geochemical surveys [5] and mass excavations [11]. Laboratory-based techniques often use trace evidence from a discovered burial to link a suspect to the crime scene [1] although there have been reliability issues [12].

There has been extensive taphonomy research on estimating the post-mortem interval (PMI) of very recently deceased above-ground discovered individuals, for example, using body temperatur-Tures [13–15], cadaver entomology [16,17] and entomofauna [18], vitreous potassium [19], serum sodium:potassium concentration ratios [20], cardiac tropinin [21] and thanatochemistry [22], etc. For longer deceased individuals, there is more date uncertainty; analysis of decomposition tissue stages [23,24] and indeed entomology have shown promise [25], and for skeletal remains, there are a variety of morphological, chemical, physical, immunological and histological PMI methods suggested [26–30], odontology and tooth loss [31] as well as radionuclides and trace elements [32,33]. With discovered buried individuals, the discussed PMI methods may also provide an estimate of the upper limit of the post-burial interval (PBI), although PBI may be different from PMI, if, for example, a body is buried some time after death [30]. Both of these dates may be critically important for forensic case investigators to determine; they may help to establish a time-line of events that would link or indeed rule out a potential suspect to a crime.

There are significantly decreased decomposition rates observed between surface and buried individuals respectively [24,34,35], with a decomposition rate difference of up to eight times being suggested [36]. Researchers have generally suggested three major site contributing factors for this difference which are: organic content, environmental factors and organism accessibility [37,38].
Environmental factors include pH [39], redox conditions [38], ambient temperatures [40–42], and hence associated decomposition rate changes [43,44], seasonality, time of burial [45] and depth below ground level [46], soil type and texture [34,44,47] and moisture content [37,44], local land use and environment [48,49].

The presence of a decomposing cadaver can have a significant effect on the surrounding surface soil or indeed buried ‘grave soil’; for example elevated levels of elements with respect to background values [27,38,47,50,51], including phosphate and nitrates [52], total carbon [53,54], potassium, magnesium, sodium and iron [55,56] and ninhydrin reactive nitrogen [35,57]. Elevated levels of volatile organic compounds [58–60] and pH [52,54,61] have also been recorded. These effects have been suggested to cause cadaver-associated clothing and textile degradation which have also been suggested to estimate a PBI [49,62].

Although poorly understood, ‘grave soil’ has been shown to be able to detect electrically by resistivity surveys in criminal investigations [10], graveyards [52,63] and controlled experiments [64,65]. Successful target detection has been found to be predominantly due to elevated conductivity levels relative to background values [52,66]. Elevated conductivity levels downstream of murder victim deposition site(s) have also been reported [67]. Recent research [65,66] has shown it is possible to repeatedly extract in situ decomposition fluids from both a buried pig cadaver and background soilwater, without the need to repeatedly disturb and refill a simulated clandestine grave or have a large number of pig cadavers within a study site that other authors have undertaken. The resulting fluids can also be directly measured in the field for conductivity using a simple, hand-held instrument.

The aim of this study was firstly to regularly extract and quantify fluid conductivities from both a shallow buried pig (Sus scrofa) carcass in situ and background soilwater, in order to create a base-line temporal data over a two-year period. The second aim was to determine if taking soil samples around a discovered shallow burial could assist in determining the approximate PBI. The third aim was to simultaneously collect appropriate site data (rainfall, soil moisture and temperature) so that results could be compared to other studies and applied to criminal investigations. The fourth aim was to compare the results to other simulated studies to determine the validity of the method and if data analysis agreed with post-burial dates. The fifth and final aim was to show, a hitherto unknown, simple and quick field technique to determine an approximate PBI of a buried murder victim, and therefore, an estimate of the lower limit of the PMI.

2. Materials and methods

2.1. Study site

The chosen controlled test site was located on Keele University campus, ~200 m above sea level, close to the town of Newcastle-under-Lyme in Staffordshire, UK (Fig. 1A). The study site and simulated clandestine grave was the same one used for geophysical investigations [66]. The test site is located ~200 m away from the Keele University weather observation station, which continually measured daily rainfall and air/ground temperatures as well as having soil temperature probes at 0.1 m, 0.3 m and 1.0 m depths below ground level (bgl). This allowed direct measurement of the below-ground site temperatures to be recorded. Fig. 2 shows summary rainfall and relevant temperature data over the monitoring period. Daily average temperatures at 0.3 m bgl was used to convert post-burial days to accumulated degree days (ADDs), which corrected for local site temperature variations by weighting each day by the average daily temperature and then giving each post-burial day an ADD value (see eTable 1 and Ref. [27]). Therefore for a two-day period, in which the average temperature of the first day was 12 °C and the second day was 15 °C, the ADD value for those two days would be 27 °C.

The local climate is temperate, which is typical for the UK. The study site was a grassed, small rectangular area (~25 m x ~25 m), surrounded by small deciduous trees. This study site was therefore representative of a semi-rural environment. Nearby borehole records show the Carboniferous Sandstone of Westphalian) Butterly Sandstone bedrock geology is present ~2.6 m bgl. Local soil maps, however, designated this area as made ground, due to the presence of demolished greenhouses. Initial soil sampling indicated a vertical site succession of a shallow (0.01 m) organic-rich, top soil (Munsell colour chart colour (Mcc): 5 YR2/2.5, with underlying A Horizon (Mcc): 5 YR3/3) comprising predominantly of a natural sandy loam that contained ~5% of isolated brick and coal fragments. The natural ground ‘B’ Horizon was encountered at ~0.45 m bgl, dominated by sandstone fragments from the underlying bedrock.

2.2. Simulated graves

The Human Tissue Act (2004) prevents human cadavers from being used for these experiments in the UK. A proxy domestic pig (Sus scrofa) carcass, sourced from the local abattoir, was therefore used instead to simulate a homicide victim, after the necessary permissions from the Department for Environment, Food and Rural Affairs (DEFRA) had been obtained. Pigs are commonly used as they comprise similar chemical compositions, size and tissue:body fat ratios [43,65]. A simulated ‘grave’ ~2 m x ~0.5 m was hand-excavated to 0.5 m bgl on the 7th December 2007. The pig cadaver, which weighed ~80 kg, was placed in the grave (Fig. 1B). The pig had been dead for less than 5 h at the time of burial, having been killed with an abattoir bolt gun. Within the grave, a soilwater sample lysimeter was placed between the carcass and the grave wall (Fig. 1B). The porous end cap of a model 1900 (SoilMoisture Equipment CorporationTM) soilwater sample lysimeter was then vertically inserted into a mixture of excavated soil and water. A ‘slurry’ was made and applied to the buried end of the lysimeter to ensure a good hydraulic conductivity between the ground and the lysimeter [68]. The simulated grave was backfilled to ground level with the excavated ground material and the ‘grave’ had the overlying grass sods carefully replaced. An empty grave was also dug nearby following the same procedure (Fig. 1A). A control site lysimeter was installed ~10 m from the grave by digging a 0.3 m x 0.3 m excavation (~0.3 m –0.5 m bgl). A similar lysimeter replacement procedure as detailed previously was followed. Once installed, the exposed ends of the lysimeters were sealed with a rubber stopper and a vacuum pump used to generate a lysimeter suction of 65 kPa, in order for the instruments to draw fluid from the soil.

2.3. Sample collection and measurements

Two days before any lysimeter sample was extracted, the rubber stopper was removed from each lysimeter and any fluid present was extracted using a plastic syringe with a narrow tube attachment, before being resealed and the vacuum pump employed to maintain vacuum pressure. On the day of sampling, the extracted fluid was first measured and the sample placed in a labelled plastic sample bottle (Fig. 1C). A portable WETTM Instrument Multi-line P4 conductivity meter was immediately placed within the sample bottle, and a reading was taken after the conductivity values and temperature readings had equilibrated. Measured conductivity values were automatically corrected by the conductivity meter to a reference temperature (25 °C) and are 0.1 °C accurate, therefore avoiding any potential diurnal variation effects when collecting samples. This measurement procedure was repeated to check reading value repeatability and reliability. The collected samples were then frozen. Finally conductivity and pH values were also measured on defrosted samples.

Volumetric moisture content and porosity were measured for grave soil samples (collected from the empty grave) and site soil samples (collected from a control location within the site). Soil samples were collected using augers, and subsequently oven dried to give moisture content and porosity measurements (see Ref. [66] for further details).

3. Results

Field soil porosity measurements averaged 59.2% (2.14 SD with 54.3–63.0% range) and 55.0% (1.98 SD with 49.9–58.5% range) for the empty grave and background site samples respectively. Field volumetric moisture content measurements averaged 31.5% (2.42 SD with 24.7–35.9% range) and 29.9% (3.12 SD with 19.7–34.5% range) for the empty grave and background samples respectively (see eTable 1 for raw data and Jervis et al. [66] for one year soil graph results). As would be expected in a northern hemisphere seasonal climate, highest moisture content values were in the late summer months. It was unseasonally dry in the autumn of year two but also the wettest early winter on UK records.

Field soilwater measurements (eTable 1) demonstrated that background soilwater conductivity values were consistent over the two year survey period (averaging 482 ± 0.1 mS/cm), the grave leachate conductivity values increased throughout the survey period, from 266 ± 0.1 mS/cm (12 days) to 31,400 ± 0.1 mS/cm (638 days post-burial) respectively (Fig. 3A). Note the last reading (727 days post-burial) had a significantly reduced conductivity of 24,600 mS/cm. Conductivity changes during the first 364 post-burial days were
reported in Jervis et al. [66]. The ‘grave’ conductivity values were twice the background values after only two weeks of post-burial. Leachate values could be grouped into three linear regressions, 0–150, 150–307 and 307–720 post-burial days respectively (cf Fig. 3A). The first two regressions had a good fit with the collected data ($R^2$ values of 0.9662 and 0.9915 respectively), with the third regression line demonstrating less confidence ($R^2$ values of 0.7189). The second linear regression represents the highest period of conductivity increase, increasing by

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**Fig. 1.** (A) Study site photograph with location (inset); (B) annotated photograph of simulated clandestine ‘grave’; (C) background lysimeter (to act as control) and fluid measuring accessories (see text).

**Fig. 2.** Summary site statistics of total rainfall (bars) and average temperature (lines) data (bgl, below ground level), measured over the two-year study period (see text).
~145 μS/cm/d every 14 days post-burial. This rapid increase in conductivity could have been a result of an increase in the rate of decomposition of the cadaver caused by higher soil temperatures in the spring and summer months (see Fig. 2). Site temperature variation could be removed from raw conductivity values by weighting each day by its average daily temperature and then giving each day post-burial an accumulated degree day (ADD) following standard methods [27]. This study had the advantage of having temperature probe measurement data available from the actual mid-cadaver depth (0.3 m bgl) from the nearby meteorological weather station, instead of using average air temperatures (Fig. 2). This allowed a data reduction to only two linear regressions being required, with an improved correlation for the first 307 days of burial ($R^2$ value of 0.9932, see Fig. 3B). The temperature of soilwater samples was also measured immediately upon extraction; leachate soilwaters averaged 0.8 ± 0.1 °C warmer than the background soilwater (Table 1). Laboratory pH measurements on defrosted samples showed significant variations between successive samples of both background and leachate soilwaters, thus not suggestive of confidence in the pH method to determine a burial date (Table 1).

4. Discussion

Every suspected burial site is unique, having different soil types with varying proportions of natural and anthropogenic materials, varying soil porosities and textures, micro-climate and associated temperature regimes, vegetation type, burial environment, etc. which all affect the potential PBI and/or the PMI determination. Many authors have attempted to quantify these parameters. The target body will also be highly variable from case to case, including target size and organic content, depth of burial and time of deposition. Burial depth is important as this will affect temperature and the associated rate of decomposition [36,43]. The time of burial will be important, especially in seasonal climates, for example, if death occurs in the summer season, the decomposition would occur more rapidly than if it occurred during the winter [45].

However, as demonstrated by this study, elevated soilwater conductivity values (compared with background values) appear to be a robust method to date a discovered burial in sandy loam soil within a rural environment. Other research [43,69] has suggested below-ground decomposition rates follow a sigmoidal pattern rather than an above-ground linear one when local site temperatures are taken into account. The data from this study suggests a two-stage linear relationship between conductivity and ADD during the first two years of burial. The first 307 post-burial days also showed a high degree of correlation (Fig. 3B). This study has the advantage over other decomposition studies (e.g. [35]) in that only one pig is sampled and the ‘grave’ does not need to be repeatedly excavated and refilled; therefore the leachate fluids remain in situ and in context, albeit extracted by the lysimeter. Using ADD also negates the need for multiple cadavers at different burial depths being simultaneously analysed, as major variations will be dominated by temperature and hence decomposition rates and this has already been corrected for. Study results show there would be greater degree of confidence with dating a burial in the first 307 post-burial days or 3257 ADD due to the comparatively steep linear regression, as compared to the second year or 6973
ADD. The leachate conductivity values were already twice that of background values after only 14 days post-burial and continued to increase until the penultimate sample (Fig. 3 and eTable 1). There was a significant decrease in conductivity in the 727 post-burial days/7533 ADD sample which does not follow the trend of the rest of the sampled data. This could be due to the unusually high rainfall during the last month of monitoring or the start of a new conductivity trend.

Obtaining an accurate date of a discovered burial would depend upon the forensic search investigators being able to quantify the major site variables already discussed. From this study, it is suggested that the two most important factors are daily site temperatures and depth of the discovered burial. Local temperature data from a nearby meteorological weather station would be required to convert ADD back to post-burial days. Average daily temperatures could be summed-back from the discovered average daily temperature to the date of burial as previously described. If only daily air temperatures are available, these can be corrected for the depth of discovered burial using the method of Ref. [70]. The accumulated degree days can then be corrected so that their measured conductivity linearly correlates.

This study also suggests that two of the other important site variables (apart from temperature and depth of burial) would be the local soil type and burial environment as suggested in previous reports [34,44,48,71]. As this research was focused on a semi-rural environment study site with a sandy loam soil, results were then compared with a previous conductivity study from a simulated clandestine grave in a mixed clay/made-ground soil in an urban depositional environment [65]. Once the 154 days post-burial data were corrected for ADD at the depth of burial and background soilwater conductivity subtracted from ‘grave’ leachate conductivity values for both studies, the resulting datasets could then be compared over the same time period (Fig. 4A and eTable 2). The linear best-fit lines were comparable, having very similar gradients (~9.3 µS/cm/d and ~10.6 µS/cm/d for this and Jervis et al. [66] study respectively), although there is almost a doubling of conductivity values. This was possibly due to the different soil type (sandy loam versus made ground) and a contrasting environment of deposition (semi-rural versus urban) for this study and Jervis et al. [65] study respectively. The urban study also used a 31 kg pig, in contrast to the 80 kg pig used in this study which may indicate that variation in cadaver size does not have a significant affect on conductivity measurements. Green and Wright [14] also showed PMI did not need adjustments for body weights. An existing method to correct for contrasting carcass weights was trialled [27], which involved multiplying measured conductivities by 0.5 and 1.1677 respectively, but this did not improve the data match (Fig. 4B).

An experimental limitation with this study is that lysimeters from which the fluid was derived would not be available to obtain samples within a discovered burial. Therefore, to test this method on a ‘discovered burial’, a separate simulated grave, ~1 m × ~0.5 m, was hand-excavated to 0.5 m bgl on the Keele test site on the 21st October 2008. A ~25 kg pig carcass was deposited before the ‘grave’ was refilled and grass sods replaced, following the described methodology. This grave was then ‘discovered’ and hand-excavated on 30th July 2009, with the observed leachate fluids being measured by insertion of the calibrated conductivity meter (Fig. 5). Once the 19,780 mS/cm conductivity value was plotted (Fig. 3), a burial date mis-match of 45 days was observed between the burial date estimated from the conductivity measurement and the actual date, which was 13.7% error over the burial time period. Once corrected for ADD the estimated 288 ADD mis-match gave an improved 11.5% error. Where a discovered burial did not have observed leachate, it would then be necessary to collect soil within the burial and then centrifuge samples to extract soilwater, following reported methodology [57].

There are still potential unknowns for burial dating purposes in casework. One potential unknown would be the determination of the time gap (if any) between death and burial. This could be determined using other methods as described in Section 1. A
second unknown would be determining if the body had been moved and re-buried. This would affect this dating method as fluids would not be present from the first burial and thus a conductivity burial date would not be accurate. Other research has also found repeated burial affects tissue decomposition rates [72].

To detect a suspected burial location rather than date a discovered one, elevated conductivity levels downstream of both murder victim deposition sites [67] and cemeteries [52] have been previously measured, and compared to upstream values. It would be difficult to apply this presumptive detection test on land, although again centrifuging collected soil samples to extract soilwater and obtain a conductivity value [35,57], would be suggested around a relatively small area which had a priori information. The authors would not recommend freezing field samples for later analysis, as comparisons between field and laboratory-derived conductivities from the first 223 post-burial days demonstrated that defrosted sample values were, on average, 40% lower from those measured in the field (see eTable 1).

Further work should firstly be to continue site monitoring, in order to extend base-line data and determine if conductivity values from the grave continue, over time post-burial, to slowly increase, stabilise or reduce back to background values. If conductivity values begin to decrease over longer time frames, this will give two potential burial times, rather than the one currently suggested by this study. Secondly, it is important that the experiment is replicated in other soil types, for example, sandy and chalky soils. Other studies have shown this can be important, for example, recording significant pH variations [39] and soil textures [44] that affect conductivity. Thirdly, different burial environments from the semi-rural and urban environments detailed in this study should be investigated. Two obvious potential burial environments would be woodland and moorland environments. Fourthly, analytical chemical techniques should be utilised to examine the soilwater samples. This would hopefully clarify why there was a clearly observed change in conductivity versus time after a year of burial. It may also determine if elements, compounds or acids could be used as a complimentary dating mechanism. For example, elevated levels of nitrates around buried pigs, total carbon and pH [54], total nitrogen, phosphorus and lipid–phosphorus [61] should be measured. Vass et al. [58,59] found specific volatile organic compounds (VOCs) to be both diagnostic of human burials and concentrations varied over post-burial time.

5. Conclusions

Regular in situ base-line temporal data collected within a buried simulated clandestine grave, containing an 80 kg pig cadaver in a sandy loam soil in a semi-rural environment, found increasing conductivity levels with respect to background levels until the end of the two-year study period. Site temperatures and burial depth were used to convert post-burial days to accumulated degree days (ADDs), which allowed an improved fit of linear regression lines. Using ADD allowed for any local temperature variation and associated burial depth to be corrected for. From this study, there would be a good level of confidence in this simple method to establish the PBI/PMI of a discovered burial up to 307 days post-burial or 3315 ADD; after this period the comparatively shallow linear regression would make dating more problematic. Comparisons with a previous buried simulated clandestine grave, containing a 25 kg pig cadaver in a mixed clay/made-ground soil in an urban environment, showed a similar increasing linear trend over the 154 days post-burial or 2040 ADD study period, but this showed a doubling of conductivity values that may have been related to the contrasting soil types and depositional environments. Conductivity measurements from a final simulated ‘discovered burial’ containing a pig cadaver showed a 15.7% burial date and an 11.5% ADD burial date mis-match respectively using the described method. Study limitations included using one pig cadaver in two depositional environments and using a lysimeter to collect in situ samples rather than analysing grave soil directly. The proposed method would also be unable to determine if there was a difference between PMI and PBI and it would possibly be unable to indicate if the body had been re-buried. This proposed method could also be applied to time burial of other organic material, e.g. illegal animal burials or landfill plumes.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.forsciint.2010.02.005.

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