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TECHNICAL NOTE

Anthropology

Veldt fires in South Africa: Implications on osteometry and the biological profile

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Abstract

Standard operating procedures for forensic anthropological analyses dictate that thermally altered remains should not be measured, hindering the creation of a biological profile. Few studies have addressed estimating biological parameters from burned remains, with the greatest focus of this research area being on cremated remains. However, veldt fires are more common than cremation in the South African forensic context. The aim of this study was to explore the degree of structural changes observed in domestic pig (*Sus scrofa*) bones associated with thermal destruction and the potential impact on the estimation of a biological profile using standard osteometric methods. A total of 96 pig femora were divided equally into two categories: fresh and dry. Within each category, equal samples were exposed to different durations of burning, namely, 5, 10, and 20 min. Ten standard femoral anthropological measurements were collected before and after burning. Technical error of measurement and Wilcoxon signed-rank tests were used to assess changes in the femoral dimensions before and after burning. Most measurements were significantly different after burning, with the fresh bones decreasing in size by up to 7.8% and the dry bones decreasing in size by up to 4.0%. The magnitude of post-burning measurement changes for both burn conditions was similar to, or smaller than has previously been reported for observer measurement errors of commonly used variables investigated for standard osteometric studies. Veldt fires are less intense than cremation, thus causing less shrinkage.

KEYWORDS
osteometry, *Sus scrofa*, taphonomy, technical error of measurement (TEM), thermal alteration, veldt fires

Highlights

- Bone condition before burning had the biggest effect on shrinkage.
- Fresh bone demonstrated more shrinkage than dry bone exposed for the same duration.
- The degree of shrinkage of bone resulting from veldt fire conditions is fairly low.
- Assessing biological parameters from burned remains with osteometry is potentially possible.

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1 | INTRODUCTION

Establishing a biological profile from skeletal remains is an important aspect of forensic anthropology required for the identification of unknown decedents. The biological profile includes estimates of population affinity (ancestry), sex, age at death, and stature. A biological profile, combined with assistance from investigating officers, provides basic information regarding an unknown set of remains that can be used when relatives are seeking a missing family member. In doing so, other aspects of formulating a positive identification, namely, antemortem dental records, fingerprints, and comparative DNA analyses can also be performed. Currently, the methodologies employed to estimate many parameters of the biological profile rely heavily on skeletal measurements to provide accurate results [1]. For example, in South Africa, cranial measurements are the preferred approach to estimate population affinity as morphological methods have lower repeatability, and more ambiguous definitions, thus making these methods less accurate [2]. Furthermore, long bone measurements are commonly used for population affinity and sex estimation especially if the body is not complete or intact, as is seen in majority of the forensic cases received in South Africa [2, 3]. However, any damage to bone due to taphonomy, pathology, or trauma may limit the number of measurements that can be taken from skeletal elements. Fire is an example of a major destructive taphonomic force that can limit the number of skeletal measurements that may be taken from the skeleton.

Human remains may be exposed to fire in a variety of scenarios, most commonly during accidents or environmental conditions, such as vehicle collisions, structural fires, lightning strikes, or veldt fires. A veldt fire, also known as a grass or bushfire, refers to a fire of around 700°C lasting for a short period (less than 30 min) using surrounding flora (grass, twigs, and dry leaves) from the field as a fuel source [4]. Therefore, these fires have a high intensity but typically stop when the fuel source runs out [4]. Veldt or bushfires are a common occurrence in some countries, with many instances making news headlines, such as the Australian bushfires or the California wildfires. In South Africa, most of the veldt fires observed in the Highveldt region occur during the dry season and winter months (May to August) [5]. The most common cause of veldt fires includes field preparation for the farming season, pedestrians or motorists starting fires next to highways, and littering of burning cigarette stubs [6]. A large proportion of the thermally altered remains received by the Forensic Anthropology Research Centre (FARC) at the University of Pretoria have been exposed to conditions consistent with veldt fires during the fall and winter periods [7].

Bone demonstrates a wide range of changes in response to exposure to fire with both extrinsic and intrinsic factors influencing the extent of observable thermal modifications. These factors include fuel content, oxygen supply, amount of flesh present, the condition of the bone (i.e., the amount of organic content present), the presence of clothes, or other protective coverings, as well as the temperature and duration of the fire [8, 9]. When fresh bone is exposed to fire, the bone tends to dehydrate, shrink, fracture, delaminate, and/or calcinate as collagen (which makes up the organic component of the bone structure) is lost [9]. However, when the bone has already lost much of its collagen prior to fire exposure, the bone burns as a homogenous structure with calcination, splintering, longitudinal fracturing, and superficial cracking occurring to various degrees, but little to no warping will be observed [10–12]. Bone warping and shrinking can change the dimensions and morphology of the bone, which will likely affect the standard measurements commonly taken to assist with the creation of a biological profile.

In South Africa, forensic anthropologists typically receive skeletonized remains or remains in an advanced stage of decomposition with no form of identification. Thus, in order to find family members to obtain comparative DNA samples, at least an estimated biological profile is necessary. Without a biological profile, the identification of unknown remains is nearly impossible. Currently, the standard operating procedure (SOP) in forensic anthropological analyses dictates that badly damaged bones (i.e., burned remains) should not be measured, hindering the process of creating a biological profile from these remains [8, 13–16]. However, these guidelines refer to thermal alteration similar to the damage seen in cremations and not in a South African veldt fire. The effects of a low temperature and short-duration fire (typical of a South African veldt fire) on the estimation of the biological profile from skeletal measurements have not been sufficiently researched.

An observational study of the remains in the FARC forensic case repository noted that most of the thermally altered remains (44 of 50 thermally altered cases housed in the repository) had most likely been exposed to veldt fires. Most of these thermally altered remains (35 of the 44) had burn patterns inconsistent with patterns expected to be seen on fleshed remains as those described in Symes et al. [9]. Charring was the most common thermal alteration observed, followed by heat-altered borders (a distinct border between burned and unburned bone) [7]. White heat lines were absent, suggesting minimal soft tissue on the remains prior to the burning event [5, 9, 17]. Charring and calcination were observed on less than 50% of the bone surface and rarely to the most extreme degree, suggesting a shorter duration of burning [7]. Therefore, the shrinkage, warping, and instability of bone might not be as severe in veldt fires and may not affect measurements as much as similar studies outside South Africa suggest [18–21].

Few published studies have addressed the estimation of biological parameters from burned remains and have mainly focused on cremated remains [20–25]. Cremation is rare in the South African forensic context compared to other burn patterns, with minimal calcination, less extensive charring, and heat-altered borders being more prevalent. While some advances have been made to better understand thermal alteration, only a few open-air and veldt fire experiments have been conducted [8, 10, 26]. This approach has mainly been employed when investigating case studies of burned human remains of various forensic scenarios including suicides, fatal domestic fires, and homicides [26, 27].

Bone condition and fire duration have been shown to have the greatest effect on the degree of thermal alteration, particularly on the degree of bone shrinkage [9]. Therefore, the purpose of this study was to assess the effects that burning associated with veldt fires in South Africa have on standard anthropological measurements. By comparing the differences between the before and after burning measurements of fresh and dry bones exposed to different fire durations, the degree of shrinkage was evaluated.

2 | MATERIALS AND METHODS

Due to the ethical issues associated with the South African legislature involved when experimenting with cadavers and the restricted access associated with destructive research using human remains (leading to a loss of biological information), an animal model was used for this study [10]. The animal model most suited for the current project was the domestic pig (*Sus scrofa domesticus*) because pigs have been found to demonstrate similar bone composition (Haversian tissue and cortical bone) to humans and are the most commonly used animal models in taphonomy-related studies [26, 28–31]. Pig models have also previously been used in South African-specific studies, including studies assessing fire damage to bone [10, 32]. Ethical clearance for the study was obtained from the Animal Ethics Committee and the Research Ethics Committees at the University of Pretoria (Ethics number 433/2019).

Ninety-six pig femora of similar age and size (based on measurements and epiphyseal fusion) were sourced from a local butcher (i.e., no pigs were bred or euthanized specifically for the current study). The femora were subdivided into two categories: 48 were assigned to the fresh group (void of flesh, but still greasy with the periosteum present), similarly, 48 were assigned to the dry group (some organic content lost, but with residual pieces of periosteum). The fresh bones were obtained by dissecting the residual flesh off the bone, but without any further treatment that might have affected the organic content of the bone. The dry bones were obtained by dissecting all flesh off the bone and allowing the bone to dry naturally, in an outdoor context (to simulate the process that remains in a forensic outdoor context would undergo). Due to time constraints, the bones were allowed to dry for 15 weeks, with a 90° rotation of the bones every 2 weeks. Forty-eight fresh and dry femora were equally distributed among four heat-duration subcategories: control (not burned), burned for 5 min, burned for 10 min, and burned for 20 min. Each bone was measured and then burned only once for the assigned time of either 5, 10, or 20 min, doused, and measured again after cooling down. Because the duration times did not exceed 20 min and fleshed bone (i.e., with intact skin and muscles) only demonstrate thermal alteration after approximately 20 min [10], this study did not include fleshed bones.

Ten measurements were collected from each femur using a standard sliding caliper and osteometric board (Table 1). The landmarks were marked with a scalpel on each bone to ensure consistency between the measurements collected before and after burning.

A natural outdoor veldt fire was replicated at the Forensic Anthropology Body Farm (FABF)—Miertjie Le Roux Experimental Farm, University of Pretoria (South Africa) using dried grass. The femora were placed on a mobile steel grid (550 mm × 700 mm × 200 mm perforated) within a round steel container (1000 mm [radius] × 300 mm [height]) to contain and control the flames. Twelve femora selected for each category were divided so that six were placed with the anterior surface facing superiorly and the trochlea (patellar surface) toward the midline of the grid. The other six femora were placed with the posterior surface facing superiorly and the popliteal surface toward the midline of the grid (Figure 1). The steel container was filled with dried grass before the steel grid was placed in the middle of the container. Once the 12 femora were in place, the grass was placed on top of the bones. The grass was set on fire from four points and the countdown started. Grass was placed on top of the bones and below the grid as the grass burned. The grass was also stirred continuously to make sure the bones stayed surrounded by the fire and that the fire had enough oxygen to continue. Two minutes before the fire was to be extinguished, no more grass was added to the fire. Each fire was extinguished with sand after the allocated duration (5, 10, and 20 minu) and the bones were left to cool down.

TABLE 1 The 10 femoral measurements with their abbreviations (modified from Moore-Jansen et al. [33]; Langley et al. [34])

Measurements	Abbreviations
Maximum length	Femxln
Bicondylar length	Fembln
Epicondylar breadth	Femebr
Vertical head diameter	Femhdd
Maximum subtrochanteric diameter	Femsam
Minimum subtrochanteric diameter	Femsin
Maximum diameter at midshaft	Femmax
Minimum diameter at midshaft	Femmin
Maximum antero-posterior length of the lateral condyle	Femlcl
Maximum antero-posterior length of the medial condyle	Femmcl

A temperature gauge was not used in this study so the temperature for the simulated veldt fire was estimated. Based on the observed colors and results of previous studies [26, 35], the fires in the current study were estimated between 300°C resulting in heat-altered borders (ivory white to tan) and 700°C resulting in calcination (gray–white), with temperatures of around 500°C resulting in charring (black) [26, 35]. The bones burned for only 5 min showed heat-altered borders, some charring, and very little calcination, indicating that fires most likely did not reach 700°C. However, the bones that were exposed to the fire for 20 min had charring and calcination on at least 50% of the bone surface, suggesting that the fires most likely reached 700°C.

Significant differences between the before and after burning measurements were explored using Wilcoxon signed-rank tests. The *p*-value indicated whether the measurement was significantly different before and after burning; a *p*-value of greater than 0.05 was not significantly different. Absolute and relative technical error

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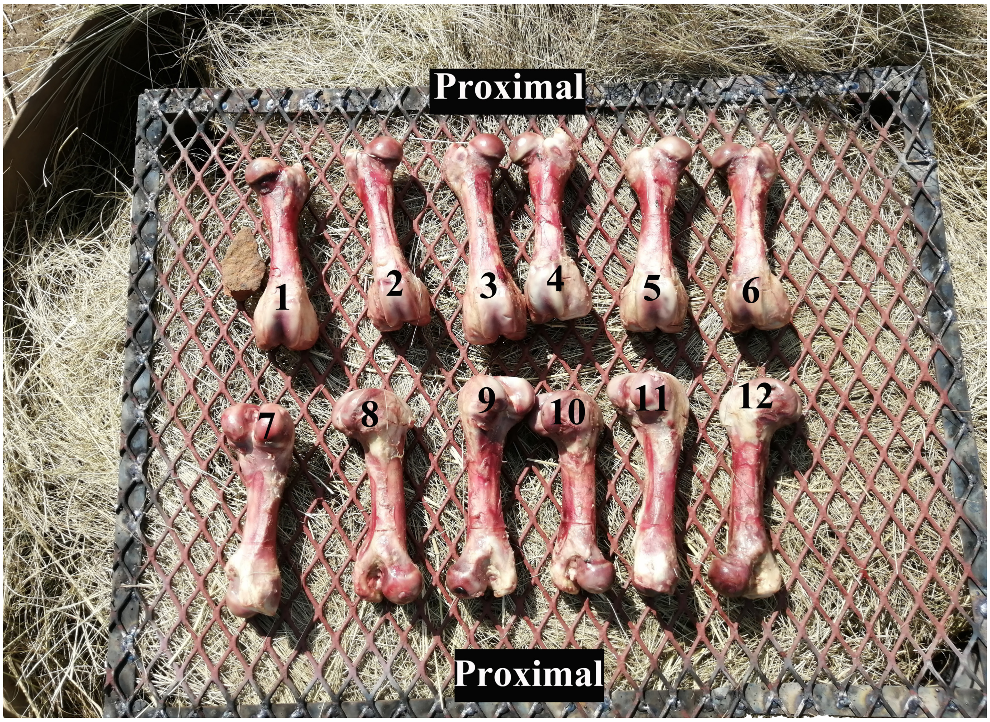

FIGURE 1 Bone placement during the burning event. Femora 1 – 6 with the anterior surface superior and the trochlea towards the midline of the grid. Femora 7 – 12 with the posterior surface superior and the popliteal surface towards the midline of the grid. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Intra-observer error TEM and %TEM of the 10 femoral measurements in the fresh and dry categories

		Fresh		Dry	
Measurements	*n*	TEM	%TEM	TEM	%TEM
Femxln	6	0.71	0.39	**0.71**	0.38
Fembln	6	0.50	0.27	0.50	0.27
Femebr	6	0.76	1.31	0.58	0.94
Femhdd	6	0.29	0.80	0.29	0.79
Femsam	6	0.29	0.91	0.00	0.00
Femsin	6	0.50	1.73	0.65	**2.07**
Femmax	6	0.58	**2.05**	0.29	0.98
Femmin	6	0.00	0.00	0.29	1.15
Femlcl	6	**0.91**	1.45	0.00	0.00
Femmcl	6	0.65	0.96	0.65	0.97

Note: Bold indicates the measurement with the highest error rate per burning period. See Table 1 for measurement abbreviations.

of measurement (TEM and %TEM) were used to gauge the degree of shrinkage. In this instance, a lower variability indicated a slighter change in the size and morphology of the bone [36]. Absolute and relative technical error of measurement was also used to test measurement repeatability. Six fresh (two from each duration subcategory) and six dry bones were selected prior to burning to test the measurement repeatability on unburned bone. A further six fresh and six dry bones were selected after burning to test the measurement repeatability on burned bone.

FIGURE 2 Three fresh bones after being burned for 5, 10, and 20-minutes respectively. All 3 bones were intact after burning and demonstrated heat-altered borders (brown)and charring (black). [Colour figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS

The first author measured 12 of the 96 femora to assess the repeatability of the measurements prior to thermal alteration as well as after thermal alteration. The measurements were found to be consistent, with observer agreement ranging between 0.00 and 0.91 mm

(TEM) and 0% to 2.1% (%TEM) (Table 2). Therefore, any observed size changes were most likely due to thermal alteration rather than measurement error. The raw data for each specimen can be found in the Supplementary Information (Table S1).

All measurements collected from the fresh femora (Figure 2) consistently decreased in size after exposure to the fire, with a maximum decrease of up to 7.8% (Table 3). After 5 min, the measurements decreased between 0.5 and 3.35 mm and 0.7% and 4.9%, with six of the 10 measurements calculated to be significantly smaller after burning. After 10 min, the measurements decreased between 0.56 and 3.36 mm and 1.0% and 4.7%, with 8 of the 10 measurements significantly smaller after burning. After 20 min, the measurements decreased between 0.41 and 5.09 mm and between 1.0% and 7.8%, with only 4 of the 10 measurements noted to be significantly smaller after burning (Tables 4 and 5). With an increase in duration, the bones became fragmentary, and some measurements could not be taken. As such, in the 20-min bone group, six of the measurements could only be taken in less than 50% of the individuals post-burning; this could have adversely affected the magnitude of change seen in the TEM and %TEM (Table 4). The most variable measurement (i.e., greatest difference before and after burning) was the maximum medial condylar length. The measurement with the lowest absolute difference (TEM) after burning was the femoral minimum midshaft diameter, and the lowest relative difference (%TEM) was the femoral maximum length.

The dry femora (Figure 3) were more combustible than the fresh femora and tended to retain the heat for longer. The majority of dry femora measurements decreased in size, but only up to 4.0% (Table 6). Thus, less shrinkage occurred in the dry femora compared to the fresh femora. After 5 min, the measurements decreased between 0.43 and 2.61 mm and 0.3% and 4.0%, with 4 of the 10 measurements becoming significantly smaller. After 10 min, the measurements decreased between 0.45 and 1.61 mm and 0.4% and 2.6%, with 4 of the 10 measurements significantly smaller after burning. After 20 min, the measurements decreased between 0.50 and 1.58 mm and between 0.7% and 3.8%, while only 3 of the 10 measurements were significantly smaller after burning (Tables 5 and 7). Similar to the fresh femora, the measurement with the biggest difference after burning was the maximum lateral condylar length. In addition, the measurement with the smallest difference was the femoral minimum midshaft diameter and the lowest %TEM was the femoral maximum length. Consistent with the observations from the fresh femora, an increase in the fire duration led to the dry femora becoming fragmentary, and some measurements could not be taken.

TABLE 3 Descriptive statistics for the fresh category with each of the duration subcategories

	5 min			10 min			20 min		
Measurements	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Femxln_b	12	189.3	4.3	12	188.0	8.0	12	188.3	7.2
Femxln_a	12	187.8	5.0	12	185.8	7.6	5	188.4	8.0
Fembln_b	12	188.8	5.4	12	188.0	6.6	12	187.1	6.8
Fembln_a	12	184.8	4.8	12	183.9	6.3	5	185.6	8.3
Femebr_b	12	59.2	2.1	12	58.4	2.4	12	57.7	1.7
Femebr_a	12	57.8	2.0	12	57.4	2.3	12	56.2	2.5
Femhdd_b	12	37.2	1.3	12	36.7	1.5	12	36.1	1.1
Femhdd_a	12	35.7	1.2	12	34.8	1.8	12	34.2	0.9
Femsam_b	12	32.2	1.9	12	32.5	1.7	12	32.0	1.5
Femsam_a	12	32.1	2.2	11	31.7	1.3	6	32.2	1.8
Femsin_b	12	29.4	1.7	12	29.5	1.9	12	29.2	1.5
Femsin_a	12	29.3	1.7	11	28.9	1.4	6	29.3	1.9
Femmax_b	12	28.1	1.4	12	28.4	1.8	12	28.2	1.2
Femmax_a	12	27.7	1.4	11	27.5	1.6	3	27.3	1.5
Femmin_b	12	24.7	1.4	12	24.8	1.0	12	24.7	0.9
Femmin_a	12	24.3	1.2	11	24.3	0.9	3	24.0	1.0
Femlcl_b	12	65.1	2.1	12	64.2	2.6	12	64.2	2.8
Femlcl_a	12	63.2	2.5	12	61.3	2.0	12	59.7	2.3
Femmcl_b	12	70.2	2.4	12	69.1	3.1	12	68.9	1.5
Femmcl_a	12	65.8	2.2	12	65.0	3.2	12	61.9	1.9

Note: Measurement abbreviations can be found in Table 1. Measurement_b is the pre-burning measurement. Measurement_a is the post-burning measurement.

JOURNAL OF FORENSIC SCIENCES

TABLE 4 TEM and %TEM for the 10 femoral measurements of the different duration groups in the fresh category

Measurements	5 min			10 min			20 min		
	N	TEM	%TEM	*n*	TEM	%TEM	*n*	TEM	%TEM
Femxln	12	1.31	0.69	12	1.81	0.97	5	1.79	0.95
Fembln	12	3.08	1.65	12	**3.36**	1.81	5	3.23	1.73
Femebr	12	1.29	2.21	12	0.82	1.41	12	1.63	2.87
Femhdd	12	1.16	3.17	12	1.53	4.27	12	1.38	3.94
Femsam	12	0.79	2.46	11	0.71	2.20	6	0.82	2.55
Femsin	12	0.79	2.69	11	0.56	1.93	6	0.58	1.98
Femmax	12	0.54	1.94	11	0.67	2.41	3	0.58	2.06
Femmin	12	0.50	2.04	11	0.56	2.30	3	0.41	1.66
Femlcl	12	1.59	2.54	12	2.39	3.81	12	3.49	5.63
Femmcl	12	**3.35**	**4.93**	12	3.14	**4.68**	12	**5.09**	**7.78**

Note: Bold indicates the highest value per burning period. Measurement abbreviations can be found in Table 1.

TABLE 5 Wilcoxon test for the 10 femoral measurements in the fresh and dry category comparing the before and after burning measurements

Measurements	Fresh			Dry		
	5 min	10 min	20 min	5 min	10 min	20 min
Femxln	*	*	0.05	0.82	0.31	0.16
Fembln	*	*	0.05	0.37	0.58	0.27
Femebr	*	*	*	*	*	*
Femhdd	*	*	*	*	*	*
Femsam	0.83	*	1.00	0.30	0.20	0.13
Femsin	1.00	0.07	1.00	0.33	0.48	*
Femmax	0.07	*	0.35	0.42	0.07	0.15
Femmin	0.13	0.07	1.00	0.30	0.07	0.07
Femlcl	*	*	*	*	*	0.05
Femmcl	*	*	*	*	*	*

Note: Measurement abbreviations can be found in Table 1.

*Significant difference ($p < 0.05$).

4 | DISCUSSION

Whether the bone was fresh or dry prior to the burn event had the greatest impact on size changes between the femoral measurements collected. The magnitude of change between the bones that burned for 5-min and the bones that burned for 20 min was relatively small, thus suggesting most of the shrinkage occurred within the first 5 min of the commencement of the fire. However, with an increase in the duration of the fire, an increase in the fragility of the bone was noted, regardless of the condition. The fresh femora demonstrated more shrinkage than the dry femora, and the epiphyses demonstrated the greatest degree of shrinkage, while the shafts demonstrated the least amount of shrinkage. A possible explanation for the greater degree of shrinkage in the epiphyseal regions might be due to the high content of trabecular bone in the epiphyseal regions providing more fuel to the flames due to the higher grease content.

Calcination appeared on the fresh femora only after the bones had burned for more than 5 min, while the dry femora demonstrated calcination when burned for 5 min. The fresh femora were protected for longer from direct contact with the flames by the residual flesh and the presence of a higher moisture content [5, 9].

Liebenberg [7] noted that charring and calcination are seen more frequently on the distal third of the human femora and less frequently on the shafts. Similarly, this study noted that the medial and lateral condyles most often presented with charring and calcination, which may be due to the greater moisture content noted in the areas with higher trabecular bone, more specifically the proximal and distal epiphyses. As the higher moisture content is typically found in trabecular bone, the proximal and distal ends were charred and calcined more often as the ends are fueled by the grease and as a result remained hotter for longer, allowing thermal alteration to occur to a greater degree [37].

While color differences do not necessarily affect measurements of the bones, the associated loss of moisture and the increase in fragility of the bones that is represented by the charred and calcined appearance may have influenced the measurements. According to

FIGURE 3 Three dry bones after being burned for 5, 10, and 20-minutes respectively. The bones that burned for 5 and 10-minutes were intact after burning and demonstrated heat-altered borders (brown) and charring (black). Whereas the bone burned for 20-minutes had some fractures and pieces of bone missing after burning, these bones also demonstrated mostly charring (black) and calcination (grey). [Colour figure can be viewed at wileyonlinelibrary.com]

Thompson [19], the higher the increase in the severity of thermal damage, the higher the measurement inaccuracies; however, in the current study, the post-burning measurement error was consistent with the pre-burning measurement error.

Similar to previous studies, the measurements with landmarks located on areas with abundant trabecular bone (e.g., epicondylar breath, femoral head diameter, and the maximum medial condylar length) changed considerably, with these areas shrinking more than areas with dense cortical bone [20, 21, 27]. Dry and compact bones burn at a lower temperature and burn for shorter periods of time even though they ignite faster. The shorter duration is most likely because of the lack of moisture present in the bone as a result of the dehydrating effects of the fire-induced weathering [37].

Most of the post-burning dry femora measurements were smaller, although there were a few that were slightly larger than the pre-burning measurements. Gonçalves et al. [38] observed as much as a 4.5% increase in the post-burning measurements (increase in bone size) and as much as a 40.1% decrease in the post-burning measurements (decrease in bone size) collected from remains cremated within 48h after death. The increase in bone size is most likely due to the re-crystallization of the hydroxyapatite during the cool-down period [4, 38]. In the Gonçalves et al. [38] study, the cremation period ranged from 50 to 250 min with a temperature between 750 and 1050°C. In comparison, the current study noted a maximum increase of 4.7% after burning and a maximum decrease of 10% in the sample of de-fleshed pig femora exposed to a veldt fire (±700°C) for relatively short periods (20 min or less). Therefore, the dehydration, shrinkage, and warping were less severe in the pig femora compared to human cremains likely because of differences in burn temperature and fire duration.

Previous studies [20–25] have been able to estimate the parameters of the biological profile from cremated remains. Van Vark et al. [24] and Gonçalves et al. [20, 38] successfully estimated the sex of burned remains using metric analyses, whereas Rodrigues et al. [22, 23] successfully estimated the sex and age at death of burned remains using morphoscopic features on the os coxa. Moreover, Grévin et al. [25] were able to estimate stature of unknown thermally altered remains by using a shrinkage factor.

The lengths of the femora in this study were not significantly different after burning; however, the pig femora tended to break at midshaft, which may make length measurements less useful for assessing thermally altered skeletal remains. This is unfortunate, as population affinity (ancestry) and stature estimations rely heavily on bone lengths [39, 40]. Nevertheless, stature estimates from the femur, or at least an estimate of the maximum femoral length, may be possible by employing the fragmentary regression equations from Bidmos [39] specifically for the South African population; however, these formulae are population affinity- (ancestry) and sex-specific [40, 41].

Regardless of the bone condition and/or duration, the post-burning measurements changed; however, the magnitude of the post-burning measurement changes was smaller for both burn conditions than observer error rates typically reported in standard osteometric studies of unaltered human bones, for example [39, 42, 43]. A TEM of less than 2 mm is typically considered satisfactory for observer error [3] and some of these studies recorded a TEM of 1.18 mm and a %TEM of 4.7% and higher, for example [39, 42, 43]. The results of the current study provide confirmation that a lower temperature and a shorter period of exposure to fire (consistent with veldt fires) will have less of an effect on measurement sizes in burned bones than higher temperatures and longer exposure times. Therefore, measurements from thermally altered remains associated with a veldt fire can still potentially be compared to measurements in the existing databases to estimate the biological profile. The measurements that can be used include the lengths and the sub-trochanteric and midshaft diameters. The measurements most frequently affected, and therefore should most likely be avoided, include the epicondylar breath and femoral head diameter. The current study demonstrated proof of concept, which can be extended to the assessment of other thermally altered bones, particularly bones of human origin. Thus, different bones (other than the femur) should also be tested to see whether the same trends would be noted on all bones, regardless of morphology and composition (ratio of trabecular versus cortical bone).

With the limited shrinkage observed in this study, osteometric methods may be feasible on remains exposed to veldt fire conditions in order to estimate parameters of the biological profile. However, further research is needed on how the condition of the bone and duration of the fire will affect the before and after burning

TABLE 6 Descriptive statistics for the dry category with each of the duration subcategories

	5 min			10 min			20 min		
Measurements	*n*	Mean	SD	*N*	Mean	SD	*n*	Mean	SD
Femxln_b	12	187.1	4.7	12	186.3	5.2	12	186.7	3.6
Femxln_a	12	187.0	5.0	12	186.7	5.1	8	188.1	3.0
Fembln_b	12	184.7	4.9	12	183.3	4.6	12	184.0	4.0
Fembln_a	12	184.2	5.0	12	183.6	4.9	8	185.0	5.0
Femebr_b	12	59.8	1.8	12	59.5	3.7	12	59.1	2.6
Femebr_a	12	58.3	2.4	12	58.2	3.5	12	57.8	2.5
Femhdd_b	12	36.2	1.2	12	36.7	1.8	12	36.1	1.5
Femhdd_a	12	35.3	1.3	12	35.5	2.0	12	34.9	0.9
Femsam_b	12	32.2	1.0	12	33.1	2.4	12	32.3	1.9
Femsam_a	12	32.5	0.9	10	33.6	2.8	8	31.4	1.4
Femsin_b	12	29.7	1.6	12	30.3	1.8	12	29.9	2.0
Femsin_a	12	30.1	1.1	10	30.7	2.0	8	28.6	1.8
Femmax_b	12	27.0	1.2	12	28.7	1.7	12	27.9	1.4
Femmax_a	11	26.9	1.4	10	28.3	2.1	6	28.0	1.8
Femmin_b	12	23.8	1.0	12	24.8	1.6	12	24.4	1.3
Femmin_a	11	23.5	0.9	10	24.6	1.5	6	24.0	1.3
Femlcl_b	12	63.7	2.2	12	61.7	2.6	12	61.4	2.2
Femlcl_a	12	61.6	2.2	12	60.2	2.3	12	60.4	1.9
Femmcl_b	12	66.8	2.6	12	65.3	2.4	12	64.0	2.4
Femmcl_a	12	64.3	2.1	12	63.7	2.5	12	62.6	2.4

Note: Measurement abbreviations can be found in Table 1. Measurement_b is the pre-burning measurement. Measurement_a is the post-burning measurement.

TABLE 7 TEM and %TEM for the 10 femoral measurements of the different duration groups in the dry category

	5 min			10 min			20 min		
Measurements	*n*	TEM	%TEM	*n*	TEM	%TEM	*n*	TEM	%TEM
Femxln	12	0.61	0.33	12	0.76	0.41	8	1.28	0.68
Fembln	12	1.06	0.58	12	0.98	0.53	8	**1.58**	0.86
Femebr	12	1.46	2.47	12	1.06	1.80	12	1.19	2.04
Femhdd	12	0.68	1.89	12	0.87	2.40	12	1.04	2.93
Femsam	12	0.54	1.67	10	0.63	1.90	8	1.09	3.41
Femsin	12	0.94	3.13	10	0.81	2.64	8	1.12	**3.80**
Femmax	11	0.43	1.58	10	0.59	2.08	6	0.50	1.79
Femmin	11	0.56	2.36	10	0.45	1.81	6	0.58	2.38
Femlcl	12	2.01	3.21	12	**1.61**	**2.64**	12	1.23	2.01
Femmcl	12	**2.61**	**3.99**	12	1.47	2.28	12	1.51	2.39

Note: Bold indicates the highest value per burning period. Measurement abbreviations can be found in Table 1.

measurements of bones other than the femur. A limitation of the current study is that the bones in the dry category were only allowed to dry for 15 weeks. It is recommended that bones that have been dried for a longer time period be tested to gauge how weathering may further impact the shrinkage of bone after being burned.

Although pig bones are good proxies for human bones, differences still exist, including the ratio of trabecular to cortical bone, the shape, and size of the bone, as well as adaptation of the bone for quadrupedal locomotion [30, 31, 44]. Only one kind of bone was used in the current study and as the composition and structure of each bone are different with different landmarks and contours, an assumption cannot be made that the radius, for instance, would yield the same results as the femur. Furthermore, different bone types have different ratios of trabecular to cortical bone, different shapes, and sizes and therefore, may produce different results [45]. Future studies should include different long bones to gauge the magnitude of change in the different bones, such as the tibia and ulna, which tend to have sharper borders than the femur and as a result may produce different results. Even though the pig femora showed relatively small changes in the post-burning measurements, human femora might present with bigger changes and therefore, future studies should be conducted on human femora that have been exposed to different durations and lower temperature fires, consistent with veldt fires in South Africa.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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