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Biological Profile Estimation Based on Footprints and Shoeprints from *Bracara Augusta Figlinae* (Brick Workshops)

Luís Miguel Marado [1,2,*] and Jorge Ribeiro [1]

1 Unidade de Arqueologia, Lab2PT, Universidade do Minho, 4710-057 Braga, Portugal; jorge.ribeiro7@hotmail.com
2 CIAS, Universidade de Coimbra, 3004-531 Coimbra, Portugal
* Correspondence: luismarado@gmail.com; Tel.: +351-253-601-270

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Abstract: Biological profile estimation is an important task of biological and forensic anthropologists. This includes sex, age, ancestry, and body morphology. In bioarchaeology, the biological profile is useful to analyze paleodemography, secular trends, paleopathology, and genetic processes, for example. Foot dimensions, footprints, and shoeprints can vary according to stature, age, sex, and body weight. The objective is to estimate these parameters in possible *laterarii* (brickworkers) from five footprints and seven shoeprints found in Roman bricks from *Bracara Augusta*. Estimation methods were applied to footprint and shoeprint measurements concerning foot length, foot breath, heel breadth, and length from heel to each finger. Three non-adult individuals were aged 1 to 4/5 years and were between 79.7 and 112.5 cm (±7.7 cm) tall. Five adults were likely female individuals, with statures between 144.2 and 159.9 cm. Methods were selected from samples preferably biologically similar to Portuguese people. This pioneer analysis provides biological insight on the *Bracara Augusta laterarii* and the population inhabiting Northwestern Iberia during Roman times. As a result of taphonomic constraints (cremation, soil acidity, and humidity), coeval osteological materials are hardly recovered, which further increases the relevance of this approach. Future research on methods based on Portuguese foot dimensions is essential.

Keywords: bioarchaeology; anthropometry; stature; sexual dimorphism; age

1. Introduction

Estimating the biological profile is one of the main tasks of biological anthropology, whether in the forensic or archaeological context. The most relevant variables in biological profile estimation are sex, age, body morphology, and ancestry. Typically, profile estimation relies on skeletal materials, mainly the skull (and teeth), *os coxis*, and long bones [1].

The results of biological profile estimates facilitate an approximation to victim identification in forensic contexts [2] and provide an individual profile in archaeological contexts [1]. These individual profiles are important in the interpretation of data collected from an archaeological skeleton, and can be gathered to portray mortuary practices and characterize the paleodemographic and paleoepidemiological profiles of their populations [1].

Aspects of the identity or biological profile of an individual can also be estimated from marks left on a crime scene or on an archaeological site [3]. Handprints and footprints are examples of this. In the archaeological context, these marks can suggest the profile of individuals involved in prehistoric art, for example [4].

Bracara Augusta (Braga, Portugal) was an economically and politically important Roman city in Hispania, founded in the late 1st century BCE or early 1st century CE. It was the center of the *conventus*

bracaraugustanus and, after the Diocletian reforms of the late 3rd century CE, became capital of the province of *Gallaecia* [5,6].

In the present work, footprints and shoeprints from *Bracara Augusta* are analyzed to estimate sex, height, weight, and age (in non-adult individuals). This approach is previously unpublished for Roman contexts, according to the available bibliography. The goals are to (1) estimate biological profiles from the prints identified on bricks and (2) contextualize the individuals (possible *laterarii*, brickmakers) present during brick production in *Bracara Augusta figlinae* (pottery and brick workshops).

2. Sample

Five footprints (one partial) and seven shoeprints (four partial) were identified on six bricks of Roman production from at least five sites in *Bracara Augusta* (from between the 1st and 4th centuries CE, approximately) (Table 1). The bricks were mostly *pedali*, *lydia,* or derived from those types. There was also a vault brick and a *bipedale* derivation. Two bricks came from Colina do Alto da Cividade, likely from the Alto da Cividade Roman baths. The other bricks came from *domus* (Albergue and Cavalariças) and necropolises (Jardim da Misericórdia and Rua 25 de Abril, *Via XVII*).

Table 1. Details of the six *Bracara Augusta* bricks with foot/shoeprints.

Inventory	Brick Type	Print Type (n)	Dimensions (mm)	Context	Chronology
2001.1281	*Pedale*/*lydion*	Foot (3)	238 × 291 × 37	Colina Roman baths (?)	Unknown
2001.1280	*Pedale* derivation; *Cuneati*	Foot (1)	335 × 256 to 274 × 91	Cavalariças *domus*' mosaic	Earlier than 3rd c.
2004.1119	*Lydion* derivation	Foot (1)	404 × 290 × 38	Misericórdia necropolis	Late Antiquity
1995.0065	Vault brick	Sandal (2)	150 × 285 × 41	Colina Roman baths	Earlier than 5th c.
1994.0492	*Pedale*/*lydion*	Sandal (1)	275 × 288 × 55	Albergue *domus*	Later than 1st c.
R25A	*Bipedale* derivation	Sandal (4)	560 × 490 × 50	R. 25 de Abril (*Via XVII*) necropolis	4th c. (under study)

c.: century.

3. Methods

Method selection of the biological profile estimation of the *Bracara Augusta* footprints and shoeprints was challenging. The available prints were heterogeneous, since they were made by bare feet and sandals, and by adult and non-adult individuals. Besides this, there are no known methods of biological profile estimation based on foot, footprint, or shoeprint dimensions developed from samples from Braga or of Portuguese origin. The resulting method selection was also heterogeneous, so as to provide sufficient scope to evaluate all prints and comparative results, when possible (Table 2).

Table 2. Methods used to estimate sex, age, stature, and weight from the footprints and shoeprints from *Bracara Augusta* bricks.

Method	Estimates	Measures	Origin	Size (n)	Age (Years)	Distance to Braga (km)
[7]	Non-adult age	Foot	Boston, Massachussets	532 (F + M)	1 to 18	5060
[8]	Non-adult stature and weight	Foot	Elefsina, Greece	5254 (F + M)	5.5 to 20	2743
[9]	Adult sex	Foot & shoe	Eskisehir University, Turkey	275 F + 294 M	19 to 77	3263
[10]	Adult sex	Footprint & shoe	Ankara, Turkey	253 F + 253 M	17.6 to 82.9	3450
[3]	Adult sex	Footprint	Western Australia	110 F + 90 M	18 to 68	15,134
[11]	Adult stature and weight	Footprint	El Minia University, Egypt	50 M	18 to 25	3837
[12]	Adult stature	Mobile & static footprints	UK	30 F + 31 M	Mean = 40	1500
[13]	Adult stature	Foot	Comenius University, Slovakia	38 F + 33 M	18 to 27	2128
[14]	Adult stature	Shoe (& foot)	Jat Sikhs, Patiala, India	256 M	Adults	7434

F: female individuals; M: male individuals.

Since there are no methods developed from local samples, methods were selected based on their geographical proximity to Braga (as a proxy for biological proximity). Yet, some of the chosen methods were developed from biologically distinct populations and others were based on distant populations that are presumably biologically similar (of European origin), as evidenced in Table 2, because of the lack of available alternatives. The other main criterion for method selection was its calculation(s) from

footprint or shoeprint measurements. Unfortunately, sometimes it was impossible to adhere to this, since such methods are uncommon in the literature (see Table 2).

The dimensions collected from the prints were analyzed using the formulas provided by the selected methods. The only exception was Anderson and colleagues' [7] work, which was used as a reference for the mean dimensions of non-adult feet.

All measurements collected from the prints are described by the note on Table 3, which reports the results for each print. Figure 1 displays the most complete and discernible footprint, from brick 2001.1280; Figure 2 distinguishes the shoeprints from brick R25A. Some measurements could not be collected because the print was incomplete (some fingers were not visible, for example) or because the brick had been fragmented. The shoeprint from brick 1994.0492 presents a fracture in the posteriormost heel that allowed for a tentative reconstitution. Yet, the lengths (either simulated or partial) of this shoeprint were not used in any further calculations.

Table 3. Dimensions of the prints from *Bracara Augusta* bricks (in mm).

Footprint Measurements	**2001.1281 #1**	**2001.1281 #2**	**2001.1281 #3**	**2001.1280**	**2004.1119**		
1	162	106	NO	215	211		
2	NO	NO	NO	209	207		
3	NO	NO	NO	199	202		
4	NO	NO	NO	185	192		
5	NO	NO	NO	175	NO		
6	67	64	58	103	100		
7	53	50	47	85	87		
8	41	NO	NO	51	52		
9	40	28	NO	46	51		
10	42	30	NO	51	53		
Shoeprint measurements	1995.0065 #1	1995.0065 #2	1994.0492	R25A #1	R25A #2	R25A #3	R25A #4
11	NO	NO	238 (245 *)	245	230	NO	NO
12	NO	NO	78	70	61	NO	NO

1: length (posteriormost point of heel to anteriormost point of toe 1); 2: length (posteriormost point of heel to anteriormost point of toe 2); 3: length (posteriormost point of heel to anteriormost point of toe 3); 4: length (posteriormost point of heel to anteriormost point of toe 4); 5: length (posteriormost point of heel to anteriormost point of toe 5); 6: width (medialmost point of hallux to lateralmost point of foot); 7: maximal metatarsophalangeal width; 8: heel width between uppermost lateral points; 9: heel width (medial concavity to lateral tubercle); 10: maximal heel width; 11: maximal shoeprint length; 12: maximal shoeprint width; NO: not observable; and *: reconstructed length.

Figure 1. Detail of footprint present on brick 2001.1280.

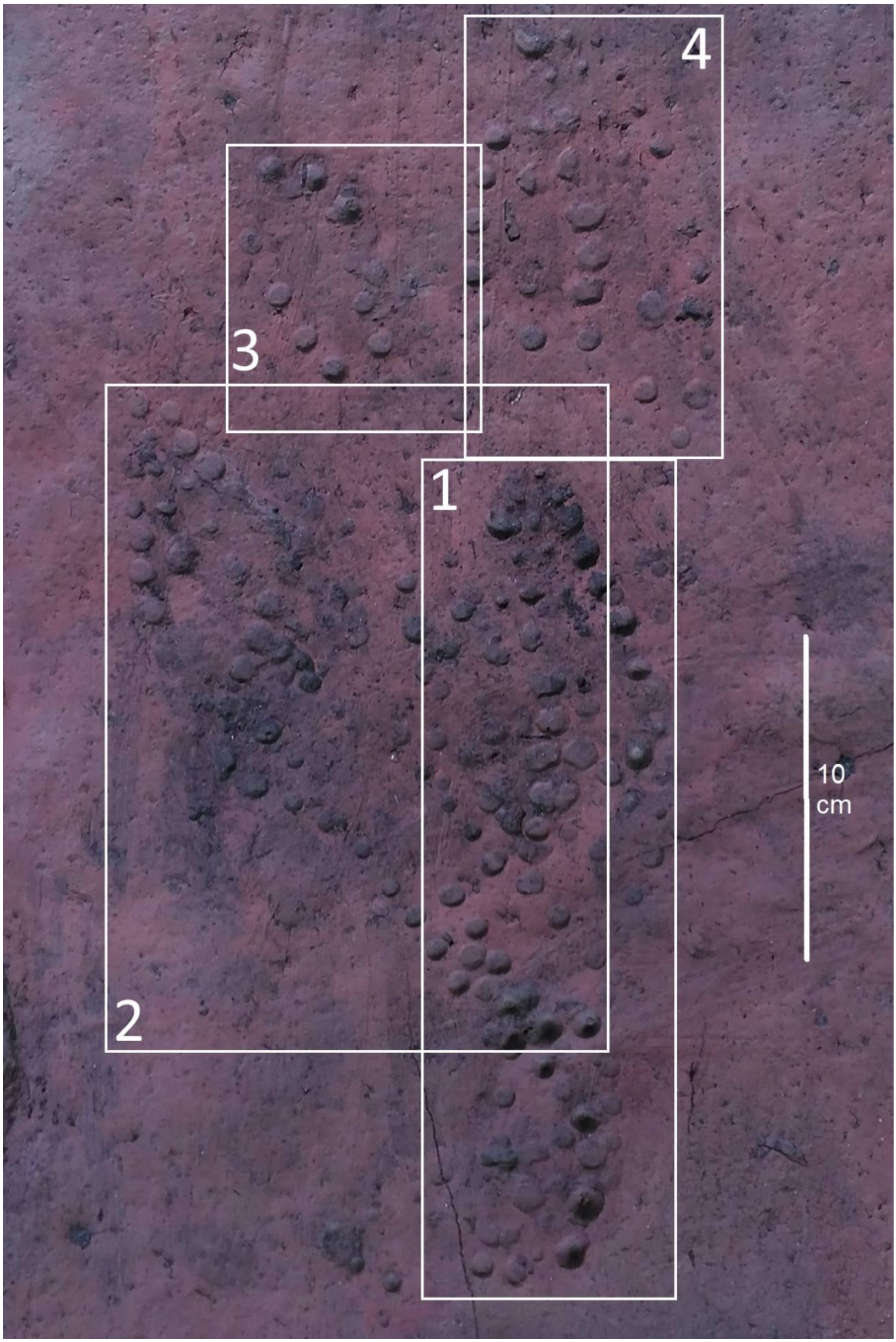

Figure 2. Detail of the shoeprints present on brick R25A.

4. Results

The preserved prints from *Bracara Augusta* bricks allowed for the estimation of sex, age, stature, and weight.

Sex was estimated for five of the twelve prints, since three prints belonged to non-adults and other prints were partial (Table 4). All analyzed prints belonged to females, which was corroborated by several formulae from at least two methods, according to the available measurements.

Table 4. Sex estimation for footprints and shoeprints from *Bracara Augusta*.

Print	Sex	Print Type	Methods
2001.1281 #1	NO (non-adult)	Left foot	-
2001.1281 #2	NO (non-adult)	Left foot	
2001.1281 #3	NO (non-adult)	Left foot	
2001.1280	Female	Right foot	[3,9,10]
2004.1119	Female	Left foot	
1995.0065 #1	NO (partial)	Sandal	-
1995.0065 #2	NO (partial)	Sandal	
1994.0492	Female	Left sandal	[9,10]
R25A #1	Female	Right sandal	
R25A #2	Female	Left sandal	
R25A #3	NO (partial)	Sandal	-
R25A #4	NO (partial)	Sandal	

NO: not observable.

Age was estimated in non-adults based on foot size development during growth [7]. The results are summarized in Table 5. The three prints from brick 2001.1281 were from non-adult individuals, and were likely produced by three different individuals. Footprint 2001.1281 #1 belonged to an individual aged four to five years, while 2001.1281 #2 was likely from an individual around one year of age. Footprint 2001.1281 #3 only preserved the ball of the foot, so its presumed age (one year) was based on measurements 6 and 7, compared between this footprint and 2001.1281 #2.

Table 5. Age estimation for footprint and shoeprints from *Bracara Augusta*.

Print	Age (Years)	Print Type	Reference
2001.1281 #1	4–5	Left foot	[7]
2001.1281 #2	1	Left foot	
2001.1281 #3	1 (?)	Left foot	
2001.1280	Adult	Right foot	
2004.1119	Adult	Left foot	
1995.0065 #1	NO (partial)	Sandal	
1995.0065 #2	NO (partial)	Sandal	
1994.0492	Adult	Left sandal	
R25A #1	Adult	Right sandal	
R25A #2	Adult	Left sandal	
R25A #3	NO (partial)	Sandal	
R25A #4	NO (partial)	Sandal	

NO: not observable.

Again, some prints could not be measured. The remaining prints were most likely made by adult individuals.

Stature could be estimated for seven prints; the results with lower error margin for each method are displayed in Table 6. For footprints 2001.1280 and 2004.1119, three different methods were applied. None of the available methods could be applied on five partial prints.

Table 6. Stature estimation for footprints and shoeprints from *Bracara Augusta*.

Print	Stature (cm)	Print Type	Methods
2001.1281 #1	112.5 ± 7.7	Left foot	[8]
2001.1281 #2	79.7 ± 7.7	Left foot	
2001.1281 #3	NO (partial)	Left foot	-
2001.1280	157.7 ± 3.5	Right foot	[11]
	159.9 ± 4.2		[12]
	155.7 ± 4.7		[13]
2004.1119	156.9 ± 3.6	Left foot	[11]
	155.6 ± 5.2		[12]
	153.3 ± 4.8		[13]
1995.0065 #1	NO (partial)	Sandal	-
1995.0065 #2	NO (partial)	Sandal	
1994.0492	155.5 ± 4.8	Left sandal	[14]
R25A #1	155.1 ± 3.6	Right sandal	
R25A #2	144.2 ± 3.9	Left sandal	
R25A #3	NO (partial)	Sandal	-
R25A #4	NO (partial)	Sandal	

NO: not observable.

Non-adult individuals provided different estimated statures, according to their different estimated growth stage, of 112.5 cm (2001.1281 #1) and 79.7 cm (2001.1281 #2). The adult (and estimated female) individuals had likely statures between 144.2 cm (±3.9 cm) and 159.9 cm (±4.2 cm). The average of the estimated adult statures is 154.3 cm (calculated using the tallest estimate when more than one is available).

Weight estimation methods were available for footprints only (Table 7). The weight of partial footprint 2001.1281 #3 could not be estimated. The estimation of the neighboring print of similar size (2001.1281 #2) was negative, and thus incorrect, because of methodological issues discussed below. The weight of footprint 2001.1281 #1 (an estimated four to five year old individual) was estimated at 14.1 kg (±9.9 kg). Adult footprints 2001.1280 and 2004.1119 provided high weight estimations between approximately 87.4 and 90.3 kg.

Table 7. Weight estimation for footprints from *Bracara Augusta*.

Footprint	Weight (kg)	Footprint Type	Methods
2001.1281 #1	14.1 ± 9.9	Left foot	[8]
2001.1281 #2	−15.1 ± 9.9	Left foot	
2001.1281 #3	NO (partial)	Left foot	-
2001.1280	87.4 ± 4.8	Right foot	[11]
2004.1119	90.3 ± 4.1	Left foot	

NO: not observable.

5. Discussion

Foot and footprint dimensions present forensic relevance in personal identification [3,8]. In the archaeological context, their bearing cannot be underestimated, since footprints (and shoeprints) are also important evidence of the presence and biological traits of past human populations. Footprints have previously provided biological profile information on hominins from Laetoli, Tanzania (3 My BP; [15]); Ileret, Kenya (1.5 My BP; [16]); and Happisburgh, United Kingdom (1 My BP; [17]). More recent prehistoric human footprints were also studied in the cave of

Pech-Merle, France [4]; in Willandra Lakes, Australia (13 to 23 ky BP; [18]); in Acahualinca, Nicaragua (4th millennium BCE; [19]); and in Jaguar Cave, Tennessee (3rd millennium BCE; [20]). However, the present work seems to be innovative in systematically estimating biological profile variables from footprints and shoeprints of Roman archaeological context. The authors could not find any other such examples.

Sex could only be estimated in 41.7% of the available prints (Table 4). The five evaluated prints likely corresponded to female individuals. This result suggests women were active in brick (and ceramics) production in Imperial and Late Roman *Bracara Augusta*. The presence of women in *figlinae* has been documented previously. An engraved *tegula* from *Samnium* (Pietrabbondante, Italy; 1st century CE) portrays female work in a *figlina* [21].

Since the methods used for sexual diagnosis were not developed from the same population, it is legitimate to question them. However, considering the use of several methods, their application to five different prints, and the existence of parallels, it seems probable that female individuals were working at *Bracara Augusta figlinae*. In fact, sex estimation from foot dimensions or their derivations (footprint and shoeprint dimensions) is promising, since feet present relatively high sexual dimorphism. Women have smaller feet than men, both absolutely and proportionately [22]. This difference may be provided by an evolutionary advantage, since smaller feet may make female individuals seem younger, nulliparous, and more attractive [22].

Another distinct occurrence found on a footprint also supports its sexual diagnosis: the footprint of brick 2004.1119 lacks a fifth toe print (Figure 3). Female individuals may not press the fifth toe while walking, since weight is distributed posteriorly by the pelvic girdle to the femur in women (and anteriorly in men). This posterior weight distribution can lead to reduced pressure on the fifth toe [12].

A study on foot growth between the ages of 1 and 18 was used as a reference [7] to estimate the age of the small footprints on brick 2001.1281. Footprint 2001.1281 #1 was estimated as belonging to a child of approximately four to five years of age, which was corroborated by other studies on foot growth by Davenport [23] and Meredith [24]. Footprint 2001.1281 #2 belonged to a child around one year of age, which was again corroborated by Meredith [24]. The five remaining complete prints were made by adults, according to their dimensions, so 62.5% of the complete prints were adult (Table 5).

In the *Cavella Atrebatum villa* (Southern England), more than 500 excavated bricks and *tegulae* portrayed children's footprints, showing at least their presence in the drying areas of local *figlinae* [25]. Bricks and roof tiles found in Gallia preserved some finger marks, footprints, and shoeprints too small to belong to adult males [26]. Some marks underline the presence of women in *figlinae* again, while others are likely to have been created by children. Any eventual child laborers could be employed in minor tasks, not very physically demanding tasks, such as transporting bricks or *tegulae* from the molding to the drying areas [26]. Alternatively, children could have crossed the drying areas and stepped on bricks accidentally while playing. The present results and the above parallels show the presence of children in such areas, and allow for the possibility of child laborers in *Bracara Augusta figlinae*.

Stature was estimated for all complete prints (Table 6). Stature estimation in non-adults is relatively reliable, since foot length represents between 15% and 16% of the stature throughout growth [7]. The estimates for both complete non-adult prints were within this range.

Stature estimation for female individuals provided results between 144.2 $\pm$ 3.9 cm and 159.9 $\pm$ 4.2 cm. The five *Bracara Augusta* women whose footprints and shoeprints were analyzed were 154.3 cm tall on average. This result is slightly higher than that found by Cardoso & Gomes [27] for the Roman period in Portugal. The average height found is 3.4 cm shorter than the average female stature of Portuguese women born in 1950 [28]. This difference may show the result of a secular trend of stature increase, permitted by enhanced access to nutrition and health from Roman *Bracara Augusta* to Contemporary Portugal.

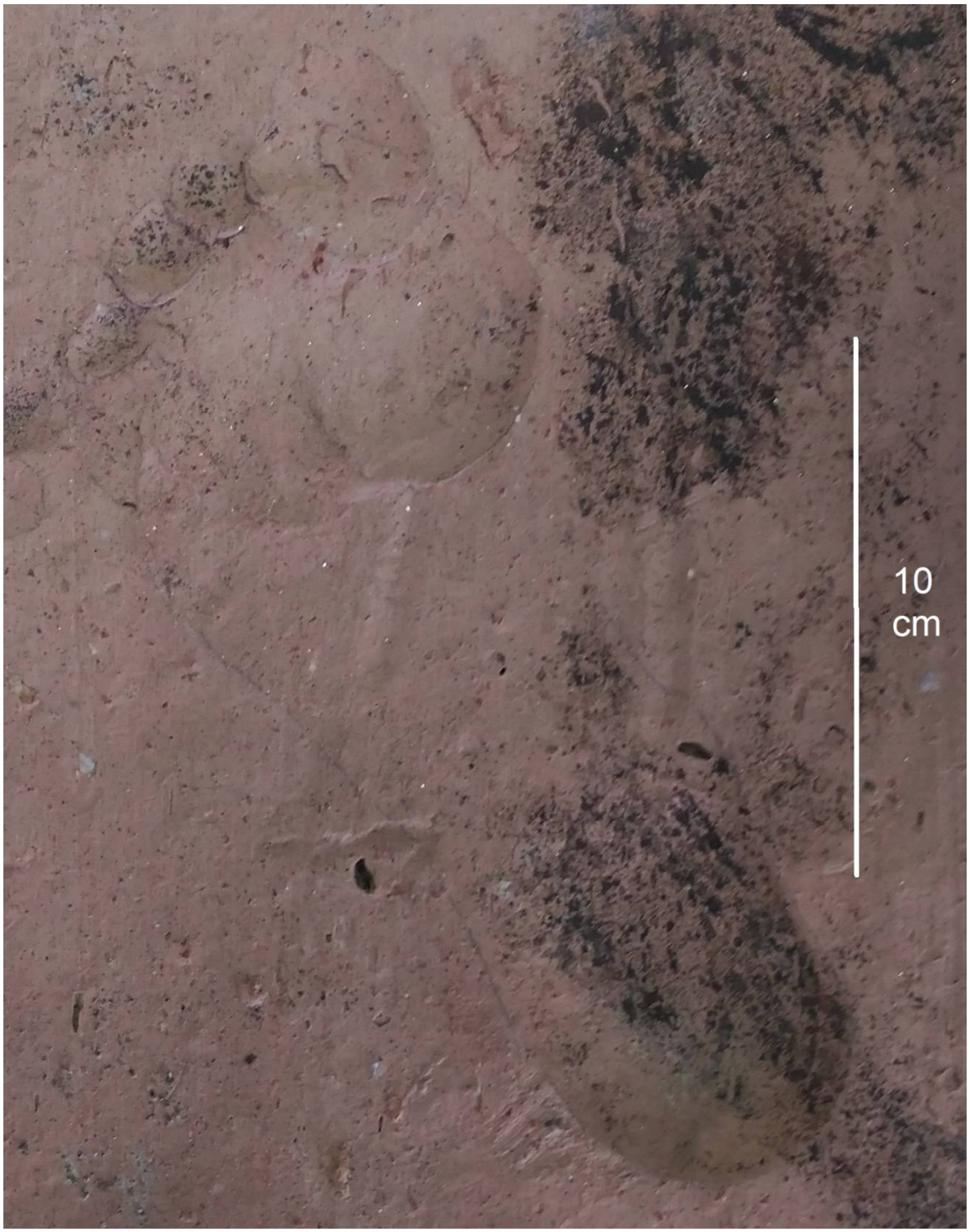

Figure 3. Detail of footprint present on brick 2004.1119.

Weight estimations were found for four complete footprints, including one negative estimate and two very high estimates (Table 7). The negative estimate for non-adult footprint 2001.128 #2 was likely caused by methodological issues. The equation used to calculate the estimated weight [8] was developed from children and young adults between the ages of 5.5 and 20 years, while this individual is likely one year old. The weight estimates for adult individuals were likely biased by different methodological issues. The equation used was developed exclusively from male individuals;

their Egyptian origin [11] also makes them likely to greatly differ from *Bracara Augusta* individuals, both biologically and environmentally. In sum, these estimates are unreliable, and thus will not be further analyzed.

Despite their value, footprints (and shoeprints) should be carefully interpreted as sources for biological profile estimation. Foot length and footprint length are not equivalent [17]. According to Atamturk [10], footprints are less accurate than foot dimensions, and especially shoe dimensions and shoe size, at estimating sex, for example. This is because footprints vary in dimensions according to foot position on the support, weight distribution on the foot, and support material [20]. For example, shallow footprints may underestimate foot length because they do not preserve the impression of the tip of the longest toe (*acropodion*) or of the heel (*pternion*) [18]. Other issues may also limit footprint dimensions when compared with feet. For example, some methods developed to estimate biological profile traits from the foot depend on dimensions like navicular or malleolar heights (e.g., [29]), which are not obtainable from footprints.

Estimating biological profile variables of a population using methods developed from other populations is not reliable, because of environmental and genetic factors [9,11]. Relying on contemporaneous samples from developed countries to estimate biological traits can also be problematic, because of foot wear. Wearing shoes affects the growth and biomechanics of feet [16,22].

These limitations, while making the presented results preliminary in nature, do not preclude their publication or diminish the relevance of this study. The existence of parallels to the presence of women laborers and of children in *figlinae* validates their identification in *Bracara Augusta*. The estimated statures of both children and adults are reasonable, considering their age and known contemporary stature averages, as well as probable secular trends, previously identified in past Portuguese populations [27,28].

The recently published paired male footprints from the Neolithic site of Barcın Höyük (6400 BCE) present particular characteristics suggesting these prints were of a ritual nature [30]. Namely, the left print is located over the presumed ritual deposition of a goat's head and both prints are located near the entrance of the small structure in which they were found, the floor of which had been renewed immediately prior [30]. Interpreting the intentions of the diverse footprints from the present study, which hail from diverse sites and periods, is speculative. These prints could have been produced accidentally, to identify their author, or even in a ritual capacity; these interpretations cannot be denied or proven from the available contextual information or parallels.

6. Conclusions

The footprints and shoeprints of bricks found in diverse contexts from *Bracara Augusta*, an important Roman city, provide relevant, if preliminary, results.

The documented evidence suggests women were working in *figlinae*, either directly in brick production or around this activity. On the other hand, young children were also present in these workshops. Their function, either as workers or as trespassers in the space where bricks were dried, is unknown.

The adult women were between about 145 cm and 160 cm tall. The average stature is 154.3 cm, slightly below mid-20th century Portuguese female averages. Therefore, there is a secular trend in stature increase that underlines the likely improvements in economic, nutritional, and sanitary conditions in the last 15 to 20 centuries. Weight estimation is clearly unreliable, and should therefore be ignored.

Given the likely biological affinity between current Braga and Northwest Iberian individuals and the populations preceding them, future research should promote the development of biological profile methodology based on hand, foot, footprint, and shoeprint dimensions of local individuals. Such methods would be applicable in forensic contexts and would allow for more reliable analysis of local prints and other archaeological evidence (shoe remains, for example). Bone scarcely survives the

taphonomic conditions typical of the region, which enhances the relevance of approaches relying on alternative evidence.

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