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Sample-specific odontometric sex estimation: A method with potential application to burned remains

Marcia Filipa Gouveia *, Inês Oliveira Santos, Ana Luísa Santos, David Gonçalves

Centro de Investigação em Antropologia e Saúde (CIAS), Department of Life Sciences, University of Coimbra, Portugal

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ABSTRACT

Metric features are often the only preserved sexually dimorphic features to allow sex estimation in burned human remains, but this is complicated by heat-induced dimensional changes. The potential of odontometry for sex estimation was investigated. A sample of permanent lower second pre-molars from 20 males and 20 females was experimentally burned at 900 °C to assess heat-induced changes in the sexual dimorphism of seven dimensions of the cementum-enamel junction and the root. Four of them, cementum-enamel junction perimeter; mesiodistal, buccolingual and perimeter at the mid-root level, were investigated for the first time. Also, five measurements combining some of the isolated standard measurements were investigated. Additionally, 10 permanent upper central incisors and 10 permanent lower first molars were experimentally burned at 400 °C and 700 ° C to document heat-induced dimensional changes and serve as comparison with the 900 °C sample. Results showed that most of the standard measurements, although presenting significant sex differences, were not reliable enough to allow for correct sex classifications close to 100% both before and after the burning. Nonetheless, the perimeter at the cementum-enamel junction and the combined measurements of the mesiodistal and buccolingual diameters, at the same level, were quite promising in the post-burning analysis with correct sex classifications above 80%. At 900 °C, females were slightly more affected by shrinkage in this measure than males thus artificially increasing sexual dimorphism after burning. Therefore, and although additional research is needed, this feature was not discarded as having potential for skeletal sex estimation.

1. Introduction

Burned human skeletal remains are frequently found in both archaeological and forensic contexts, as the result of cremation practices, accidents, foul play or natural disasters [1]. Heat can induce several changes in skeletal tissues but these may nonetheless provide us with important information regarding the circumstances of death and the combustion conditions [1–3]. For example, heat-induced changes can be used to infer the approximate maximum temperature [4–6]. Regrettably, the usefulness of burned skeletal remains for the estimation of sex is not as simple. Heat-induced changes and fragmentation often prevent sex estimation based on the most sexually dimorphic features such as the ones from the pelvis [7,8,72]. Therefore, alternative methods must be investigated. Teeth are very important in any bioanthropological analysis due to their fair resistance to physical and chemical insults [9–20]. Therefore, their potential for sex estimation based on burned remains is clearly worth of investigation.

Metric sex estimation of burned skeletal remains can basically be achieved in four different ways. First, a shrinkage correction factor may be used according to the extent of heat-induced change which is usually predicted by resorting to the interpretation of chromatic changes since these are approximately correlated to the maximum temperature at which bones have been subjected to [3,5,21–24]. For example, Buikstra and Swegle [25] proposed a 10% shrinkage correction factor for calcined bones. Second, again based mainly on chromatic changes, the interval of the measurement can be enlarged in function of the predictable heat-induced dimensional change affecting a bone or tooth [11]. The upper bound is calculated assuming that the bone was affected by maximum possible shrinkage while the lower bound is calculated assuming that the bone was affected by maximum possible expansion [26]. Both correction factors are documented in the literature according to bone and burning intensity (e.g. [4]). Third, metric references obtained from samples of burned skeletal remains can be applied directly to bones burned at similar intensities [27–29,30–33]. Finally, sample-specific metric references can be obtained when large samples composed of remains burned at similar burning intensities are available. All approaches are somewhat problematic. For example, the enlargement of the estimation confidence interval, may be quite large and have low precision. Also, heat-induced dimensional changes are too variable thus taking out some of the reliability of the remaining approaches [34]. Nonetheless, metric analysis is not without value. Besides allowing

* Corresponding author.
E-mail address: uc2010132835@student.uc.pt (M.F. Gouveia).

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for univariate sex estimation, an aspect extremely useful in usually very fragmented burned remains that dispenses a more systemic analysis of the skeleton, it allows to identify very masculine features. In other words, when very large features are found despite heat-induced shrinkage, a male classification can be more confidently attributed to the individual.

Odontometry has been demonstrated to provide reliable sex estimation, particularly in poorly preserved and highly fragmented skeletal remains, as is often the case for assemblages comprising burned skeletal remains [18,35–42]. In the vast majority of cases, the standard measurements used for that purpose are the mesiodistal (MD) and the buccolingual (BL) crown diameters of permanent teeth. Several authors have demonstrated that these dimensions have significant sexual dimorphism within a population [40,43–53]. However, similar investigations regarding the dental roots have been much less frequent [52,54] which is somewhat surprising given that crown measurements present obvious problems. Slight crown rotations can lead to considerable inter- and intra-observation variation [55,56]. In addition, tooth wear may prevent measurements, especially the MD diameter [52,56–58]. Dental calculus can also prevent measurements in both the crown and cement-enamel junction, but rarely so at the level of the root [56]. In the case of burned teeth, crowns present another problem. They tend to preserve very poorly. It has been reported that, when subjected to high temperatures, fractures occur on dental crowns due to the increase of pressure, caused by water evaporation, between the enamel and the dentine [11,21,59,60]. Dental roots have no enamel and contain less water thus leading in turn to less pressure and less fractures [11,21,52,59,60,85]. Recently, Hillson et al. [56] proposed alternative standards measurements based on the cementum-enamel junction (CEJ) to overcome such problems and Tuttösí and Cardoso [61] demonstrated their potential for sex estimation. These, along with those from the root, could prove useful for sex estimation of burned skeletal remains but research is needed to assess this.

The problem of using odontometry on burned teeth is that they may have been affected by heat-induced dimensional changes which can be particularly large in high temperature burnings [4,21,62]. That is why this investigation focused not only on burned teeth but also on their pre-burned versions. Although some of the standard measurements used in this research have been investigated previously, the true value for sex estimation of the new standard measurements here proposed had to be assessed prior to the experimental burning. In addition, heat-induced dimensional changes were documented to determine how impeditive of sex estimation they really are. As for heat-induced warping, apparently this is not a common problem in teeth according to Sandholzer et al. [63], contrary to what has been documented for bones [4]. Therefore, warping does not seem to interfere with odontometric analysis of burned teeth.

In some contexts, large assemblages of burned skeletal remains from multiple individuals need to be analysed. For example, that is the case involving mass disasters. In such situations, it is possible that the remains have been subjected to similar heat conditions. It would then be useful to evaluate the potential of sample-specific methods for sex estimation in these situations. Therefore, a secondary objective was to test this kind of procedure in a sample burned at similar conditions. If proven useful, sample-specific methods may be one practical way of solving the problem that heat-induced dimensional changes pose to metric sex estimation. Compared with the other three approaches, the sample-specific one has the advantage of automatically taking into consideration the extent of heat-induced dimensional changes affecting the sample instead of trying to estimate it based on references obtained from unrelated researches [72]. It does so because it generates methods internally consistent with the sexual dimorphism present in the sample [61].

Measurements from the CEJ and the root have been investigated in this paper. One disadvantage of using these features is that they are harder to identify due to the frequent lack of the crown. However, if demonstrated to be reliable, an approach based on those measurements would turn out in several important benefits. First, dental roots resist better to high temperatures than dental crowns [19,52,64] so they are more often recovered in good condition. Second, root measurements are less often affected by wear. Third, CEJ and root measurements are allegedly more objective than crown measurements and other non-metric techniques based on non-dental features of the skeleton [37,52]. Four, dental sex estimation can be applied to non-adult individuals since several teeth are formed before adulthood [52,65,66]. Given all these benefits, the approach here proposed will expectantly contribute for the sex estimation of skeletal remains, especially those that are very incomplete, fragmented and affected by heat-induced changes.

The objective of this paper is to evaluate the reliability of dental standard measurements, some already established and others here proposed, for sex estimation of burned human skeletal remains. For that purpose, the sexual dimorphism and the heat-induced changes present in a sample of experimentally burned teeth from individuals of known sex and age was investigated to better assess their potential for sex estimation. Ultimately, the goal was to detect if any tooth dimension was more successful at withstanding heat-induced dimensional changes.

2. Material and methods

Sixty teeth, 20 permanent lower second pre-molars from each sex and 10 permanent upper central incisors and 10 permanent lower first molars, extracted in dental offices were donated to the University of Coimbra after informed consent of the patients (Ref. 108-CE-2014). Sex, age and nationality of the individuals were known. Additionally, the cause of dental extraction and associated oral pathologies were recorded. Teeth were then cleaned and removed from soft tissues. Sample selection focused on (1) the most represented tooth-types which were the upper central incisors, the upper first molars and the second lower pre-molars (in the specific case of the sex estimation investigation, the second lower pre-molar was used due to its previously reported high level of sexual dimorphism [52,67,77]; the other two kinds of teeth were used to investigate heat-induced dimensional changes); (2)

Table 1
Description of standard measurements investigated in this research.

Standard measurement	Abbreviation	Description	Reference
Mesiodistal diameter (CEJ level)	CEJ-MD	Distance between two parallel lines, perpendicular to the mesiodistal axis and tangential to the most mesial and most distal parts of the cement-enamel junction	Hillson et al. [56: 416]
Buccolingual diameter (CEJ level)	CEJ-BL	Greatest distance between the buccal and lingual surfaces of the tooth at the cement-enamel junction	Hillson et al. [56: 416]
Perimeter (CEJ level)	CEJ-P	Tooth contour at the CEJ level	This study
Root height	RH	Measured from of cement-enamel junction to the root apex	Garn et al. [54: 636]
Perimeter (MRH level)	MRH-P	Tooth contour at the mid-root height	This study
Mesiodistal diameter (MRH level)	MRH-MD	Distance between two parallel lines, perpendicular to the mesiodistal axis and tangential to the most mesial and most distal parts at the mid-root level	This study
Buccolingual diameter (MRH level)	MRH-BL	Greatest distance between the buccal and lingual surfaces of the tooth at the mid-root level	This study