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ORIGINAL ARTICLE

Test of the lateral angle method of sex estimation on Anglo-Saxon and medieval archaeological populations with genetically estimated sex

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Abstract

The lateral angle method of sex estimation is tested on an archaeological population with genetic sex estimates. Casts of the internal auditory canal were made using a quick drying impression material on 90 individuals (76 adults and 14 nonadults) from Anglo-Saxon and Medieval Cambridgeshire. The anterior and posterior angles of the internal auditory canal were measured, and the relationship of the angle to genetic sex was tested. The posterior angle failed intra-observer error tests, and only the anterior angle could be analysed. Using the previously published sectioning point for unburnt remains (45°), the method did not adequately distinguish between the sexes. Furthermore, the difference between male and female was insufficient to create population-specific discriminant functions. The anterior angle does not meet the requirements for an osteological method of sex estimation, exhibiting no statistical correlation with genetic sex in this population.

KEYWORDS

ancient DNA, genetic sex, internal auditory canal, intraobserver reliability, lateral angle, method accuracy, sex estimation

INTRODUCTION

Sex estimation of individuals from their skeletal remains is an essential component of bioarchaeological analyses, enabling demographic profiles to be constructed for individuals and populations. Numerous anatomical regions demonstrate a high degree of sexual dimorphism, mostly on the cranium, mandible, and *ossa coxae* (Acsádi & Nemeskéri, 1970; Brůžek et al., 2017; Buikstra & Ubelaker, 1994; Ferembach et al., 1980; Phenice, 1969). However, the utility and accuracy of many sex estimation methods is undermined when skeletal remains are not well-preserved (Inskip et al., 2019; Kjellström, 2004), for example when the cranium and *ossa coxae* are highly fragmented or when circumstances such as modern disasters or past funerary practices have resulted in commingled and fragmented remains from which distinct individuals cannot be identified. In such cases, alternative methods for sex estimation have been sought and tested to enable greater potential for constructing individual demographic profiles despite their fragmentation.

The petrous portion of the temporal bone is a robust intracranial element that is usually well-preserved. The lateral angle (LA) sex estimation method, involving the measurement of the anterior and/or posterior angle of the internal auditory canal (IAC) appears to present a good option for sex estimation in cases of fragmented or poorly preserved collections (Norén et al., 2005). However, it is still unclear how accurate the method is, as there have been conflicting reports in the literature (e.g., El-Sherbeney et al., 2012; Morgan et al., 2013). The aim of this study is to test the reliability and accuracy of the anterior and posterior angles of the IAC in relation to genetic sex. Casts of the IAC were made on individuals from several archaeological sites from Cambridgeshire dating to the Anglo-Saxon and Medieval periods, for which genetic sex had previously been estimated. Repeated measurements were taken on the anterior and posterior angles of the IAC to test intraobserver error and the reliability of the method. The mean LA between sexes and between adults and nonadults was compared to assess the degree of dimorphism. A previously published sectioning point (45°) was used to estimate 'expected sex' and to test the accuracy of the method. This work constitutes the first examination of this method on an archaeological population with genetic sex estimates and therefore offers a better test of the method's applicability to estimate the sex of archaeological human remains.

The angle has been measured inconsistently in previous studies, providing a challenge to the replicability of the method (Table 1). In Norén et al. (2005, p. 320), the anterior angle is measured and described as the 'lateral angle'; a measurement in the same location in Graw et al. (2005, p. 115) is denoted the medial angle. As commented on by Benson (2014), several studies have utilised the posterior LA, formed by the meeting of the posterior wall of the IAC and the posterior 'lip' of the internal aspect of the petrous portion. Subsequent tests of the method on the posterior angle, utilising the sectioning point determined through analysis of the anterior angle, are therefore flawed. The different locations of the anterior and posterior angles are illustrated in Figure 1.

Anatomy of the IAC

The LA is the acute angle at which the lateral wall of the internal auditory (or acoustic) canal (*meatus acusticus internus*) opens up to the posterior wall of the petrous portion of the temporal bone (*facies posterior*). The IAC is located approximately in the mid region of the posterior wall of the petrous (Figure 2). The opening is usually smooth and rounded, although the rugosity of the posterior wall varies between individuals, particularly in the regions of the subarcuate fossa (*fossa subarcuata*) and the superior petrosal sulcus. The IAC is short (usually <1 cm) and narrows laterally at the fundus, where it splits into canals for nerve transmission, including the

TABLE 1 Angle measured, method used and reported accuracy rates in previous studies of the lateral angle (LA) method.

Study	Angle measured	Method	Accuracy rate(s)
Norén et al. (2005)	Anterior	Casts	83.2%
Graw et al. (2005)	Both	Casts	Discriminant functions produced 62.5%–73.3% accuracy rates
Akansel et al. (2008)	Anterior	CT scans	Large
Wendell Todd et al. (2010)	Posterior	Casts	None given
Benson (2014)	Both	CT scans	Anterior: 40%–72.5%; posterior: 40%–68.6% (depending on age group)
Gonçalves et al. (2011)	Posterior	Casts	62.9% (using sample-specific sectioning point of 44°)
El-Sherbeney et al. (2012)	Anterior	CT scans	80.78%
Masotti et al. (2013)	Posterior	Casts	58.1%
Morgan et al. (2013)	Anterior	CT scans	62.3% (with logistic regression, 55.8%)
Gonçalves et al. (2015)	Posterior	Casts	No significant difference between male and female mean angles ($p = 0.860$)
Duquesnel Mana et al. (2016)	Anterior	CT scans	No significant difference between male and female mean angles ($p = 0.063$)

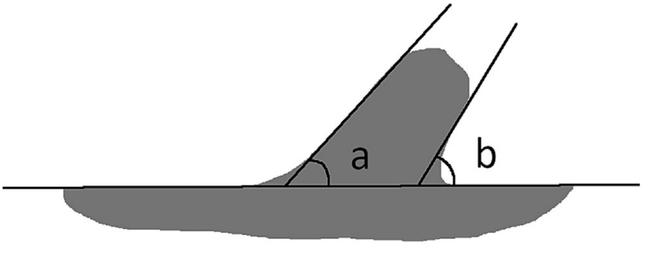

FIGURE 1 Illustration of a cast of the IAC, (a) anterior angle; (b) posterior angle. *Source*: Adapted from Gonçalves et al., p. 1184.

facial and vestibulocochlear nerves as well as the vestibular ganglion (transmitting the superior and inferior vestibular nerves and the posterior semicircular canal). Research has suggested that the petrous bone reaches approximately 46% of full size after 2 years of age (Schmid & Dahm, 1977). It is suggested that dimorphism in the LA, including in nonadults from >6 years of age, is caused by dimorphism in the occipital and temporal bones as a result of increased rugosity of muscle attachments in men (Norén et al., 2005, p. 319).

Development of the LA method

Wahl (1981) originally reported that the LA was sexually dimorphic, and both Ahlbrecht (1997) and Graw and Wahl (2003) later reported a statistically significant sectioning point, with women exhibiting ≥45° LA and men <45°. Norén et al. (2005) applied the method to a forensic sample of 173 petrous bones (60 paired petrous bones and 53 left side petrous bones from persons of known sex) and an archaeological sample from a Viking Age site and an early Medieval site comprising 60 unpaired petrous bones of either the left or right side, all from adults

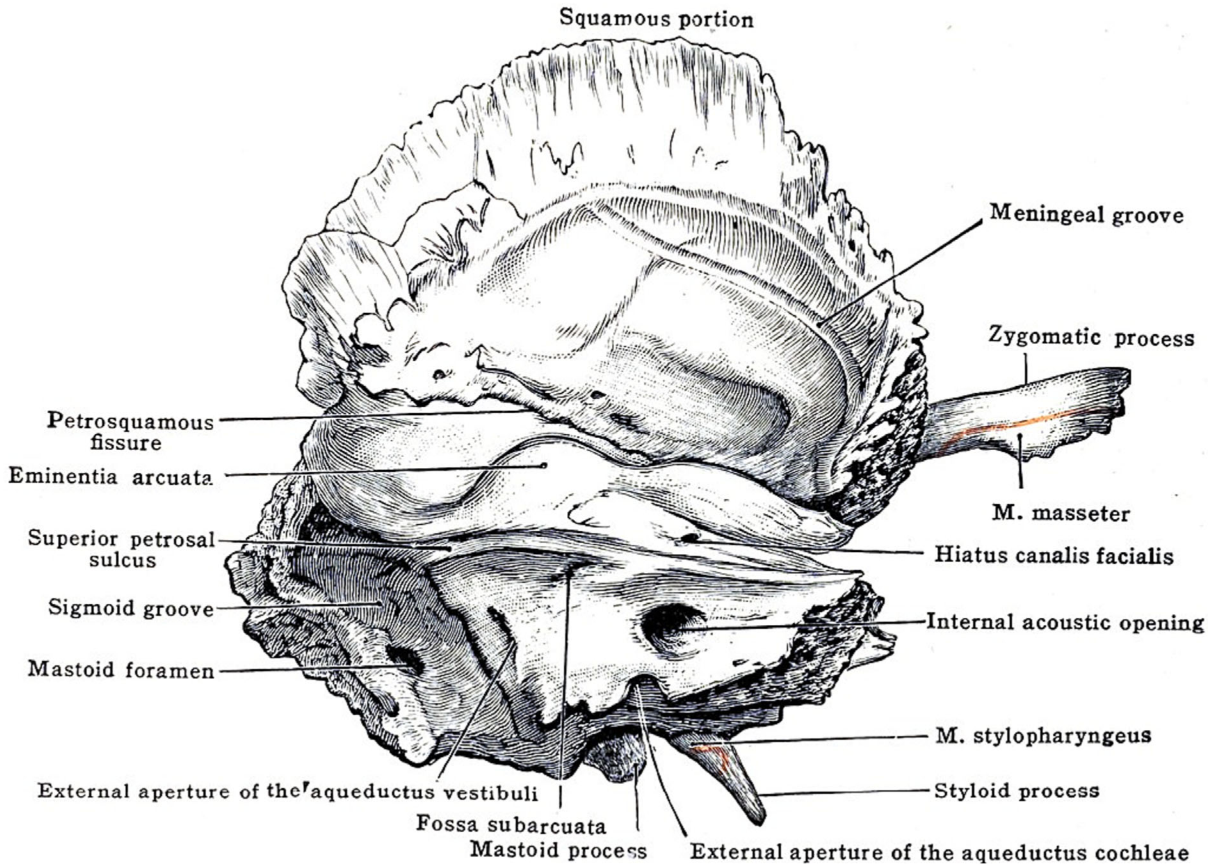

FIGURE 2 Annotated illustration identifying anatomical landmarks on the medial/internal aspect of a left temporal bone. *Source*: Adapted from Morris (1933, p. 150) (Wikimedia Commons).

(>19 years). The distribution of sex was almost equal in all groups: the forensic sample of paired bones comprised 31 women and 29 men; the forensic sample of unpaired bones, 48 women and 65 men; and 26 women and 34 men in the archaeological sample. The 45° sectioning point was tested on unilateral and bilateral forensic samples, and the total forensic sample was analysed to test the accuracy of the method. A mean difference in angle size between male and female individuals of 8.9° was identified in the unilateral sample, and the forensic sample supported the 45° sectioning point (Norén et al., 2005, p. 321). When applied to the archaeological sample, sex as estimated by the LA more often agreed with sex estimated from the *ossa coxae* (86.6%) than the cranium (79.6%), and men were more often correctly sexed (91.2%) than women (76.2%), but a high correspondence overall was found between osteological sex and LA size (Norén et al., 2005, p. 321). Given the apparent high accuracy of the method, and the rapid development of the petrous portion in infancy, it was suggested that this method may be applicable to nonadults (Norén et al., 2005, p. 319). Following this study, Graw et al. (2005) moulded the IAC on a substantial forensic sample ($n = 410$) and measured both the anterior and posterior angles. The LA was more dimorphic overall, but accuracy was low across both metrics, with 66.3% correct sex estimations for women and 68.5% for men (Graw et al., 2005).

Recent tests of the LA method

Tests of the discriminatory power of the LA have continued on diverse populations, often on modern collections of individuals of known sex or on living patients, and have also explored its accuracy in nonadults (El-Sherbeney et al., 2012; Gonçalves et al., 2011). The first investigation of the LA using CT scans ($n = 92$) showed that measurements overlapped between the sexes among both nonadults and adults, such that no sectioning point could be identified (Akansel et al., 2008). Instead, Akansel et al. (2008, 95) stated that angles ≤35° most often support a determination of male, and angles ≥60° were most often observed in women. Gonçalves et al. (2011) investigated the dimorphism of the IAC in nonadults on a Portuguese collection of 47 individuals up to 15 years of age, calculating a sample-specific sectioning point of 44°. Using CT scans ($n = 276$), Benson (2014) found that the LA did not differ significantly between the sexes among nonadults (6–19 years) or young adults (20–24 years). With both sexes combined and the sample divided into age groups, the method did not exceed 68.6% accuracy (for the 6–10 year age group) (Benson, 2014). El-Sherbeney et al. (2012) found a significant difference in the anterior LA between Egyptian female and male adults ($n = 120$), calculating a sectioning point of 37.187°, although there was no significant difference in LA size among nonadults. In contrast, Morgan et al. (2013) found no significant difference in the mean angle between sexes and did not recommend the method for forensic or archaeological use. It is therefore important to investigate whether the IAC itself lacks sexual dimorphism or whether its relationship to sex differs on a population-specific basis.

Taking into account the numerous tests of the LA method that had failed to reach the published accuracy levels of earlier studies, Duquesnel Mana et al. (2016) carried out an independent study using a sample of 102 forensic CT scans. From these, they found only a 2.82° difference in the mean anterior angle between women and men, and no significant difference between the sexes. Geometric morphometric analysis of shape variation from 12 landmarks on the basicranium showed a substantial overlap in shape between the sexes, with the greatest dimorphism present in the region of the transverse and sigmoid sinuses (on the endocranial posterior aspect of the temporal bone) and the internal occipital protuberance (p. 94). Their results verify numerous studies that have found the LA method to be inaccurate because of limited sexual dimorphism in the size and shape of the base of the cranium.

Yet, the LA method has continued to be tested on recent populations, specifically of cremated individuals (Masotti et al., 2013, 2019). On a cremated sample of modern Italian adults of known sex ($n = 155$), the LA was found to be more acute and, although the mean angle differed between the sexes, the standard deviation was large and accuracy was low (58.1% overall) (Masotti et al., 2013). An expanded cremated dataset ($n = 322$) was later used to identify a cremation-specific sectioning point of 41° (Masotti et al., 2019). This increased the overall accuracy of the method (63.2%), although it is still not recommended for use on individuals >70 years of age (Masotti et al., 2019). Furthermore, Gonçalves et al. (2015) found that the LA measurement differed by side in a cremated sample, sometimes by 25°+, likely as a result of the effects of differential burning. The method has recently been applied to prehistoric cremated remains from Britain, including the Stonehenge Aubrey Hole cremations, using the sectioning point for unburnt remains (Willis, 2019; Willis et al., 2016). As these works show, however, there are heat-related changes in the LA caused by shrinking and warping, which necessitate its use alongside other sexually dimorphic characteristics to estimate sex in cremated remains (Depierre, 2022; Masotti et al., 2013). Because there is not strong sexual dimorphism in the petrous portion of the temporal bone in living individuals or unburnt human remains (Duquesnel Mana et al., 2016), significant doubt is cast upon the relevance and accuracy of the LA as a method of sex determination in burnt remains.

MATERIALS

As part of the ‘After the Plague: Health and History in Medieval Cambridge’ Project, petrous portions and dentition of 318 adult and 52 nonadult individuals from Anglo-Saxon and Medieval sites located in Cambridgeshire were subject to aDNA analysis, the results of which permitted the genetic estimation of sex (see Inskip et al., 2019 for methods). Of these, the petrous portion of the temporal bone was accessible, with a complete IAC and posterior wall, for a total of 90 individuals (Table 2). Intact, or mostly intact, crania were excluded, as the IAC was not accessible for casting through the foramen magnum. As the LA is almost identical bilaterally (Benson, 2014; Masotti et al., 2013; Norén et al., 2005; Wendell Todd et al., 2010), only one petrous bone was selected from each individual. When both were accessible, the left side was favoured, but the right side was substituted if the left was absent (this was often the case as it had been removed for aDNA analysis) or too fragmented. Overall, 55 casts were taken from the left side and 35 from the right side.

The individuals included in this study were distributed across four sites spanning from the 5th–16th centuries CE. The genetic sex distribution of the sample was almost even, comprising 47 men (52.2%) and 43 women (47.7%). The adult sample was larger, comprising 76 individuals (84.4%) compared to 14 nonadults (15.6%).

TABLE 2 Total of adults and nonadults according to genetic sex sampled from each archaeological site included in this study.

Site	Period	Male adults	Female adults	Male nonadults	Female nonadults
Edix Hill	5th–7th century	5	4	0	2
Gamlingay	7th–8th century	5	8	0	2
Cherry Hinton	10th–12th century	9	12	0	0
St John’s Hospital	13th–16th century	20	13	8	2
Total		39	37	8	6
Overall total		76		14	

METHODS

All IAC were cleaned of any adhering sediment while dry using wooden bamboo sticks before inserting the impression material. A quick drying silicone-based casting material, Impress-E Wash light body, was inserted using a dispenser gun until the IAC was filled (approximately 0.5–1 mL per each). A small area surrounding the opening was cast to provide a base for the measurements to be taken from. Once dry, the cast was removed and bisected, and the anterior and posterior angles were read from a protractor in increments of 5° (following Norén et al., 2005).

To evaluate the reproducibility of the method and whether this has any implications for its use, one author (JET) remeasured the anterior and posterior angles after a gap of 4 weeks. Interrater tests for consistency using the intraclass correlation coefficient (ICC) were carried out to test for correlations between repeat measurements and their absolute agreement. Prior to analysis of the relationship among sex, adult status, and angle measurement, the normality of the data was assessed using Shapiro–Wilk tests for each measurement, by site, and by sex and age groups (male/female adults and nonadults). All were normally distributed, permitting the use of parametric tests (Table 3).

To test whether there were differences in angle measurements between the pooled sites sample, and hence whether it is appropriate to combine the data, an ANOVA with a Welch's test statistic for uneven sample sizes was used. We used the same test to evaluate whether there are differences in angle measurements between children and adults. Means between the sexes (considering nonadults and adults separately) were compared using independent samples *t*-tests. All statistical tests were carried out in IBM SPSS v. 28 and the significance level was set at 0.05.

RESULTS

Reliability: intraobserver error

Intraobserver error was tested through repeated measurements of the anterior and posterior angles for all individuals analysed (Table 4). The mean anterior angle was measured on average 1.8% lower on repeated measurement. An interrater test showed good to excellent consistency (ICC = 0.893) and high absolute agreement (ICC = 0.892) between measurements of the anterior angle, indicating that the method is repeatable and reliable. For the posterior angle, three casts failed to be measured, as the angle was too acute to clearly read from the protractor. In contrast to the anterior angle, the mean posterior angle measurement increased by 12.2% on

TABLE 3 Descriptive statistics for Shapiro–Wilk test of normality according to groups divided by age and sex, and site.

Group	Statistic	df	sig
Male adult	0.963	39	0.218
Female adult	0.939	37	0.042[a]
Male nonadult	0.861	8	0.122
Female nonadult	0.818	6	0.085
St John's	0.963	43	0.184
Edix Hill	0.912	11	0.261
Gamlingay	0.926	15	0.234
Cherry Hinton	0.941	21	0.233

[a]Histogram displayed normal distribution.

TABLE 4 Mean and standard deviation for each set of measurements.

Measurement	*N*	Mean (°)	*SD* (°)	Std. error mean
Anterior angle 1	90	43.50	8.123	0.856
Anterior angle 2	90	42.72	7.501	0.791
Posterior angle 1	87	43.39	15.392	1.650
Posterior angle 2	87	48.68	13.348	1.431

Abbreviations: *N*, number of samples; *SD*, standard deviation.

TABLE 5 Descriptive statistics of anterior lateral angle (LA) size.

	Female					Male				
	N	Min. (°)	Max. (°)	Mean (°)	SD (°)	*N*	Min. (°)	Max. (°)	Mean (°)	*SD* (°)
Adult	37	22.5	60	44.7	7.1	39	27.5	57.5	43.1	7.7
Nonadult	6	37.5	50	42.1	5.3	8	30.0	47.5	36.9	2.2

Abbreviations: *N*, number of samples; *SD*, standard deviation.

average, and differences of up to 45° for single measurements were obtained. The interrater test for consistency supported that measurements of the posterior angle were dissimilar (ICC = 0.402), and there was low absolute agreement between measurements (ICC = 0.384), showing that it was extremely difficult to obtain the same measurement on repeat tests. Given the poor performance of the posterior LA, we only investigated the relationship between genetic sex and expected sex as measured from the anterior LA.

Accuracy: anterior angle and sex

Pooling the adults and nonadults from each site, Welch's ANOVA showed that the mean anterior LA between sites did not differ significantly for women ($p = 0.146$) or men ($p = 0.317$). As such, the sites were pooled and analysed according to age and sex groups. The mean anterior angle for male and female adults was similar: 43.1° and 44.7° respectively (Table 5). The range of values for the anterior LA was larger among female adults (37.5°) than among the male adults (30°), mostly due to one notable female outlier with an acute angle (Figure 3). Removing the outlier to test its effect on the mean, the mean anterior LA among female adults increased only 1.3%, to 45.3°. An independent samples *t*-test, including all adult individuals ($n = 76$), shows that between men ($\bar{x} = 43.1°$, $SD = 7.7°$) and women ($\bar{x} = 44.7°$, SD = 7.1°), there is no significant difference in the anterior angle; $t(74) = -0.930$, $p = 0.355$. A similar trend for overlap between the sexes is present among the nonadult sample, but the overall mean is 12.3% higher for female nonadults. A *t*-test of the nonadult sample ($n = 14$) reveals that male ($\bar{x} = 36.9°$, SD = 6.4°) and female nonadults ($\bar{x} = 42.1°$, $SD = 5.3°$) also do not present a significant difference between the anterior angle; $t(12) = -1.617$, $p = 0.132$. When assessing the differences between adult and nonadult sexed samples, Welch's ANOVA detected no significant difference between anterior LA angle in female adults and nonadults ($p = 0.327$), but there was a significant difference in angle size between male adults and nonadults ($p = 0.033$).

In this sample population, genetic sex, both in adults and nonadults, has no relationship with the anterior LA, and this feature cannot be used to estimate osteological sex. In the nonadult sample, values <37.5° are currently attested only in male nonadults ($n = 3$).

As a population-specific sectioning point for the anterior LA could not be determined, the 45° sectioning point established in previous studies was tested (Norén et al., 2005). The mean of

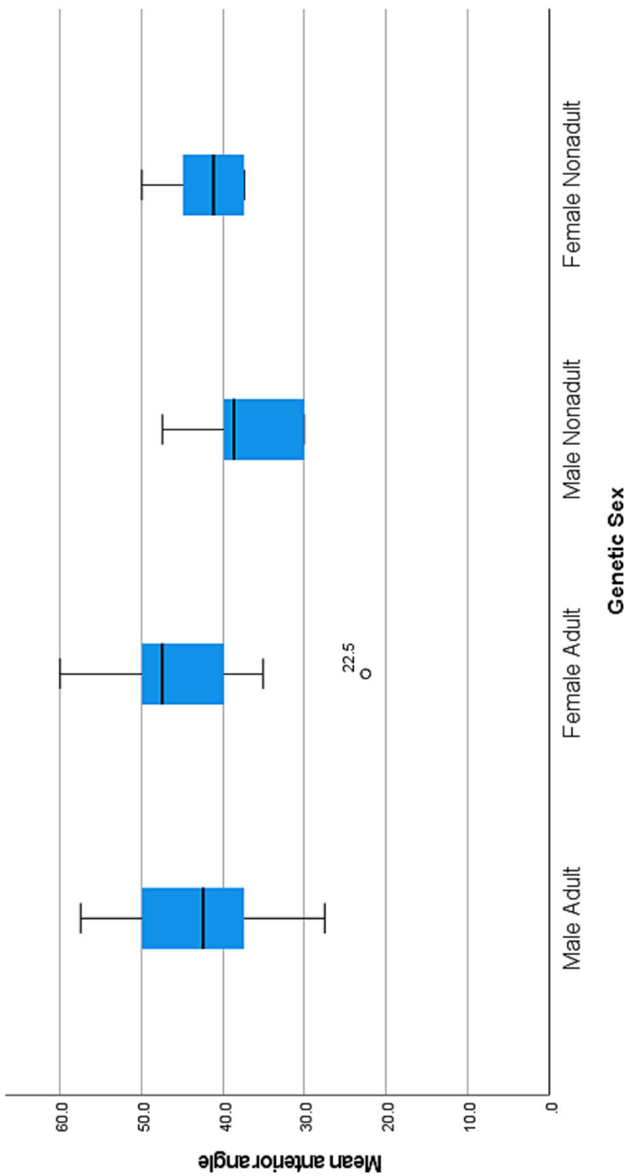

FIGURE 3 Box and whisker plots of mean anterior lateral angle (LA) according to sex and age.

TABLE 6 Sex estimation from mean anterior lateral angle (LA) using the 45° sectioning point.

	Predicted				
Observed	Male adult	Female adult	Male nonadult	Female nonadult	% correct
Male adult (39)	23	16	0	0	58.97
Female adult (37)	15	22	0	0	59.45
Male nonadult (8)	0	0	7	1	87.5
Female nonadult (6)	0	0	3	3	50
Total					61.1

the first and second measurements of the anterior LA was used to determine 'expected sex'. When compared with genetic sex, this sectioning point incorrectly identified 16 (41%) male adults as female, and 15 (40.5%) female adults as male (Table 6). Errors were reduced among the nonadults, with 1 (12.5%) male nonadult incorrectly identified as female, and 3 (50%) female nonadults incorrectly identified as male. The increased agreement between anterior LA size and genetic sex among the male nonadults in this population is most likely an artefact of small sample size ($n = 8$). Overall, accuracy of sex estimation using the 45° sectioning point for the Anglo-Saxon and Medieval Cambridgeshire sample populations was low, at 61.1%. This is similar to rates achieved in previous studies on the anterior LA (Benson, 2014; Morgan et al., 2013), illustrating that this metric estimates sex with a level of accuracy which is only about 10% higher than chance.

DISCUSSION

The LA method has been used by archaeologists to estimate sex in fragmentary and cremated skeletal remains (Gonçalves et al., 2015; Masotti et al., 2013, 2019; Willis, 2019; Willis et al., 2016). Our research aimed to investigate whether a relationship exists between LA size and sex in Anglo-Saxon and Medieval individuals from Cambridgeshire with sex estimated from genetic testing. We sought to address a core issue identified in previous studies regarding whether LA size differs on a population basis or is not sexually dimorphic at all, and to test the repeatability and accuracy of the method. To do this, we tested the reliability of the casting method of measuring LA size with a view to its application on fragmented archaeological collections and/or in circumstances when access to a CT-scanner is not available. The casting method offered several advantages as it was more expedient, required few low-cost resources, and could be applied in situ in the laboratory without necessitating transport of human remains. Overall, however, we identified that the posterior angle measurement was not repeatable, and the anterior angle showed little to no sexual dimorphism. These results indicate that the LA sex estimation method is not effective in this sample population, supporting recent studies that have similarly proven it to be inaccurate (Duquesnel Mana et al., 2016; Gonçalves et al., 2015). Therefore, we do not recommend the application of any method to measure the LA in unburnt or burnt human remains from modern or archaeological populations.

In this study, intraobserver error testing showed that it was challenging to measure the posterior angle from a cast using a protractor. As shown by a low ICC on repeated measurements, the posterior angle measurements from casts were not reliable and could not be assessed for statistical relationship to genetic sex. The discrepancy between repeated measurements of the posterior angle may be explained by the difficulty of identifying the apex of the angle when measuring from casts as the posterior wall of the IAC displays a more exaggerated curvature when it meets the lateral wall than does the anterior angle. Several individuals also displayed an extremely acute angle of the posterior LA. As such, the posterior angle should not be used to estimate sex. In contrast, good to excellent agreement was found between repeated measurements of the anterior LA, showing that this angle could be obtained reliably from the cast method. Therefore, any issues in the accuracy of sex estimates based on this measurement are unlikely to be the result of measurement problems.

The cast method is less precise than obtaining digital measurements from CT scans, as measurements are read in increments to the nearest 5°. A lack of precision in measurements from casts is problematic when the difference between male and female means is <5°. As with results published by Akansel et al. (2008), Benson (2014) and Morgan et al. (2013), we found the mean anterior LA in the adults from Anglo-Saxon and Medieval Cambridgeshire overlapped to such a great extent that no sectioning point could be determined. Indeed, the use of sectioning points can be highly misleading because sexual dimorphism is not binary; instead, it is highly variable within and between populations. Those using such models need to take into consideration the confidence intervals associated with the data. Usually, it is only possible to confidently estimate sex for individuals that are at the extreme ends of the range of the data. For example, although female adults presented a range of anterior LA values, values <27.5° and >57.5° were only present in female adults and not in male adults or nonadults of either sex. These results differ slightly from previous studies. Akansel et al. (2008) found that only men had values ≤35° and El-Sherbeney et al. (2012) found that only men had values under <30°. In this population, 28.6% of individuals with mean LAs ≤35° were female adults.

The morphology of the IAC is highly variable, related to the structures affecting the posterior wall of the *pars petrosa*, as well as the nerve openings at the lateral fundus. The depth and circumference of the IAC is diverse, with some individuals exhibiting a notably supero-inferiorly compressed and antero-posteriorly elongated IAC. This variability, as is evident from the anterior LA results in this study, cannot be explained by sexual dimorphism (Duquesnel Mana et al., 2016). Although there is sexual dimorphism in the temporal bone and cranial base (e.g., Boucherie et al., 2022), discriminant functions developed from these regions typically fail to perform accurately when they are subsequently applied to populations unrelated to those on which the methods were developed (Inskip et al., 2018; Pezo-Lanfranco & Haetinger, 2021; Uhl et al., 2020). It is therefore not surprising that the IAC anterior angle sectioning point developed on a forensic sample population has failed to estimate sex among Anglo-Saxon and Medieval inhabitants of Cambridgeshire.

The mean anterior LA differed between the male adults and nonadults. The small ($n = 8$) sample of male nonadults exhibited a surprising, with 87.5% correctly assigned to sex using the 45° cutoff. This was the only group with a high degree of accuracy in sex estimation. Although the sample size was small, most of the individuals in this group had angles that were 5° or more below the sectioning point, classifying them as male. This was reflected in the mean angle, which was some 5.2° below that of female nonadults, representing a larger difference in mean angle between the sexes than in the adults. However, the overall distribution of values for the mean LA was also smaller among nonadults than adults, probably as a result of small sample size. The mean LA in nonadults was 39°, and 71% of the nonadult sample produced mean angles at or below the 45° cutoff, resulting in a male sex bias using this sectioning point. There is little information about the size of the angle during growth and development, making it difficult to interpret the acute angles in these nonadult males. Benson (2014) analysed the anterior and posterior LA in children and young adults of five different age groups (6–10, 11–13, 14–16, 17–19, and 20–24 years). Although girls and women always had a slightly higher mean, they found no consistent age-related pattern in the angle size for girls or boys (e.g., increasing or decreasing), and there was no consistent pattern in the degree of difference between the sexes. It is notable that the difference between the Cambridgeshire male and female nonadults is similar to that obtained in Benson's study. As such, it is likely that the acute angles in the nonadult males in this study are an artefact of the small sample size. Unfortunately, it was not possible to increase the sample size in this study to test this further. More studies on the growth and development of the LA in more populations are needed to better understand the relationship between any sexual dimorphism and early growth environments.

CONCLUSION

Despite growing recognition of the unreliability of the LA sex estimation method (including by one of the original developers) on the basis of lack of sexual dimorphism in the IAC (Duquesnel Mana et al., 2016), the method has continued to be tested and applied to chronologically and geographically diverse archaeological and historical populations (e.g., Masotti et al., 2019; Willis, 2019). Surprisingly, these recent works have applied the method to burnt human remains, which have been subjected to processes of dehydration, shrinking, and warping. Given its ongoing use and testing, the retraction of the method does not appear to have reached a wide readership. Carrying out an independent test of the method on archaeological populations with genetic estimations of sex for the first time, our results further support the inaccuracy of the LA method for sex estimation. Morgan et al. (2013) concluded that the LA should only be used in conjunction with other diagnostic traits for sex estimation. Even where previous studies have reported a population-specific sectioning point (El-Sherbeney et al., 2012; Gonçalves et al., 2011; Masotti et al., 2019; Norén et al., 2005), the LA angle does not meet a robust threshold for sex estimation and should not be used in isolation. Our results further support the assertion that other traits for sex estimation should be consulted and that the LA should not be applied, given its strong variation across populations. The interpopulation and age-related variability in LA size might be worthy of future study, even though the feature lacks sex-related differences.

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PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/arcm.12927.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available online as Supporting information.

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SUPPORTING INFORMATION

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