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Original communication

Determination of sex from the hyoid bone in a contemporary White population☆

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A B S T R A C T

Six discriminant functions, developed from an historic White population, were tested on a contemporary White population for determination of sex from the hyoid. One hundred and thirty four fused and unfused hyoids from a contemporary White population were used. Individuals ranged between 20 and 49 years old. Six historic White discriminant functions were applied to the fused and unfused hyoids of the pooled contemporary White population, i.e. all males and females and all age ranges combined. The overall accuracy rates were between 72.1% and 92.3%. Correct sex determination for contemporary White males ranged between 88.2% and 96.3%, while correct sex determination for contemporary White females ranged between 31.3% and 92.0%. Discriminant functions were created for the contemporary White population with overall mean accuracy rates between 67.0% and 93.0%. The multivariate discriminant function overall accuracy rates were between 89.0% and 93.0% and the univariate discriminant function overall accuracy rates were between 67.0% and 86.8%. The contemporary White population data were compared to other populations and showed significant differences between many of the variables measured. This study illustrated the need for population-specific and temporally-specific discriminant functions for determination of sex from the hyoid bone.

1. Introduction

The determination of sex is important in the analysis of skeletal remains of unknown individuals. The osteological determination of sex uses non-metric and metric methods. Non-metric methods use morphological features to determine the sex of the individual. These methods are subjective and accuracy is dependent on observer experience.[1] Non-metric methods used with a complete skeleton show accuracy rates between 90% and 100%.[2–4] Metric methods use measurements and statistical analyses to objectively validate results. These methods remove observer bias of identifying the presence, absence, or prominence of characteristics that are utilized in morphological methods. Metric methods can also detect dimorphism in skeletal traits that may be characterized as ambiguous by morphological assessments.[5,6] The pelvis and skull have been shown to be the most accurate bones for the determination of sex.[7–10] However, incomplete or fragmentary human remains are often found during a forensic recovery especially in cases of mass disasters and human rights investigations.

Several studies have shown high accuracy rates for the determination of sex from the hyoid bone.[11–21] However, these studies focused on historic skeletal samples or obtained measurements from radiographs or pictures and not directly from the hyoid bone. Kindschuh et al.[17] measured hyoid bones directly using the Terry Collection, which contains historic individuals born in the late nineteenth and early twentieth century. Since mid-to late-twentieth century, i.e. contemporary, individuals are larger and more robust than historic peoples the accuracy rates of these discriminant functions should be tested on modern skeletal samples.[22,23]

The goal of this research is to test the accuracy of discriminant functions developed on an historic White population for use with a

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contemporary White population for determining sex from the hyoid bone.

2. Materials and methods

This study used 134 hyoid bones of males and females, both fused (27 males, 16 females) and unfused (41 males, 50 females), of contemporary White individuals from the McCormick Skeletal Collection housed at the University of Tennessee, Knoxville, Forensic Anthropology Centre (Table 1). Age at death ranged between 20 and 49 years old. Demographic information was known for each individual, i.e. sex, year of birth, age at death. The collection contains more than 900 individuals with mid-to late-twentieth century birth years and it is therefore a contemporary sample. Hyoids displaying pathologies, trauma, or deformities were not included in this study.

Following the protocol of Kindschuh et al.,[17] 10 variables from each fused and unfused hyoid were examined (Table 2, Figs. 1–2). All data were collected by one researcher using a digital Vernier calliper and measured to the nearest 0.0l mm. Measurements were taken directly from the hyoid bone. Intra- and inter-observer rates were calculated by re-measuring 10 randomly selected fused (10 males and 10 females) and 10 randomly selected unfused (10 males and 10 females) hyoids.

Descriptive statistics were assessed for each skeletal feature using MiniTab 17. Males and females were analyzed separately. The mean values of the 10 measurements were compared between the sexes to determine if statistically significant differences existed. The level of significance was $p < 0.005$ for fused hyoids and $p < 0.007$ for unfused hyoids (Bonferroni adjustment). Comparisons of bilateral features of the hyoid were tested. Paired sample t-tests were used to assess differences between left and right CHS, CL, CWI and CHI measurements as they were normally distributed. Paired Wilcoxon tests were used to assess the differences between the left and right CWS measurement, as it was not normally distributed. The level of significance was $p < 0.01$ (Bonferroni adjustment).

Using SPSS (version 22.0), discriminant function equations were created for fused and unfused hyoids using the contemporary White population data. The variables were subjected to direct and stepwise discriminant function analyses.

Independent two-sample t-tests were used to compare the mean, standard deviation, and sample size of each of the skeletal features from fused and unfused hyoids of the contemporary White population to the analogous mean, standard deviation, and sample size in the Kindschuh et al.[17] historic White population. The Kindschuh et al.[17] historic discriminant functions were applied to the contemporary population to test for accuracy in the determination of sex; functions 1 and 4 were applied to fused hyoids, functions 2 and 5 were applied to unfused hyoids, and functions 3 and 6 were applied to both fused and unfused hyoids. For each function, the percent accuracy for determining males was calculated by adding the total number of true determinations of sex, then dividing by the total number of males in the sample, and then multiplying by 100. This method was repeated for the female hyoids. The contemporary White hyoid measurements were compared with other populations using two sample t-tests: historic Whites,[17] Turkish,[20] Korean,[15] Czech,[18] and archaeological Italians.[21]

Table 1
Male and female fused and unfused hyoid bones.

Age range (years)	Fused hyoids (n)		Unfused hyoids (n)	
	Males	Females	Males	Females
20–29	4	4	18	17
30–39	16	8	9	15
40–49	7	4	14	18
Total n	27	16	41	50

All data were tested for normality and all variables were normally distributed with a Bonferonni-adjusted level of significance $\alpha = 0.005$ for fused hyoids and $\alpha = 0.007$ for unfused hyoids; males and females were tested separately and all ages combined. As the variables were not skewed, means and standard deviations were used as the most appropriate measures of central tendency. The two sample t-tests were selected as the appropriate statistical test because the sample was randomly and independently selected, the variances were similar for the measurements, and the data exhibited a normal distribution.

3. Results

3.1. Intra- and inter-observer error rates

Using the Bonferonni-adjusted level of significance $\alpha = 0.005$ for fused hyoids and $\alpha = 0.007$ for unfused hyoids none of the variables were statistically significant therefore there were no differences within or between observers. Statistically acceptable coefficients of reproducibility were obtained.

3.2. Assessment of sexual dimorphism

The measurement means and standard deviations for males and females in the contemporary White sample are shown in Table 3. Results of the two-sample independent t-test for sexual dimorphism between the contemporary White male and female populations are shown in Table 4. The Bonferroni adjusted level of significance was $p < 0.005$ for fused hyoids and $p < 0.007$ for unfused hyoids. The BL, BH, CWI, CHI, CL, THL, THW, and WCS variables showed sexual dimorphism. However, the CWS and CHS variables did not display sexual dimorphism.

3.3. Assessment of bilateral features

Table 5 shows comparisons of bilateral features of the hyoid. The paired sample t-tests showed no differences between left and right CHS, CL, CWI and CHI measurements. The paired Wilcoxon tests showed no differences between the left and right CWS variable. The level of significance was $p < 0.01$ (Bonferroni adjustment). As there were no significant differences between left and right hyoid measurements, further statistical testing used a mean measurement for each variable that was calculated from the average of the left and right hyoid measurements.

3.4. Discriminant function equations

Discriminant function equations were created from the contemporary White population with fused and unfused hyoids analyzed separately (Tables 6 and 7). For fused hyoids, function 1 used all eight variables (BL, BH, CWI, CHI, CL, THL, THW, WCS) that displayed sexual dimorphism. Function 2 used only the three (BL, CHI, THL) most sexually dimorphic measurements from the eight variables employed in Function 1. Functions 1 (93.0%) and 2 (93.0%) showed the highest overall classification accuracies. Function 3, which used only variables of the hyoid body (BL, BH), displayed the lowest overall accuracy rate (90.7%). The classification accuracies for males ranged from 85.2% to 92.6% and for females they ranged from 93.8% to 100.0%. When analyzing single variables, the CHI measurement displayed the highest over accuracy rate (90.7%) and the CWI measurement showed the lowest accuracy rate (67.4%). The classification accuracies for males ranged from 66.7% to 88.9% and for females they ranged from 68.8% to 93.8%. Although the