Chapter 9

Methodology and Reliability of Sex Determination From the Skeleton

Jaroslav Bruzek and Pascal Murail

Summary

Once a body is completely decomposed, it is necessary to determine sex from the skeleton. The hip bone is the most reliable indicator for sex determination because the pattern of sexual dimorphism is common to the whole human race. Two reliable visual methods are suggested to assess sex from the hip bone. However, the authors recommend the use of a method based on discriminant function analysis including a probabilistic approach that the authors recently developed with a large sample of known-sex individuals. The population specificity of sexual dimorphism of the other parts of the skeleton is also discussed. The authors particularly insist on the inherent limits of discriminant functions on extrapelvic measurements.

Key Words: Sex determination; adult; hip bones; pelvic measurements; probability; discriminant function.

1. INTRODUCTION

For forensic anthropologists and bioanthropologists, studying skeletal remains from past populations, estimating age, and sex is a fundamental step for establishing the biological profile of an individual (1–4). In the forensic context, it is necessary to use bone and dental indicators on decomposed bodies.
for age-at-death assessment, but sex determination is more problematic when the body is skeletonized than at other times. If the aims of sex determination differ in paleoanthropological studies and police investigations, both fields are confronted with the same biological and methodological limits and require a high level of reliability. However, the reliability and accuracy of sex assessment from skeletal remains depends on the anatomical region available.

After presenting the fundamental theoretical backgrounds of performing sex assessment methods, this chapter suggests the reliable methods to assess sex from the hip bone and the skull, and comments on the application of the methods based on the other bones of the skeleton.

2. WHAT IS A RELIABLE METHOD TO ASSESS SEX FROM THE SKELETON?

The identification process from skeletal remains requires the use of methodological approaches and methods whose performance is demonstrated. One should not confuse the accuracy and the reliability of a method. The accuracy is the percentage of skeletons whose sex is correctly assigned in the sample on which the method is elaborated. The reliability is evaluated by testing the method on an independent population. As the legal consequences of the identification of individuals are significant, the level of reliability needs to be higher in the legal context than those presented in current sexing methods (around 85%). A minimum threshold of 95% is required (5).

When a biological character and/or the preservation of skeletal remains prevent such reliability, the result of sex assessment must be expressed by the probability of a skeleton being male or female. Moreover, the risk of error must be specified by the expert in charge of the identification. The risk of sex misclassification should be underlined in any expert opinion.

Over the last two decades, gradual loss of empirical and typological approaches to elaborate methods of sex determination from the skeleton was observed. Recent methods are instead based on biological and statistical backgrounds.

Describing morphological sexual differences on the skeleton is not enough to elaborate a method of sexing. No single trait of the human skeleton enables a reliable sex determination (6). For example, the “mandibular ramus flexure,” which is supposed to be present in males mandibles and missing in females mandibles, is asserted to be a reliable indicator of sex by Loth and Henneberg (7,8) because the reliability level reaches 94% of cases. However, when tested by others authors, the results fail to give such reliability (80% and less [5,9,10]).
Sex Determination

It is not appropriate either to use extreme values of a single measurement, such as the femur head diameter, when applied to a population different from the reference sample. Neither the technique of demarking points (11) nor indices that are also population-specific (12) are appropriate for sexual assessment.

When testing sex determination methods, trained scientists with long-term practice obtain a higher accuracy level; their experience is sufficient to supply the putative lack of precise and reliable methods. It is rather difficult to quantify the part of observer experience when assessing accuracy and reliability of a method (13). Both new and experienced observers should achieve the same level of reliability in determining the sex of an individual.

Only a combination of an optimum number of traits (or measurements), which are evaluated (or measured) according to precise definitions, provides a reduction of the subjectivity and enables the reproducibility of observations and, therefore, a correct sex determination. Only such approaches, including well-documented instructions, can be considered as correct methods. In addition, each method must be elaborated on osteological collection of known sex and its practical and effective reliability tested on independent samples.

3. Sex Determination From the Hip Bone: The Most Reliable Sex Determination

3.1. The General Pattern of Sexual Dimorphism of the Hip Bone

It is widely accepted that the hip bone is the part of the skeleton that provides the most accurate and reliable results for sex determination. The hip bones exhibit the most sexually dimorphic elements of the skeleton. The discrete sex-specific differences in size and shape are based on the differing reproductive roles of males and females. Sexual dimorphism of the hip bone is the result of functional modification and evolutionary adaptation. The male pelvis is adapted to bipedal striding. In females, the pelvis reflects a compromise between locomotion and parturition that requires a voluminous pelvis in female for the safe passage of a large fetal head through the birth canal. This specificity absent in males leads to a biomechanical advantage for more efficient locomotion. Therefore, male pelvises are generally narrower than the female’s.

The hip bone can be divided into three morphofunctional parts or segments. The first part is the sacroiliac segment; it concerns the auricular surface of the sacroiliac joint and its surroundings structures. The most important sexual difference that increases with age is the shape of the sciatic notch. The
second part is the ischiopubic segment, whose sexual dimorphism occurs in puberty because of the hormonally controlled transformation of the pelvis in females (open subpubic angle and relatively greater length of pubis than ischium). The third morphofunctional part of the pelvis is the acetabular segment; it reflects the spatial organization of the three bones that form the pelvis and contributes to its general architecture.

This pattern of sexual dimorphism of the pelvis is common in the human race and has existed for at least 100,000 yr (14). Sexual dimorphism of the pelvis as the whole is also presented in isolated hip bones. Because the relationship between locomotion and reproduction is not population-specific, morphometric methods of sex determination by discriminant function analysis (DFA) are not population-specific. However, it is necessary to use these DFAs in an appropriate manner.

Observing traits or taking measurements of a single morphofunctional segment of the hip bone is not appropriate. The sexual dimorphism observed on a single segment is often influenced by size and thus, population-specific. This is the case with Phenice's method (15), which is based on the pubic bone. A test of this method showed a reliability ranging from 60 to 90%, depending on the population studied (16). Similar conclusions are valid for sex determination from the posterior pelvis and the sacrotuberal joint surface (17–19). In fact, the variation in sexual dimorphism of one segment of the hip bone influences the variation in the other segments of the hip bone. This equifinality principle of sexual dimorphism is observed on the hip bone considered as a whole (13,16,20).

Sexing immature skeletons is a point largely debated among both forensic and osteoarchaeological communities. Nevertheless, until the fusion of the three different segments of the hip bone, sex dimorphism is not sufficiently expressed to elaborate a reliable method for sexing immature individuals.

### 3.2. Reliable Methods of Sex Determination

Reliable sex assessment from the hip bone is obtained either by visual techniques based on the evaluation of morphological traits or by statistical tools with hip bone measurements.

Two visual methods that take into account the total sexual dimorphism of the hip bone provide a reliable sex determination and are highly recommended for sex determination (20,21). Those methods are described in details in the cited literature. From a practical point of view, it is necessary that the methods employ a limited number of traits. Increasing the number of variables does not provide a higher accuracy; it is time-consuming and gives redundant results.
### Table 1

Four Reliable Discriminant Functions Using Hip Bone Measurements

<table>
<thead>
<tr>
<th>Reference</th>
<th>Discriminant function</th>
<th>Discriminant value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novotny, 1975</td>
<td>$SD = (7.178 \text{ ISM}) - (4.789 \text{ PUM}) - (4.262 \text{ AC}) - (0.788 \text{ IIIT})$</td>
<td>$F &lt; 292.53 &lt; M$</td>
</tr>
<tr>
<td>Bruzek, 1991</td>
<td>$SD = (0.4666 \text{ HOAC}) - (0.2126 \text{ PUBM}) + (0.2959 \text{ ISM}) - (0.2849 \text{ AC}) - 37.307$</td>
<td>$F &lt; 0.093 &lt; M$</td>
</tr>
<tr>
<td>Bruzek, 1985</td>
<td>$SD = (0.1942 \text{ HOAC}) - (0.15688 \text{ PUM}) + (0.10323 \text{ ISM}) - (0.0273 \text{ IIIT}) - (0.05105 \text{ AC}) - 7.44678$</td>
<td>$F &lt; 0.402 &lt; M$</td>
</tr>
<tr>
<td>Schuler-Ellis et al., 1985</td>
<td>$SD = 25.1462 \text{ (HOAC + PUM)} + (0.1318 \text{ ISMM}) - 31.8388$</td>
<td>$F &lt; 0 &lt; M$</td>
</tr>
</tbody>
</table>

The dimensions used and their definitions are as follows, where "M" corresponds to the marking according to Martin (61): HOAC (M.22), PUM (M.14), IIIT (M.15.1), ISM (62), ISMM, PUBM (24-25), AC (22).

$F$, female value; $M$, male value.

However, visual methods, if reliable, are quite difficult to apply for new applicants. Therefore, it is much easier to use metrical methods. Four discriminant functions (22–25) previously published have been shown to be reliable after tested on several independent samples (/26) Table 1). However, the sex determination of an individual depends on the discriminant score obtained compared with the discriminant value (this particular point is developed under Subheading 4.2.2). To avoid this problem, the authors recently developed a method based on discriminant function analysis including also a probabilistic approach for sex assessment (27,28). Current developments in software enable extension of the classic computation of DFAs to the calculation of posterior probabilities of a skeleton being male or female, without discussing the discriminant value (Fig. 1). The method the authors proposed was elaborated on a large sample of hip bones ($n = 2040$) of known-sex individuals. This sample was composed of several populations from preindustrial and contemporary periods and diverse geographical areas (Europe, Africa, Asia, North America) (Table 2). The aim was to take into account a large variability of human hip bone sexual dimorphism. The measurements used for this approach were selected from published osteometric studies of sex determination according to their relevance in discriminating sex. The level of reliability of the authors' method (for a posterior probability $\geq 0.95$) is impressive. Using a combination of eight or four measurements, it varies from 98.7
Fig. 1. Principles of probabilistic sex determination. Classification of the posterior probabilities (probability for a specimen to be classified in the good category) in the European sample (A). At a 0.95 threshold, sex is assessed for 95.9% of the sample. The level of reliability is 100%. It demonstrates that these three different samples (from England, France, and Portugal) share the same sexual dimorphism of the hip bone. This model is tested on an African-American sample (Terry and Hamann-Todd Collection); probabilities are calculated from the European sample (B). At a 0.95 threshold, sex is assessed for 92% of the sample, and the reliability is 98.6% (error rate is 1.4%). Pelvic measurements describe a common sexual dimorphism among different populations (see also Table 1 for other tests). The final version of the probabilistic tool includes all the samples of different origins as a reference sample.

to 100%, depending of the target samples (Table 3). In addition, it is possible to select various combinations of measurements, depending on the state of preservation of the hip bone. For each case, posterior probability is calculated from the whole reference sample. It allows assessment the sex of an individual, knowing the exact probability of being male or female, which is of
<table>
<thead>
<tr>
<th>Country</th>
<th>City</th>
<th>Collection</th>
<th>Group</th>
<th>Date (century)</th>
<th>Females</th>
<th>Males</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Paris</td>
<td>Olivier</td>
<td>—</td>
<td>Early 20th</td>
<td>62</td>
<td>98</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>London</td>
<td>Spitalfields</td>
<td>—</td>
<td>18th, 19th</td>
<td>31</td>
<td>31</td>
<td>62</td>
</tr>
<tr>
<td>Portugal</td>
<td>Coimbra</td>
<td>Tamagnini</td>
<td>—</td>
<td>19th, 20th</td>
<td>130</td>
<td>102</td>
<td>232</td>
</tr>
<tr>
<td>Lituania</td>
<td>Vilnius</td>
<td>Garmus</td>
<td>—</td>
<td>20th</td>
<td>112</td>
<td>108</td>
<td>220</td>
</tr>
<tr>
<td>Africa</td>
<td>South Africa</td>
<td>Johannesburg</td>
<td>Dart</td>
<td>Early 20th</td>
<td>153</td>
<td>153</td>
<td>306</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zulu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Soto</td>
<td>Early 20th</td>
<td>58</td>
<td>52</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Afrikaner</td>
<td>Early 20th</td>
<td>56</td>
<td>56</td>
<td>112</td>
</tr>
<tr>
<td>North America</td>
<td>United States</td>
<td>Cleveland</td>
<td>Hammann-Todd</td>
<td>Black</td>
<td>Early 20th</td>
<td>57</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>White</td>
<td>Early 20th</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Washington D.C.</td>
<td>Terry</td>
<td>Early 20th</td>
<td>110</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Black</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>White</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Thailand</td>
<td>Chiang-Mai</td>
<td>Forensic</td>
<td>Late 20th</td>
<td>96</td>
<td>102</td>
<td>198</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1023</td>
<td>1017</td>
<td>2040</td>
</tr>
</tbody>
</table>

Adapted from ref. 28.
### Table 3
Reliability of the Pooled European and American Model of Probabilistic Sex Determination From Hip Bone Measurements and Its Testing in Other Populations

<table>
<thead>
<tr>
<th>Population</th>
<th>Combination of eight variables</th>
<th>Best combination of four variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' $\lambda$ statistic</td>
<td>Sexing (%)</td>
</tr>
<tr>
<td>Reference sample of European and American samples</td>
<td>0.179</td>
<td>99.7</td>
</tr>
<tr>
<td>Thai</td>
<td></td>
<td>94.1</td>
</tr>
<tr>
<td>Zulu (Dart Collection)</td>
<td>88.7</td>
<td>98.8</td>
</tr>
<tr>
<td>Soto (Dart Collection)</td>
<td>86</td>
<td>100</td>
</tr>
<tr>
<td>Afrikaner (Dart Collection)</td>
<td>95.1</td>
<td>100</td>
</tr>
<tr>
<td>Lithuanian</td>
<td>94.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Wilks' $\lambda$ is the discriminatory power of the discriminant function analysis. Sex is assessed for individuals whose posterior probability is $\geq 0.95$ (cf. percentage of sexing).
great interest in forensic context. This method under publication (28) is easy to run via software, which is available on request to the authors (jbruzek@u-bordeaux1.fr).

4. **How to Determine Sex When the Hip Bones Are Not Preserved**

4.1. Sex Assessment From the Skull

The skull is the second element of the skeleton that expresses a relevant sexual dimorphism. Therefore, it is possible to use a classic visual technique by skull dimorphism (29). However, one should keep in mind that sexual dimorphism of the skull depends on the population observed. Sex determination from cranial morphological features is less reliable than sex assessment from the hip bone. Therefore, it is more appropriate to use cranial measurements of a specimen and to compare them to a large reference database, such as the one published by Howells. This database includes a worldwide variation of human skull measurements (30). The software FORDISC 2.0 enables application of such a principle (31). However, this system determines sex by the greater probability. For example, if a specimen has a probability of 0.48 of being male and 0.52 of being female, the specimen is determined to be female. Taking into account the discriminant value reduces the reliability of the determination, the authors therefore recommend using FORDISC 2.0 by limiting sex assessment to the specimens whose the probability of being male or female is greater than 0.95. Another possibility is to compute the probabilities from the Howells database (30). Depending of the case studied, one may choose one or several reference populations to calculate specific DFAs according to the available measurements in the specimen. In this case, measurements are also selected according to previous works that already showed satisfactory results (32–34). Most of statistical software enables computation of probabilities and estimation of the reliability of such analysis. Again, the sex of a specimen should be assessed according to a probability higher than 0.95. Because sexual dimorphism of the skull is more population-specific than the hip bone, it is not surprising that the sex of some individuals will not be determined.

4.2. Sex Determination When Hipbones and Skull Are Absent: A Fundamental Problem

When hip bones and skull are missing, it is commonly accepted to apply DFAs elaborated on measurements of other elements of the skeleton, such as long bones. However, this solution is not appropriate because the sexual dimorphism is population-specific.
4.2.1. **Population Specificity of Extrapelvic Osteometric Methods for Sex Determination**

In general, males have larger body size, more massive joints, and stronger musculature compared with females. However, the degree of this sexual dimorphism varies between populations. Therefore, methods of sex determination that use measurements are population-specific. Many authors have demonstrated the population specificity of the DFAs (29,35–37). To remove the variations affecting discriminant values when applied to a sample different from the sample on which the DFA was computed, it was proposed modifying the discriminant value by a new target sample of bones. Because of the lack of suitable data, this proposal is not applicable (16).

İşcan (38) proposed elaboration of specific DFAs for each population. The calculation of new discriminant functions is nowadays an easy task with common software. Therefore, the number of publications proposing DFAs from most of the bones of the skeleton to determine sex increased in the last decade (reviewed in ref. 5) and are still being developed (39–42). However, one might ask the legitimate question of whether these publications actually serve any purpose. The assessment of ethnic origin remains one of the most difficult tasks in forensic osteology, as culturally and politically defined groups do not necessarily coincide with biological parameters (31–43). In the context of the current globalization, a phenomenon characterized by the flow of individuals (and populations) over great distances, there is no guarantee that any discovered skeletonized body in one country belongs to the local population group living in this geographic area. Therefore, there is no reason to use a specific national or regional population standard. In past populations, migration and population movements may have led to modifications of the biological characteristics by the influence of rapid changing conditions.

Therefore, any population standard is only valid for individuals who belong to this population. The authors assert that population-specific discriminant function analyses do not enable reliable sex determination in archaeological and legal contexts. Their application may actually be erroneous and misleading. For example, specific discriminant functions derived from the dimensions of the long bones in the limbs of a recent American population sample (44) were applied on a Neolithic population sample from Denmark. Parallel to the establishment of the biological profile, DNA analysis was conducted. This study showed that the sex determination by DFAs failed to give the same results than those obtained by DNA analysis ([45] see also Fig. 2).
Fig. 2. Population specificity of extrapelvic discriminant function analysis (DFA). The DFA proposed by Iscan and Miller-Shaivitz (33) takes into account two variables of the femur (M21 and M18). Elaborated in a North American sample of known-sex skeletons (Hamann-Todd: 56 males and 55 females), its accuracy level is 91%. Nevertheless, its application in another sample of known sex (Spitalfields, London: 32 females and 26 males) shows that the reliability level is reduced to 42%. This DFA is specific to the original population: 11 males are misclassified (reliability is only 58% for the male group). Wrong sexual determination may be explained by a specific size pattern of sexual dimorphism that introduces the shift of the discriminant value. This DFA should not be applied to individuals from a different origin. F, female; M, male; DV, discriminant value.

Inferring ethnic origin from bones in order to choose the appropriate DFA is not recommended for two reasons. First, sex dimorphism varies among individuals from the same origin. Second, inferring ancestry from bones is not a reliable process. Goodman (46) related a famous example: “A left leg was found in the debris of the Oklahoma City bombing. By measuring the lower leg and plugging the numbers into computer programs that categorize bones by race and sex, Snow confirmed the hunch: the leg probably came from a white male.” It was asserted later that “the leg belonged to Lakesha R. Levy,” who was female, and “obviously black.”

Even the sexual dimorphism in a single population modifies through time. The secular trend causes not only changes in size and height between generations (47,48), but also modifies the size of individual bones (49–53). A
population-specific standard elaborated in a well-documented osteological collection from the past should not be applied to recent individuals from the same origin. The sexual dimorphism observed on the osteological sample would not reflect the sexual dimorphism of the current population.

4.2.2. Pitfall for Users: The Interval of Overlapping Values in DFAs

The other limit of DFAs is the overlapping value, which can reach 85% (54). A DFA computed by combined measurements reduces the range of the overlapping area, but it is not completely removed (Fig. 3A). Success of a DFA is generally evaluated by its statistical power, expressed by a Wilks’ lambda statistic (varying from 0 to 1). The lower the value is, the greater the power of DFA. However, results of a DFA emphasize the classification accuracy, depending on the discriminant value. Level of accuracy is highly variable and covers a wide range: 66% for skull fragments (55), between 75 and 85% for long bones (56,57), the highest values being for the hip bone (see Subheading 2.2).

When determining sex, the overlapping values area is not taken into account because it may change the success of a DFA into a completely useless tool. Use as an example a DFA with a discriminant value equal to 0, where “female” corresponds to negative values and “male” to positive values. If the determination of the sex of an unknown forensic specimen or from a cemetery is by the same DFA (see Fig. 3B) in the overlapping area, there is no rule to decide whether the individual’s sex has been correctly determined. Moreover, the variation of the discriminant value between populations increases the influence of the overlapping area and may lead to important misclassification (see Fig. 2). In the forensic context, a DFA that fails to provide a maximum error rate of 5% is useless. Yet, this is the case of the majority of published DFAs, regardless of the population on which they were elaborated. This failure comes from the use of the discriminant value as a classification criterion. A discriminant value corresponds to a probability of 0.5, whereas the classification reliability of a DFA should reach an optimum value of 95%.

Sex assessment when the hip bone and the skull are absent is problematic. Metric analyses are population-specific and are not reliable enough when applied to individuals of unknown origin. As the origin of a skeletonized body is unknown, it is not recommended to assess sex based on isolated bones.

In archaeological context, there is a solution for sexing skeleton missing hip bones. The authors call it “secondary sex diagnosis” (58). The first step is to perform sex determination for skeletons with hip bones, using one of the
Fig. 3. Discriminant function analysis (DFA) in a sample of known-sex specimens (A) vs its application to an unidentified skeleton (B): pitfall of discriminant value (sectioning point). In a series of bones belonging to subjects of known sex (A), the DFA separates males and females with an error rate (misclassification) that corresponds to the percentage of the subjects misclassified. This DFA applied in a sample of unknown sex ([B] forensic or archaeological samples) separates subjects in an exhaustive way. Distinguishing true and false allocations of sex in the overlapping area is impossible. Furthermore, the zone of overlapping is unknown. Thus, the use of discriminant value is not recommended for most DFAs. Probabilistic assessment is highly recommended. F, female; M, male; DV, discriminant value; OA, overlapping area.

methods listed previously. The second step consists of elaborating specific DFAs from this subsample. After verifying their reliability, it is possible to apply the DFAs to the others skeletons. Stojanowski (59) has recently used nearly the same principle.
5. Conclusion

Sex determination from the skeleton can be assessed with reliability when the methods take into account a common sexual dimorphism between populations. The best indicator is the hip bone. At least three reliable methods based on this element can be applied (visual, pelvic DFA, and probabilistic approaches). When the hip bone is missing, it is recommended examining cranial sexual dimorphism by visual methods or by computing the sex affinity of the specimen from wide reference morphometric data. However, for cranial methods, when a specimen exhibits no marked sex dimorphism or when cranial measurements provide a lower probability than the required threshold, one should not determinate sex. One has to accept that the quest for reliability leads to unidentified individuals. For isolated bones, sex determination is rather problematic. Sexual dimorphism is population-specific, and furthermore, ethnic origin determination is limited on skeletonized remains. Consequently, population specific standards are useless.

For nonadult skeletons, no reliable methods have been proposed yet. One solution is to perform molecular diagnostics by genetic markers on X/Y chromosomes (60). This technique may also solve the problem of sex determination with isolated bones.

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