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Sex estimation with the total area of the proximal femur: A densitometric approach

Francisco Curate[a,b,c,*], Anabela Albuquerque[d], Izilda Ferreira[d], Eugénia Cunha[b,e]

[a] Research Centre for Anthropology and Health, Department of Life Sciences, University of Coimbra, Coimbra, Portugal
[b] Laboratory of Forensic Anthropology, Department of Life Sciences, University of Coimbra, Coimbra, Portugal
[c] Interdisciplinary Center for Archaeology and Evolution of Human Behavior, University of Algarve, Faro, Portugal
[d] The Coimbra Hospital and University Centre, Coimbra, Portugal
[e] Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Coimbra, Portugal

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ABSTRACT

-The estimation of sex is a central step to establish the biological profile of an anonymous skeletal individual. Imaging techniques, including bone densitometry, have been used to evaluate sex in remains incompletely skeletonized. In this paper, we present a technique for sex estimation using the total area (TA) of the proximal femur, a two-dimensional areal measurement determined through densitometry. TA was acquired from a training sample (112 females; 112 males) from the Coimbra Identified Skeletal Collection (University of Coimbra, Portugal). Logistic regression (LR), linear discriminant analysis (LDA), reduce error pruning trees (REPTree), and classification and regression trees (CART) were employed in order to obtain models that could predict sex in unidentified skeletal remains. Under cross-validation, the proposed models correctly estimated sex in 90.2–92.0% of cases (bias ranging from 1.8% to 4.5%). The models were evaluated in an independent test sample (30 females; 30 males) from the 21st Century Identified Skeletal Collection (University of Coimbra, Portugal), with a sex allocation accuracy ranging from 90.0% to 91.7% (bias from 3.3% to 10.0%). Overall, data mining classifiers, especially the REPTree, performed better than the traditional classifiers (LR and LDA), maximizing overall accuracy and minimizing bias. This study emphasizes the significant value of bone densitometry to estimate sex in cadaveric remains in diverse states of preservation and completeness, even human remains with soft tissues.

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1. Introduction

The assessment of biological sex constitutes a focal research demand in the forensic examination of human skeletal remains, with additional parameters of the biological profile (*e.g.*, stature or age) typically estimated as sex-specific [1,2]. Superlative approaches for the sexual estimation of unknown skeletal individuals usually depend on the recovery and analysis of well-preserved pelvic bones [1–3]. Likewise, the cranium and long bones have been employed to accurately assess sex in human skeletal remains [3–6]. The femur is the longest and, as a rule, the strongest skeletal element, being commonly recovered in both forensic and archeological contexts [5]. As such, it is not surprising that, alongside the cranium and pelvis, the femur has received most of the attention in studies of sexual dimorphism, with several dimensions of the femur employed for the prediction of sex in skeletal remains [4,6–10].

In forensic settings, sex estimation is usually performed in fully skeletonized bodies with the support of standard osteometric techniques, but periodically forensic identification of unknown individuals requires the study of incomplete, partially fleshed or charred remains [11,12]. Medical imaging techniques can be used to observe remains not completely skeletonized in which skeletal preparation (*e.g.*, maceration) is impractical, or even unreasonable from a social or cultural standpoint. Accordingly, imaging techniques, such as computer tomography or projectional radiography, have been extensively used to address the estimation of sex in cranial and postcranial bones [12–18], including the femur [11,19,20].

Dual X-ray absorptiometry (DXA), or bone densitometry, is an application of low energy projectional radiography, generally recognized as the gold-standard technique to evaluate bone mineral density (BMD) and diagnose osteoporosis [21,22]. Given that DXA is a two-dimensional scan, real bone density cannot be

* Corresponding author.
E-mail address: fcurate@uc.pt (F. Curate).

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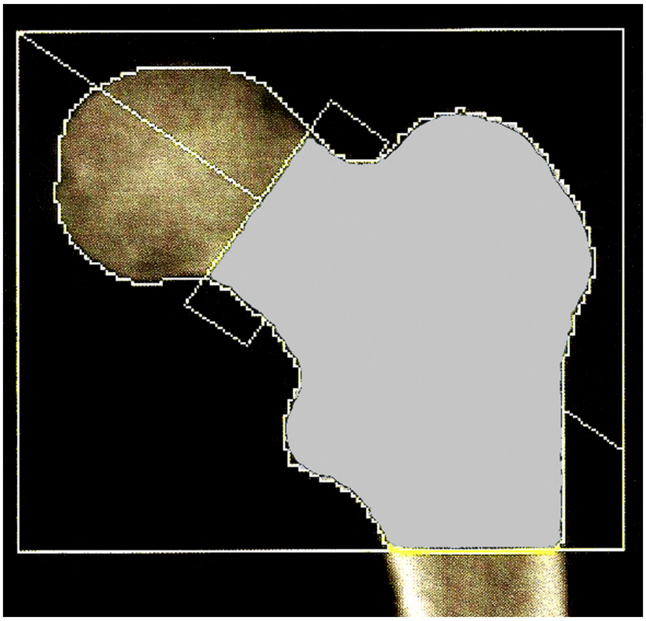

Fig. 1. The total area (cm^2) of the proximal femur (gray color).

determined; instead, bone mineral content (BMC, in grams) in a given projected area (in cm^2) is measured. Areal BMD is thus determined by dividing the BMC by area. DXA has been infrequently applied in the forensic sciences, although it can be exploited to estimate sex, age at death and ancestry [10,23–26]. Some advantages of DXA application in the forensic sciences are summarized by Wheatley [23].

The main purpose of this study is to generate and test models for the prediction of sex based on the total area of the proximal femur, a two-dimensional areal measurement performed with DXA. Also, the performance of classical classifiers, such as logistic regression and Fisher's linear discriminant analysis, which have been extensively used for classification of problems where the dependent variable is dichotomous, is compared with that of classification and regression trees and reduce error pruning trees, which are non-parametric decision tree learning techniques.

2. Materials and methods

The samples used in this study were obtained from two Portuguese Identified Skeletal Collections [27,28]. A training set from the Coimbra Identified Skeletal Collection (CISC, University of Coimbra, Portugal), comprising 224 individuals (112 females and 112 males), was used to fit the models for sex estimation. Individual ages at death ranged from 20 to 96 years. Dates of death spanned from 1910 to 1936. A second sample, from the 21st Century Identified Skeletal Collection (ISC/XXI, University of Coimbra, Portugal), included 60 individuals (30 females and 30 males) and was employed to test the predictive value of the models generated in the CISC sample: this is the testing, or holdout, sample. All individuals died between 1995 and 2001. Age at death ranged from 33 to 97 years old. Only individuals with at least one femur showing no macroscopical signs of post-depositional change and lacking significant pathological modifications were included in the samples.

In the domain of densitometry, the proximal femur has been partitioned into distinctive regions of interest. The total area (TA, cm^2) of the proximal femur (also known in the medical literature as total area of the hip) is the sum of three individual areas: femoral neck, trochanteric region, and intertrochanteric/proximal diaphysis regions (Fig. 1) [21,22]. A femur from each individual (as a rule, the bone from the left side) was scanned with a Hologic QDR-4500A densitometer (Hologic, Inc., Bedford, MA) at the Nuclear Medicine Unit (Coimbra Hospital and University Centre, Portugal) and the computer produced the above designated semi-automated regions of interest (if required the technologist made minor adjustments) and the area (cm^2) for each region is calculated. Subsequently TA was automatically determined by the densitometer's software (Fig. 2). Femora were placed in anteroposterior position; with the femoral neck parallel to the plane of the scanner; in a low-density cardboard container with 10 cm depth of dry rice acting as a surrogate for soft tissue (soft tissues and bone marrow slightly influence the reading of bone mineral content but not TA). Fifty femora were scanned in two different days to check repeatability of the DXA measurements. The magnitude of the intraobserver error was assessed with the relative technical error of measurement (rTEM) [29] and it was very low (rTEM = 0.42), suggesting that the positioning of the femur was performed appropriately. Physiological length of the femur was obtained following Martin [30].

DXA Results Summary:

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	T - score	PR (%)	Z - score	AM (%)
Neck	**4.98**	**2.53**	**0.508**	**-3.1**	**60**	**-0.6**	**88**
Troch	12.48	5.90	0.473	-2.3	67	-0.4	92
Inter	25.77	16.15	0.627	-3.1	57	-1.1	79
Total	43.24	24.58	0.569	-3.1	60	-0.8	85
Ward's	1.12	0.38	0.343	-3.3	47	-0.2	93

Total BMD CV 1.0%

WHO Classification: Osteoporosis

Fracture Risk: High

Fig. 2. Results summary for a DXA scanning (CISC, female, 80 years old). In this example, TA is 43.24 which is the sum of three different areas: neck, trochanteric and intertrochanteric.

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