HIP 1.0 – Novel software for sex determination using traditional and geometric morphometrics of human hip bone

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Introduction

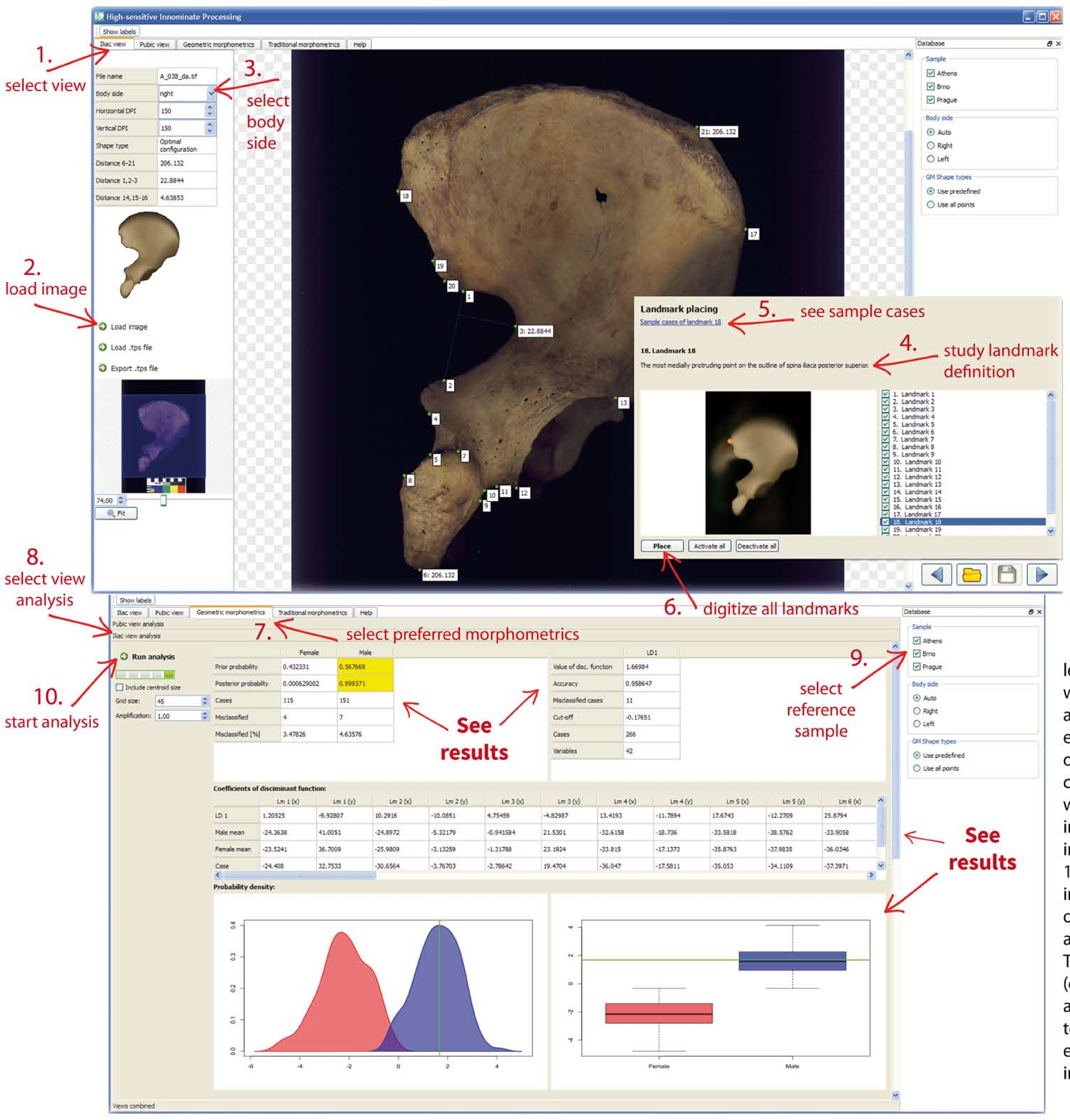
The determination of sex in unknown skeletal remains is considered one of the most difficult task and controversial matter in the forensic settings and anthropological circles. The pelvic bone stands at the forefront of the interest due to its high sexual dimorphism and it is acclaimed to be the most appropriate skeletal portion for reliable sex determination from adult human skeletal remains. To date, number of methods for morphoscopic sex assessment (e.g. Bruzek 2002) and metric sex estimation (e.g. Novotný 1986) using hip bone have been developed. However, recent studies can profit from progress in computer processing (Murail *et al*. 2005) and advanced morphometric techniques (e.g. Gonzalez *et al*. 2009).

Objectives

The aim of the project was to create a novel computer program for sex estimation using image-based measurements of the adult hip bone.

Results

The computer software HIP 1.0 (High-sensitive Innominate Processing ver. 1.0) has been proposed. The HIP is distributed under the terms of GNU GPLv3 license and is *freely available* at web site of the Laboratory of Morphology and Forensic Anthropology (www.sci.muni.cz/lamorfa/veda-a-vyzkum#projekty). The program environment was designed to fit experts without previous experience in computer-aided morphometric methods. The software allows performing the entire analytical procedure in following 10 illustrated steps:



Methods

The reference sample consisted of 611 adult pelvic bones from 315 individuals of documented sex (179 males, 136 females), originated in three documented European skeletal collections: Charles University (Prague, CZ), Masaryk University (Brno, CZ) and National and Kapodistrian University of Athens (Athens, GR). The hip bones were scanned by a standard 2D desktop scanner Canon CanoScan 4400F for the morphometric analysis in two standardized positions – from *pubic* and *iliac* view (Fig.1). Definitions of 45 landmarks of several types were proposed and their *x* and *y* coordinates were manually recorded on each digital image.

The coordinates were used for calculating inter-landmark distances in terms of traditional morphometrics, and for processing via techniques of geometric morphometrics (Procrustes superimposition). In order to develop new predictive models for sex assessment based on (morpho)metric variables (linear measurements, Procrustes coordinates), the multivariate statistical methods and permutation procedures were employed, including stepwise linear discriminant analysis, cross-validation and computing posterior probability of estimates.

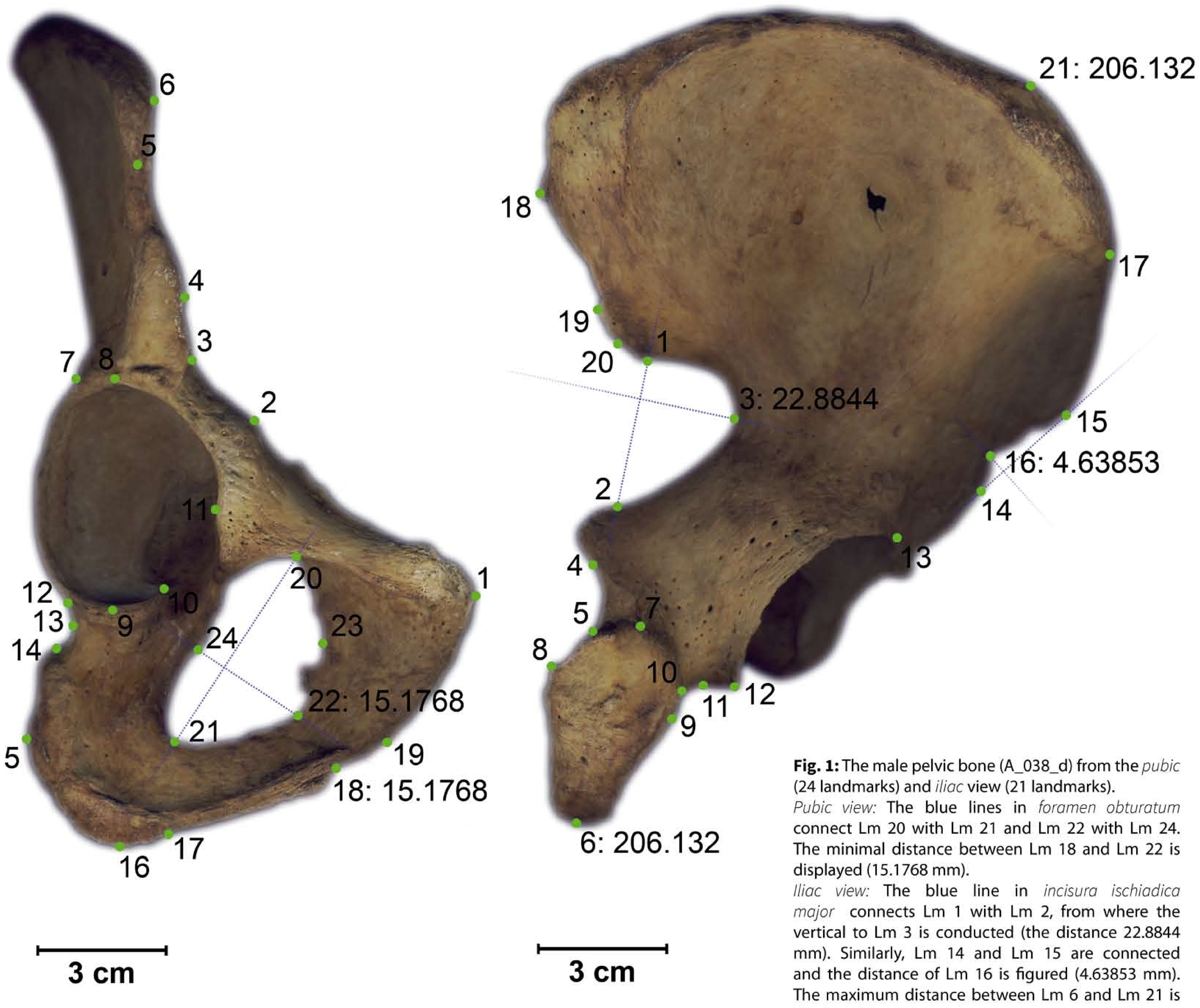


Fig. 1: The male pelvic bone (A_038_d) from the *pubic* (24 landmarks) and *iliac* view (21 landmarks).
Pubic view: The blue lines in *foramen obturatum* connect Lm 20 with Lm 21 and Lm 22 with Lm 24. The minimal distance between Lm 18 and Lm 22 is displayed (15.1768 mm).
Iliac view: The blue line in *incisura ischiadica major* connects Lm 1 with Lm 2, from where the vertical to Lm 3 is conducted (the distance 22.8844 mm). Similarly, Lm 14 and Lm 15 are connected and the distance of Lm 16 is figured (4.63853 mm). The maximum distance between Lm 6 and Lm 21 is displayed (206.132 mm).

Cross-validation testing (exhaustive leave-one-out) was performed on the whole reference sample. To present an example of the results, the sex estimation accuracy test by means of pure shape variables (Procrustes coordinates) was assessed. On the whole, the test performed 1782 individual estimations. In each of the individual estimations, on average 106 females and 151 males were included, and accuracy of estimates of training samples (resubstitution accuracy) ranged from 86.7 % to 99.2 %. The overall cross-validation accuracies (counts and percentages of correct sex assignment) are presented in Table 1. This test showed the ability of the method to estimate sex by shape variables without including size factors.

Table 1: Frequency tables of sex estimation accuracies using method of geometric morphometrics (percentage in brackets). It is evident that frequencies of correctly assigned male bones are slightly higher (97.3 %) and in both sexes accuracies slightly increases from iliac to pubic view to their combinations.

Documented sex	Sex estimation	Pelvic view: Iliac	Pelvic view: Pubic	Pelvic view: Combination	Total
Male	Male	328 (95.3)	335 (97.7)	339 (98.8)	1002 (97.3)
	Female	16 (4.7)	8 (2.3)	4 (1.2)	28 (2.7)
	Total	344 (100.0)	343 (100.0)	343 (100.0)	1030 (100.0)
Female	Female	236 (91.5)	229 (92.7)	237 (96.0)	702 (93.4)
	Male	22 (8.5)	18 (7.3)	10 (4.0)	50 (6.6)
	Total	258 (100.0)	247 (100.0)	247 (100.0)	752 (100.0)

Conclusions

The computer program HIP 1.0 brings new possibilities in the process of sex estimation of adult human skeletal remains. It is an open source software allowing variable setting of multiple methods. Some limitations of the software include dependence on graphical inputs derived from one particular scanning device and limited number (3) of reference samples. Future development will aim at widening range of image acquisition devices, database manager for building user-derived reference samples, and attached tools for multivariate comparisons of reference and testing samples at the population level.

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References

Bruzek, J. (2002): A method for visual determination of sex, using the human hip bone. *Am J Phys Anthropol*, 117: 157-168.

Gonzalez, P. N. - Bernal, V. - Perez, S. I. (2009): Geometric morphometric approach to sex estimation of human pelvis. *Forensic Sci Int*, 189: 68-74.

Murail, P. - Bruzek, J. - Houët, F. - Cunha, E. (2005): DSP - A tool for probabilistic sex diagnosis using worldwide variability in hip-bone measurements. *Bulletins et Mémoires de la Société d'Anthropologie de Paris*, 17 (3-4): 167-176.

Novotný, V. (1986): Sex determination of the pelvic bone - a systems approach. *Anthropologie*, 24 (2-3): 197-206.

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