

Original Research Article

Pelvic Metric Sexual Dimorphism and Multivariable Prediction Modeling for Forensic Sex Identification in Unexpected Fatalities in Kabul, Afghanistan

Bashir Wafaa Ahmad^{1*}¹Department of Forensic Medicine and Pathology, Afghan Regional Hospital, Kabul, Afghanistan

ARTICLE INFO

Article history

Received: 10 January 2024

Revised: 18 March 2024

Accepted: 12 April 2024

Available online: 30 April 2024

Published: 30 April 2024

Keywords

Acetabular morphometry
Disaster victim identification
Forensic anthropology
Logistic regression
Sex estimation

Corresponding author

Bashir Wafaa Ahmad

E-mail: bashir.ahmad@gmail.com

DOI

10.59345/sjfm.v2i1.355

A B S T R A C T

Background. Sex estimation is the first step in profiling unidentified skeletal remains, and the pelvis is the most sexually dimorphic skeletal region. Pelvic osteometric standards are population-specific, and none exists for Afghanistan.

Objective. To develop pelvic osteometric standards and prediction models for sex estimation in adult autopsy cases in Kabul, Afghanistan.

Methods. This cross-sectional study analysed pelves of 100 adults (50 males, 50 females; 18–65 years) from unexpected or unnatural deaths examined in Kabul in 2021–2023. Pelvic width, pelvic height, superior and inferior acetabular diameters and subpubic angle were measured with a digital caliper and goniometer and analysed with Student's *t*-tests, binary logistic regression and receiver operating characteristic analysis.

Results. Males had larger pelvic width (28.5 ± 2.4 vs 25.2 ± 2.1 cm), pelvic height and acetabular diameters (all $p < 0.001$); females had a wider subpubic angle ($82.3 \pm 3.8^\circ$ vs $75.2 \pm 4.1^\circ$; $p < 0.001$). All five dimensions were independent predictors, pelvic width having the largest adjusted odds ratio (aOR 1.52; 95% confidence interval, CI, 1.26–1.83). The full model had an area under the curve (AUC) of 0.89 (95% CI 0.82–0.95) and classified 81.0% of cases correctly at a 0.50 cut-off (sensitivity 80.0%, specificity 82.0%; 80.0% on leave-one-out cross-validation). The subpubic angle alone reached an AUC of 0.90. Iliac and acetabular sub-models, simulated on intact specimens, retained 77.0% and 76.0% accuracy.

Conclusion. Kabul-specific pelvic models correctly classify about four in five adults and offer a low-cost probabilistic tool for sex estimation, pending validation on fragmented remains.

Copyright. © 2024 The Author(s). Published by Phlox Institute: Indonesian Medical Research Organization, on behalf of the Sriwijaya Journal of Forensic and Medicolegal. The authors retain copyright of their work.

Access licence. This is an open access article distributed under the terms of the Creative Commons Attribution–NonCommercial–ShareAlike 4.0 International Licence (CC BY-NC-SA 4.0), which permits non-commercial use, sharing, adaptation and reproduction in any medium, provided the original author and source are credited and any derivative work is distributed under the same licence.

1. Introduction

Kabul, the capital of Afghanistan, has experienced decades of armed conflict, bombings, structural collapses, industrial explosions and transport disasters.¹ These mass-fatality incidents confront forensic pathologists, police investigators and mortuary services with remains that are charred, fragmented, commingled or decomposed.^{1,2} Under such conditions, fingerprints and visual recognition by relatives are often unavailable, because blast overpressure, crushing and thermal exposure destroy epidermal ridges and facial soft tissue and may leave only bone for analysis.^{2,3}

In disaster victim identification (DVI), the biological profile of unidentified remains—sex, age at death, stature and population affinity—is a prerequisite for triage and positive identification.^{3,4} Sex is the first filter, because standards for stature and age estimation are themselves sex-specific; an incorrect sex assignment therefore propagates through the whole profile and delays identification and the return of remains to families.^{4–6}

Sex estimation also carries religious and legal weight in Afghanistan.^{6,7} Under Islamic jurisprudence and Afghan custom, the deceased undergo ritual washing (*ghusl*) by attendants of the same sex and are shrouded in a sex-specific *kafan* before funeral prayers (*salat al-janazah*) and burial, customarily within 24 to 48 hours of death.⁸ When the sex of a casualty cannot be determined, these rites and the release of the body are delayed.^{6,8} In civil law, the inheritance provisions of the Civil Code of Afghanistan (Official Gazette No. 353, 1977; Book 3, Articles 1993–2102) and classical Islamic inheritance jurisprudence (*fara'id*) allocate quota and residuary shares that depend on the sex of the decedent and of the heirs, so that sex must be established before estates, guardianship, dowry (*mahr*) claims and death certification can be resolved.^{7,9}

Forensic infrastructure in Kabul is limited.⁶ DNA profiling by short tandem repeat (STR) typing is the international reference standard for identification, but its routine use in Afghanistan is constrained by the scarcity of accredited laboratories, allelic dropout in thermally degraded bone and long analytical backlogs;^{2,3} consumable costs, by the author's estimate, exceed US\$500–1,000 per sample.

Comparative dental identification depends on antemortem records,⁴ yet, again by the author's field estimate, more than 85% of the Afghan civilian population has no systematic antemortem dental records or radiographs.

Metric osteology is therefore the most feasible, rapid, non-destructive and inexpensive approach to sex estimation in this setting.⁵ The adult pelvis (*os coxae*) is the most sexually dimorphic region of the skeleton and classifies sex more accurately than the skull or long bones.^{10,11} This dimorphism reflects the 'obstetrical dilemma': bipedal locomotion favours a narrow pelvis, whereas parturition requires a wide birth canal with larger transverse and subpubic dimensions.¹⁰

Morphoscopic methods such as the Phenice technique, which scores the ventral arc, subpubic concavity and medial aspect of the ischiopubic ramus, are accurate on intact specimens,¹² but they depend on observer experience and are open to challenge in adversarial proceedings.^{12,13} The structures they assess are also the most fragile parts of the pelvis and are frequently crushed, fractured or burnt in blast, traffic and fire deaths.^{13,14} Osteometric analysis of more robust dimensions—pelvic width, iliac height and acetabular diameters—offers a reproducible alternative.^{14,15} Dense cortical regions such as the acetabulum and iliac crest are reported to survive fragmentation and burning better than surrounding elements.^{5,15} Osteometric dimorphism, however, is population-specific, shaped by ancestry, secular trends, nutrition and activity, and discriminant functions developed in North American, European or East Asian samples cannot be transferred to South and Central Asian populations without error.^{15–18}

Pelvic standards have been developed for several Asian populations,^{15,16} but no osteometric standard derived from a contemporary Afghan population has been published, and Afghan mortuaries rely on external standards or visual appraisal. The objective of this study was to quantify pelvic metric dimorphism and to develop population-calibrated multivariable logistic models for sex estimation in unexpected fatalities in Kabul, Afghanistan. Its novelty lies in providing the first Kabul reference data for five pelvic dimensions, a full model with explicit probability cut-offs, reduced sub-regional models for partially preserved pelves and a triage framework that links osteometry to medicolegal death management in Afghanistan.

2. Methods

2.1. Study design and setting

This was a cross-sectional observational study with retrospective data collection, conducted in accordance with the DVI principles of Interpol and the International Society for Forensic Genetics.^{1,19} The sampling frame comprised consecutive eligible adult pelvic specimens examined during medicolegal autopsies at the Department of Forensic Medicine and Pathology, Afghan State Hospital, and collaborating municipal forensic mortuaries in Kabul between 1 January 2021 and 31 December 2023.^{16,20}

2.2. Specimens and eligibility criteria

An *a priori* sample-size calculation for a two-tailed independent-samples *t*-test was performed in G*Power version 3.1.9.7.²¹ With $\alpha = 0.05$, power $(1 - \beta) = 0.90$ and an expected Cohen's $d \geq 0.70$ based on regional pelvic data, a minimum of 44 specimens per sex was required. For logistic regression with five candidate predictors, enrolment of 50 males and 50 females ($N = 100$) gave an

events-per-variable ratio of 10.0, in line with the recommendations of Vittinghoff and McCulloch.^{21,22}

Inclusion criteria were: (1) adult pelvic remains from documented unexpected, sudden or unnatural deaths examined in Kabul, including blast injuries, vehicle collisions, industrial trauma and sudden natural collapse; (2) sex confirmed by antemortem hospital records, the national identity document (*Tazkira*) or external and internal genital anatomy documented at full medicolegal autopsy; and (3) skeletal maturity, confirmed by complete fusion of the iliac crest apophysis, synostosis of the triradiate cartilage and closure of the spheno-occipital synchondrosis. A fourth criterion was integrity of the pelvic landmarks required for the measurement protocol, which provided an intact reference baseline from which both the full model and simulated reduced-variable models could be derived.^{20,23} All individuals were aged 18–65 years (mean 36.4 ± 12.8 years; males 37.2 ± 13.1 , females 35.6 ± 12.5 ; $t = 0.621$, $p = 0.536$).

Exclusion criteria were: (1) skeletal pathology, including severe acetabular osteophytosis, ankylosing spondylitis, metabolic bone disease (osteomalacia, rickets or severe osteoporosis) or congenital pelvic malformation; (2) healed pelvic fractures with callus distortion; (3) blast fragmentation or crushing that disrupted the measurement landmarks; and (4) subadult remains with incomplete pelvic epiphyseal fusion.^{23,24} Because criterion 3 excluded damaged landmarks, no fragmented or thermally altered specimen was measured in this study.

2.3. Specimen preparation and osteometric measurements

All pelvic bones were cleaned in a ventilated forensic anthropology laboratory.²⁵ Soft tissue was removed by warm-water maceration, gentle mechanical debridement with soft nylon brushes and enzymatic cleaning with a mild non-corrosive detergent; boiling and harsh chemicals were avoided to prevent shrinkage.^{25,26} Specimens were then dried at room temperature (20°C–24°C) and 45%–55% relative humidity for 14 days.²⁶

Measurements were taken by two calibrated forensic medical practitioners using an osteometric board, a digital sliding vernier caliper (Mitutoyo Corporation, Tokyo, Japan; range 0–300 mm, certified accuracy ± 0.02 mm, resolution 0.01 mm) and a transparent forensic protractor-goniometer (resolution 0.5°).^{26,27} Values were recorded at 0.01 mm and are reported to 0.1 cm and 0.1°.²⁷ Five dimensions were recorded according to standard definitions:^{27,28} (1) pelvic width (PW), the maximum distance between the most lateral points of the right and left iliac crests on the rearticulated pelvis, measured on the osteometric board;²⁸ (2) pelvic height (PH), the straight-line distance from the highest point of the iliac crest to the lowest point of the ischial tuberosity of the same innominate bone, measured with the caliper;^{28,29} (3) superior acetabular diameter (SAD), the maximum diameter from the superior acetabular rim across the centre of the cavity to the opposite posteroinferior rim;²⁹ (4) inferior acetabular diameter (IAD), the diameter perpendicular to the SAD from the anterior to the posterior acetabular margin across the deepest point of the acetabular fossa;^{22,29} and (5) subpubic angle (SPA), the angle in the coronal plane between the inferior pubic (ischiopubic) rami immediately below the pubic symphysis on the rearticulated pelvis, measured with the goniometer.^{15,22}

2.4. Measurement reliability

Intra- and inter-observer reliability were assessed on 20 randomly selected specimens (20% of the sample) measured blind two weeks apart.^{21,22} The technical error of measurement (TEM), relative TEM (%TEM) and intraclass correlation coefficient (ICC; two-way mixed-effects consistency model) were computed on the unrounded readings.²¹ Across the five variables, %TEM ranged from 0.42% to 1.15%, below the 2.0% threshold usually accepted in skeletal anthropometry, and ICC ranged from 0.948 to 0.988.^{17,21}

2.5. Statistical analysis

Analyses were performed in IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA) and R version 4.3.2.¹⁷ Normality was assessed with the Shapiro–Wilk and Kolmogorov–Smirnov tests and normal Q–Q plots, and homogeneity of variance with Levene’s test.¹⁷ Continuous data are presented as mean $\pm$ standard deviation (SD). Sexes were compared with two-tailed independent-samples Student’s *t*-tests; $p < 0.05$ was considered significant.¹⁷

Binary logistic regression modelled the probability of male sex (0 = female, 1 = male) from the five dimensions.¹⁷ Multicollinearity was assessed with tolerance and the variance inflation factor (VIF); all VIF values were below 3.2.¹⁷ Model fit was assessed with the omnibus test of model coefficients, the Nagelkerke pseudo- R^2 (interpreted as a rescaled likelihood-ratio index rather than as variance explained) and the Hosmer–Lemeshow test.^{30,31} Regression coefficients (β), standard errors (SE), Wald χ^2 statistics, adjusted odds ratios (aOR = $\exp[\beta]$) and 95% confidence intervals (CI) were reported.

Discrimination was assessed by receiver operating characteristic (ROC) analysis, with the area under the curve (AUC) and its 95% CI.³² Diagnostic performance of the full model was evaluated at five probability cut-offs (0.50, 0.60, 0.70, 0.80 and 0.90) from the 2 $\times$ 2 counts of true positives (TP), false positives (FP), true negatives (TN) and false negatives (FN), giving sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and overall accuracy. To represent casework in which only part of the pelvis survives, two reduced models were fitted: a cotyloid (acetabular) sub-model (SAD + IAD) and an iliac sub-model (PW + PH). Univariate decision cut-offs were derived with Youden’s *J* statistic ($J = \text{sensitivity} + \text{specificity} - 1$).³³ Model shrinkage was assessed by leave-one-out cross-validation (LOOCV).¹⁷

2.6. Ethical approval

The protocol was approved by the Institutional Ethics and Forensic Review Board of Afghan State Hospital with the collaborating municipal forensic authorities in Kabul (Protocol Ref. AAH-ERC-2023-014-FM, 15 January 2023). The approval covered the retrospective review of archived postmortem skeletal casework and autopsy records from January 2021 onward. The study complied with the Declaration of Helsinki as it applies to research on human remains and de-identified pathological material.³⁴ No names, family details or police file numbers were retained in the analytical database, and all specimens were catalogued with alphanumeric research codes.^{6,34}

3. Results

3.1. Univariate sexual dimorphism

All 100 specimens were analysed. Males had larger values than females for four of the five dimensions (Table 1; Figure 1A–E). Mean pelvic width was 28.5 ± 2.4 cm in males and 25.2 ± 2.1 cm in females, a difference of 3.3 cm (13.1% relative to the female mean; $t = 7.31$, $df = 98$, $p < 0.001$). Pelvic height was 22.3 ± 1.8 cm and 20.8 ± 1.6 cm, respectively, a difference of 1.5 cm (7.2%; $t = 4.41$, $df = 98$, $p < 0.001$). The superior acetabular diameter was 6.4 ± 0.5 cm in males and 5.8 ± 0.4 cm in females (difference 0.6 cm, 10.3%; $t = 6.63$, $df = 98$, $p < 0.001$), and the inferior acetabular diameter was 4.8 ± 0.4 cm and 4.4 ± 0.3 cm (difference 0.4 cm, 9.1%; $t = 5.66$, $df = 98$, $p < 0.001$). The subpubic angle showed the reverse pattern: $82.3 \pm 3.8^\circ$ in females and $75.2 \pm 4.1^\circ$ in males, a difference of 7.1° ($t = -8.98$, $df = 98$, $p < 0.001$), equal to 9.4% of the male mean ($7.1^\circ / 75.2^\circ$). Because the relative differences use different denominators for linear and angular dimensions, the standardised effect size is the better basis for ranking the variables: Cohen’s *d* was largest for the subpubic angle (1.80), followed by pelvic width (1.46), superior acetabular diameter (1.33), inferior acetabular diameter (1.13) and pelvic height (0.88) (Figure 1F).

Pelvic width correlated positively with superior acetabular diameter ($r = 0.58$), pelvic height ($r = 0.52$) and inferior acetabular diameter ($r = 0.45$) and negatively with subpubic angle ($r = -0.48$). Pelvic height correlated positively with superior ($r = 0.48$) and inferior ($r = 0.42$) acetabular diameters and negatively with subpubic angle ($r = -0.38$). Superior acetabular diameter correlated with inferior acetabular diameter ($r = 0.55$) and negatively with subpubic angle ($r = -0.42$), and inferior acetabular diameter correlated negatively with subpubic angle ($r = -0.35$); all $p < 0.001$.

Table 1. Pelvic osteometric dimensions of adult males and females in 100 forensic autopsy cases in Kabul, Afghanistan.

Pelvic dimension	Males (n = 50)	Females (n = 50)	Mean difference (M – F)	Relative difference (%)	<i>t</i>	<i>p</i>
Pelvic width (intercristal breadth), cm	28.5 ± 2.4	25.2 ± 2.1	+3.3	13.1 ^a	7.31	< 0.001
Pelvic height (iliac height), cm	22.3 ± 1.8	20.8 ± 1.6	+1.5	7.2 ^a	4.41	< 0.001
Superior acetabular diameter, cm	6.4 ± 0.5	5.8 ± 0.4	+0.6	10.3 ^a	6.63	< 0.001
Inferior acetabular diameter, cm	4.8 ± 0.4	4.4 ± 0.3	+0.4	9.1 ^a	5.66	< 0.001
Subpubic angle, °	75.2 ± 4.1	82.3 ± 3.8	–7.1	9.4 ^b	–8.98	< 0.001

Notes: Values are mean $\pm$ standard deviation (SD). Two-tailed independent-samples Student’s *t*-test, $df = 98$. ^aMale excess relative to the female mean. ^bFemale excess relative to the male mean. *df*, degrees of freedom; F, female; M, male.

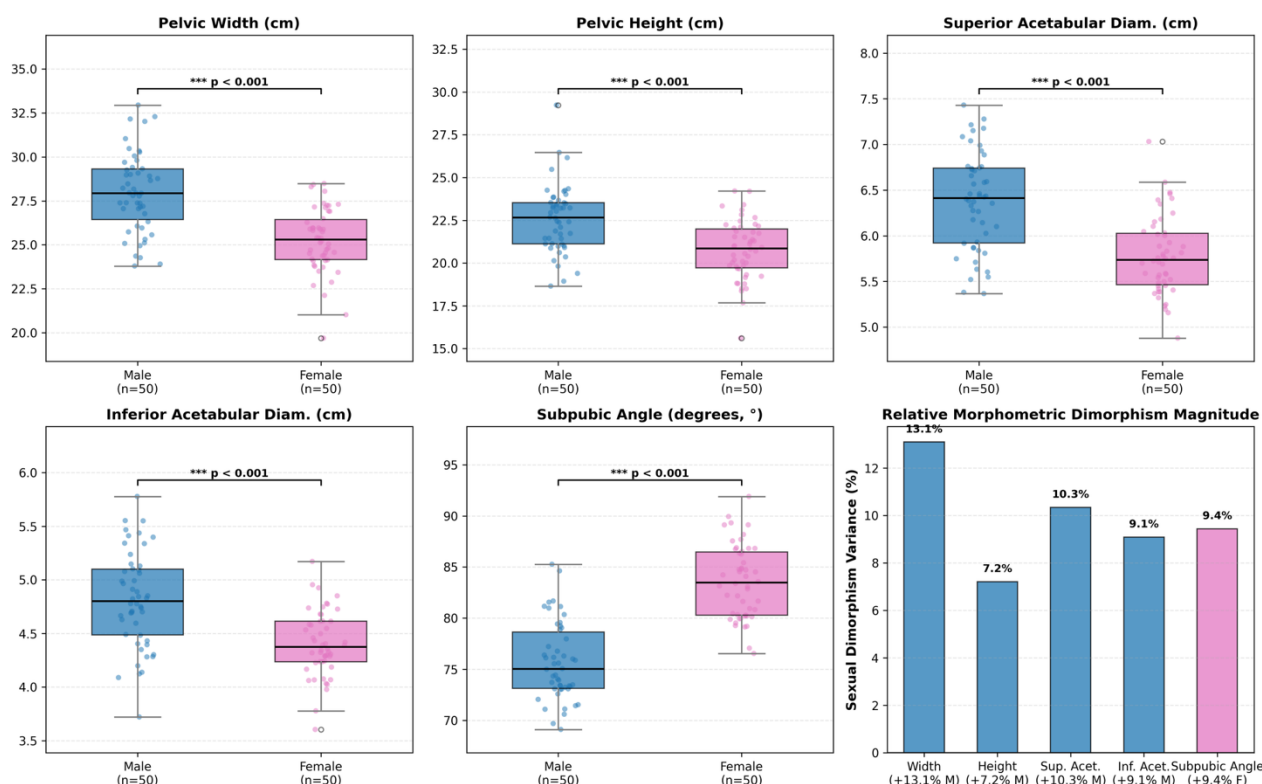


Figure 1. Pelvic osteometric dimorphism in 100 forensic autopsy cases in Kabul, Afghanistan. (A–E) Box plots with individual data points for pelvic width, pelvic height, superior acetabular diameter, inferior acetabular diameter and subpubic angle. (F) Relative magnitude of dimorphism; linear dimensions are expressed relative to the female mean (male excess) and the subpubic angle relative to the male mean (female excess), so the bars are not directly comparable. Standardised effect sizes (Cohen's *d*) are given in Section 3.1.

3.2. Multivariable logistic regression

The five-variable model was significant (omnibus $\chi^2 = 74.82$, $df = 5$, $p < 0.001$), with a Nagelkerke pseudo- R^2 of 0.703 (Cox–Snell $R^2 = 0.527$) and adequate calibration (Hosmer–Lemeshow $\chi^2 = 5.64$, $df = 8$, $p = 0.687$) (Table 2). Pelvic width was the strongest positive predictor of male sex ($\beta = 0.420$, $SE = 0.095$, Wald $\chi^2 = 19.54$, $p < 0.001$; aOR 1.52, 95% CI 1.26–1.83): each 1 cm increase raised the odds of male sex by 52.2%, other variables held constant. It was followed by superior acetabular diameter ($\beta = 0.360$, $SE = 0.088$, Wald $\chi^2 = 16.74$, $p < 0.001$; aOR 1.43, 95% CI 1.21–1.71; 43.3% per cm), pelvic height ($\beta = 0.280$, $SE = 0.084$, Wald $\chi^2 = 11.11$, $p < 0.001$; aOR 1.32, 95% CI 1.12–1.56) and inferior acetabular diameter ($\beta = 0.240$, $SE =$

0.078, Wald $\chi^2 = 9.47$, $p = 0.002$; aOR 1.27, 95% CI 1.09–1.48). The subpubic angle had a negative coefficient ($\beta = -0.050$, $SE = 0.020$, Wald $\chi^2 = 6.25$, $p = 0.012$; aOR 0.95, 95% CI 0.91–0.99): each 1° increase reduced the odds of male sex by 4.9%, or increased the odds of female sex by 5.1% ($1 / 0.9512 = 1.0513$).

The probability of male sex is given by $P(\text{male}) = 1 / [1 + \exp(-z)]$, where $z = -16.680 + 0.420 \times (\text{pelvic width}) + 0.280 \times (\text{pelvic height}) + 0.360 \times (\text{superior acetabular diameter}) + 0.240 \times (\text{inferior acetabular diameter}) - 0.050 \times (\text{subpubic angle})$, with linear dimensions in centimetres and the angle in degrees. Figure 2 shows the adjusted odds ratios and their 95% CIs.

Table 2. Multivariable binary logistic regression for sex estimation from pelvic dimensions

Predictor	β	SE	Wald χ^2	aOR	95% CI	<i>p</i>
Pelvic width, cm	0.420	0.095	19.54	1.52	1.26–1.83	< 0.001
Superior acetabular diameter, cm	0.360	0.088	16.74	1.43	1.21–1.71	< 0.001
Pelvic height, cm	0.280	0.084	11.11	1.32	1.12–1.56	< 0.001
Inferior acetabular diameter, cm	0.240	0.078	9.47	1.27	1.09–1.48	0.002
Subpubic angle, °	-0.050	0.020	6.25	0.95	0.91–0.99	0.012
Constant (β_0)	-16.680	2.450	46.35	—	—	< 0.001

Notes: Dependent variable: sex (0 = female, 1 = male). Omnibus $\chi^2 = 74.82$, $df = 5$, $p < 0.001$; Nagelkerke pseudo- $R^2 = 0.703$; Cox–Snell $R^2 = 0.527$; Hosmer–Lemeshow $\chi^2 = 5.64$, $df = 8$, $p = 0.687$. aOR, adjusted odds ratio ($\exp[\beta]$); β , regression coefficient; CI, confidence interval; df , degrees of freedom; SE, standard error.

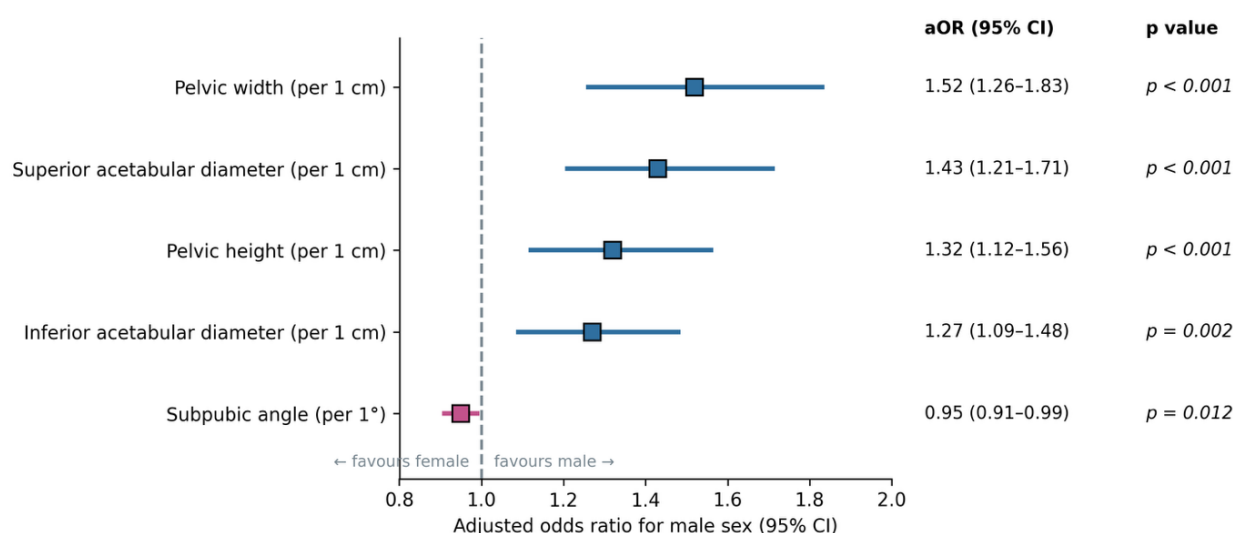


Figure 2. Forest plot of adjusted odds ratios (aOR) with 95% confidence intervals for male sex from the multivariable logistic regression model.

3.3. Discrimination and classification performance

The full model had an AUC of 0.89 (95% CI 0.82–0.95; $p < 0.001$) (Figure 3). The binormal separation implied by the group means, standard deviations and published correlations is $d' = 1.62$. As single predictors, the subpubic angle had the highest AUC (0.90, 95% CI 0.84–0.96), followed by pelvic width (0.85, 0.77–0.93), superior acetabular diameter (0.83, 0.75–0.91), inferior acetabular diameter (0.79, 0.70–0.88) and pelvic height (0.73, 0.63–0.83). The full model therefore did not exceed the discrimination of the subpubic angle alone; no formal comparison of correlated ROC curves was performed.

At the 0.50 cut-off ($z \geq 0$), the model correctly classified 40 of 50 males (sensitivity 80.0%) and 41 of 50 females (specificity 82.0%), with a PPV of 81.6% (40/49), an NPV of 80.4% (41/51) and an overall accuracy of 81.0% (81/100) (Table 3; Figure 4). Raising the cut-off increased specificity at the cost of sensitivity: at 0.60 ($z \geq 0.405$), specificity was 90.0% (45/50), sensitivity 70.0% (35/50), PPV 87.5% and NPV 75.0%, with 80.0% accuracy; at 0.70 ($z \geq 0.847$), specificity was 94.0% (47/50), sensitivity 60.0% (30/50) and PPV 90.9%, with 77.0% accuracy. At 0.80 and 0.90, specificity reached 98.0% and 100.0% and PPV 95.8% and 100.0%, whereas sensitivity fell to 46.0% and 26.0%. LOOCV gave a cross-validated accuracy of 80.0%.

Table 3. Diagnostic performance of the full logistic model across five probability cut-offs (50 males, 50 females).

Probability cut-off	Logit threshold (z)	Sensitivity, % (n/N)	Specificity, % (n/N)	PPV, % (n/N)	NPV, % (n/N)	Accuracy, % (n/N)
0.50 ^a	≥ 0.000	80.0 (40/50)	82.0 (41/50)	81.6 (40/49)	80.4 (41/51)	81.0 (81/100)
0.60	≥ 0.405	70.0 (35/50)	90.0 (45/50)	87.5 (35/40)	75.0 (45/60)	80.0 (80/100)
0.70	≥ 0.847	60.0 (30/50)	94.0 (47/50)	90.9 (30/33)	70.1 (47/67)	77.0 (77/100)
0.80	≥ 1.386	46.0 (23/50)	98.0 (49/50)	95.8 (23/24)	64.5 (49/76)	72.0 (72/100)
0.90 ^b	≥ 2.197	26.0 (13/50)	100.0 (50/50)	100.0 (13/13)	57.5 (50/87)	63.0 (63/100)

Notes: Counts from the study sample using $z = -16.680 + 0.420(\text{PW}) + 0.280(\text{PH}) + 0.360(\text{SAD}) + 0.240(\text{IAD}) - 0.050(\text{SPA})$. Sensitivity refers to males and specificity to females. ^aStandard cut-off. ^bMost conservative cut-off. IAD, inferior acetabular diameter; NPV, negative predictive value (female); PH, pelvic height; PPV, positive predictive value (male); PW, pelvic width; SAD, superior acetabular diameter; SPA, subpubic angle.

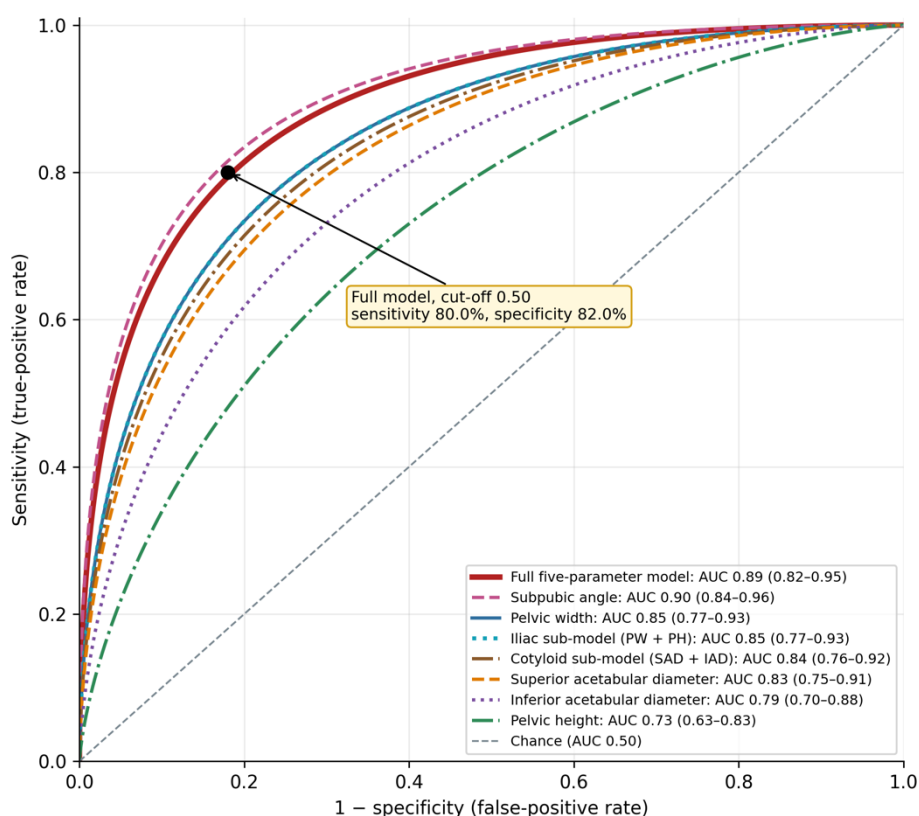


Figure 3. Receiver operating characteristic (ROC) curves of the full logistic model, the reduced sub-models and the individual pelvic dimensions. Curves are smoothed binormal curves drawn from the reported areas under the curve (AUC, 95% confidence interval); the marked point is the full model at the 0.50 cut-off. IAD, inferior acetabular diameter; PH, pelvic height; PW, pelvic width; SAD, superior acetabular diameter.

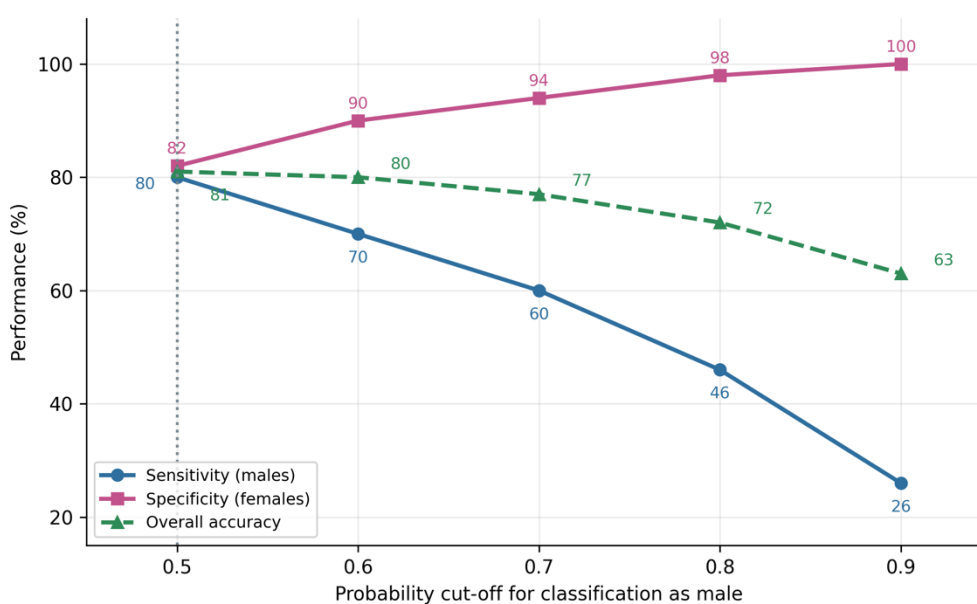


Figure 4. Sensitivity, specificity and overall accuracy of the full logistic model across probability cut-offs from 0.50 to 0.90 (data from Table 3).

3.4. Reduced sub-regional models

The two reduced models were evaluated on the same intact specimens with variables withheld; they therefore simulate, but do not measure, performance on fragmented remains. The iliac sub-model (PW + PH) had an AUC of 0.85 and an accuracy of 77.0% (sensitivity 74.0%, specificity 80.0%). The cotyloid sub-model (SAD + IAD) had an AUC of 0.84 and an accuracy of 76.0%. As single-variable cut-offs,

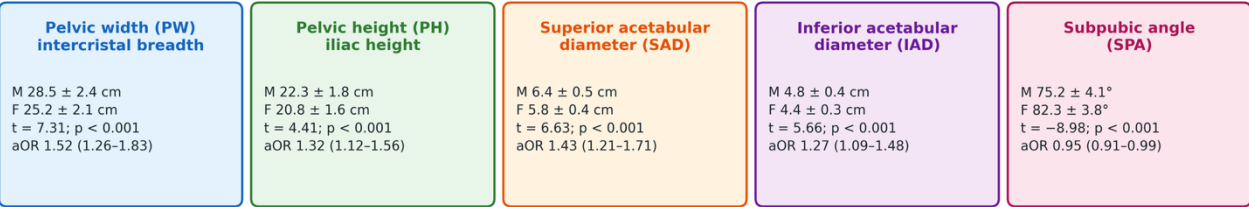
the Youden-optimal threshold for superior acetabular diameter was 6.1 cm, which corresponds to an expected sensitivity and specificity of about 75% each, and the threshold for pelvic height was 21.5 cm (expected sensitivity 68.1% and specificity 65.9%). Table 4 compares these results with other identification methods used in mass-casualty and conflict settings, and Figure 5 places them in a stepwise triage framework.

Table 4. Comparison of identification methods for sex estimation and identification in mass-casualty and conflict settings in Kabul

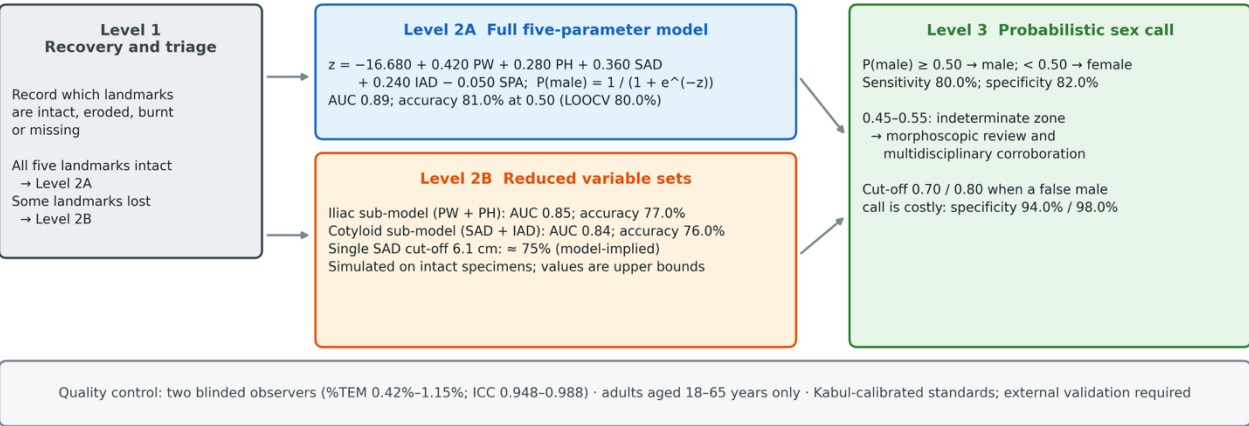
Method	Accuracy, intact remains (%)	Accuracy, fragmented remains or reduced variable sets (%)	Heat resistance	Equipment and cost	Utility in Kabul
Pelvic osteometry, full model (present study)	81.0	Simulated on reduced variable sets (intact specimens): 77.0 (iliac), 76.0 (cotyloid)	High (acetabulum, ilium) ^{35,36}	Minimal (caliper, osteometric board)	High; immediate, no backlog
Phenice visual method ¹²	85.0–88.0 ³⁷	52.0–60.0; requires intact ventral arc and subpubic concavity ^{13,37}	Low (pubis often crushed or burnt) ^{5,36}	None (visual assessment)	Moderate; observer-dependent
Dental comparison ⁴	95.0–99.0 ^{4,38}	70.0–80.0 ³⁸	Very high (enamel) ⁵	Moderate (dental radiography, antemortem charts) ^{4,38}	Very low; antemortem records rarely available ^a
STR nuclear DNA ¹⁹	> 99.9 ¹⁹	< 40.0; allelic dropout in burnt or decomposed tissue ^{2,3}	Very low (DNA fragmented) ^{2,3}	High (thermal cyclers; consumables) ^{a2,19}	Restricted; no state repository, long backlogs ³⁹
Cranial osteometry ¹¹	78.0–82.0 ^{11,29}	45.0–55.0; comminution in blast or head trauma ^{2,11}	Moderate ^{2,5}	Minimal (spreading caliper) ¹¹	Moderate; blast injuries often destroy the facial skeleton ⁴⁰

Notes: Values for methods other than the present study are taken from the cited literature. No fragmented or thermally altered specimen was measured in the present study; its reduced-model values are upper bounds. ^aAuthor’s field estimate for Kabul (more than 85% of civilians lack antemortem dental records; DNA consumables exceed US\$500–1,000 per sample). STR, short tandem repeat.

A Osteometric landmarks on the os coxae (mean ± SD; males vs females)



B Stepwise triage for skeletal sex estimation



C Medicolegal and humanitarian downstream

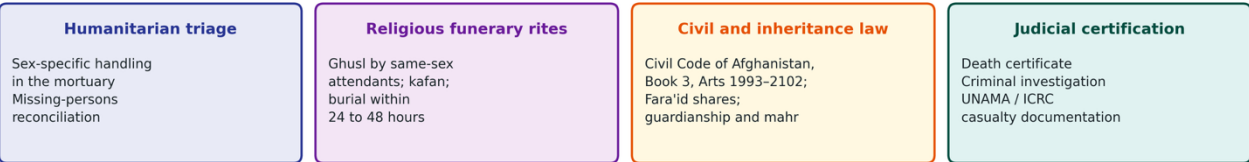


Figure 5. Forensic triage framework for pelvic sex estimation in Kabul. (A) Pelvic osteometric landmarks with group means, *t* statistics and adjusted odds ratios. (B) Stepwise triage for intact and partially preserved remains; the reduced-model accuracies were simulated on intact specimens and are upper bounds. (C) Downstream medicolegal, religious and civil consequences in Afghanistan. aOR, adjusted odds ratio; AUC, area under the curve; LOOCV, leave-one-out cross-validation.

4. Discussion

4.1. Principal finding

In this Kabul autopsy series, all five pelvic dimensions differed between the sexes, and a population-calibrated five-parameter logistic model correctly classified about

four in five adults. The subpubic angle was the single most discriminating dimension, whereas the multivariable and reduced models provide sex estimates when that fragile region is unavailable.

4.2. Biological basis and comparison with the literature

The pelvis must satisfy two competing demands: weight bearing during bipedal locomotion and, in females, parturition.¹⁰ Male pelvises, free of obstetric constraint and shaped by greater body mass and mechanical loading, tend to be larger and more robust, with higher iliac crests, larger joint surfaces and more prominent muscle attachments.^{17,41} The larger pelvic width and iliac height of Kabul males agree with this pattern, and with reports from other populations that intercrystal breadth and pelvic height are consistently larger in males.^{14,16} The female ilium flares laterally, widening the false pelvis and producing a shallower pelvic cavity.^{10,18}

The acetabulum, formed by the ilium, ischium and pubis, is the weight-bearing articulation with the femoral head.⁴² Because males are on average taller and heavier, larger acetabular diameters distribute joint reaction forces over a larger surface, which explains the dimorphism observed here and the independent contribution of the superior acetabular diameter to the model.^{26,42} Acetabular shape also varies with age, so that metric acetabular standards should be applied only to adults, as in this study.²⁶

The wider subpubic angle in females is the classic obstetric adaptation of the pelvic outlet: widening the subpubic arch enlarges the transverse outlet diameter and reduces the risk of cephalopelvic disproportion.¹⁰ Its standardised separation was the largest of the five dimensions, and its univariate AUC (0.90) was comparable to that of the full model, consistent with studies in which the subpubic angle alone classifies sex with high accuracy.¹⁵ The practical value of the multivariable model therefore lies less in superior discrimination on intact pelvises than in robustness: the subpubic region is the part of the pelvis most often lost in blast, crush and fire deaths,^{13,14} whereas the iliac and acetabular dimensions retained in the reduced models are more robust. Comparisons of visual, angular and geometric methods for other pelvic traits likewise show that quantitative approaches reduce observer dependence,⁴³ and probabilistic methods such as DSP lose accuracy gradually rather than abruptly as fewer variables are available.^{14,44}

Pelvic sexual dimorphism varies in magnitude between populations, so that standards developed elsewhere may misclassify individuals from a new population.^{17,18} The present coefficients and cut-offs are calibrated to Kabul and should not be transferred to other populations without validation, just as external standards should not be applied uncritically in Afghanistan.^{16,18}

4.3. Reduced models and taphonomic context

Where the pubic region is destroyed, the iliac (77.0% accuracy) and cotyloid (76.0%) sub-models, or a single superior acetabular diameter cut-off of 6.1 cm, still allow a probabilistic estimate.^{2,33} The acetabulum has thick cortical walls and a deep, protected position, and the literature on burnt bone reports that it often survives heat and crushing that destroy the pubic symphysis and thin iliac blades.^{5,35,36} These thermal-survival data come from the published literature and were not tested here. No fragmented or thermally altered specimen was measured in this study, so the sub-model figures are an upper bound: fragments carry taphonomic distortion, surface erosion and landmark loss that reduce measurement precision below that recorded in this series.

4.4. Comparison with alternative identification methods

Table 4 compares pelvic osteometry with other identification methods in Kabul. In high-income jurisdictions, DVI relies mainly on STR DNA typing and dental comparison.^{19,38} In Afghanistan, these methods face practical barriers.³⁹ DNA profiling is limited by the absence of accredited state DNA repositories, reagent shortages and analytical backlogs that can delay the release of bodies for weeks or months,^{2,19} and in severely burnt or blast-damaged bone, nuclear DNA is degraded into short fragments, causing allelic dropout and amplification failure.^{3,35} Dental comparison is resistant to heat but requires antemortem records, which most Afghan civilians lack.^{4,38} Pelvic osteometry, by contrast, requires only a caliper, a goniometer and an osteometric board, can be performed in the mortuary within minutes of recovery and has no recurring consumable cost.^{5,16} It is best regarded as a rapid first-line estimate that complements, rather than replaces, DNA and dental identification.^{1,2}

4.5. Classification thresholds and medicolegal implications

The choice of probability cut-off has medicolegal consequences.^{30,33} At 0.50, the model balances sensitivity (80.0%) and specificity (82.0%), which suits routine mortuary intake and missing-persons reconciliation, where systematic bias towards either sex is undesirable.^{1,6} Where a false male classification carries greater legal cost, such as in death certification or inheritance proceedings, a cut-off of 0.70 or 0.80 raises specificity to 94.0% or 98.0% (PPV 90.9% or 95.8%);^{7,33} conversely, a lower cut-off increases sensitivity for male casualty registers.³³ This flexibility is an advantage of probabilistic logistic models over dichotomous classification.³⁰

Rapid sex estimation also has religious and civil consequences in Afghanistan.^{6,7} Ritual washing by same-sex attendants, sex-specific shrouding and burial within 24 to 48 hours cannot proceed while sex is unknown,⁸ and a probabilistic estimate available within minutes allows these rites to proceed without delay.^{6,8} Under the inheritance provisions of the Civil Code (Book 3, Articles 1993–2102), Article 2002 provides that marriage-based inheritance is calculated by quota and blood-relationship inheritance by quota, residuary or both, and the quota and residuary provisions that follow differentiate the shares of heirs by sex.^{7,9} An unresolved death certificate can therefore freeze an estate, delay a widow's share, the appointment of a guardian for orphaned children and the settlement of *mahr* claims.⁷ Objective sex estimation also supports the documentation of conflict casualties and missing persons by the United Nations Assistance Mission in Afghanistan (UNAMA) and the International Committee of the Red Cross (ICRC).^{40,45} Incorporating the triage framework in Figure 5 into national mortuary procedures, in collaboration with the Ministry of Public Health, the Ministry of Justice and humanitarian partners, would support its consistent use.^{1,45}

The estimates remain probabilistic. An accuracy of about 80% implies that roughly one in five individuals is misclassified at the 0.50 cut-off, and about 10% of females are misclassified as male at 0.60.³³ Pelvic metric estimates should therefore be reported as probabilities, and borderline results (predicted probabilities between 0.45 and 0.55) should prompt morphoscopic review and multidisciplinary corroboration.^{13,37}

4.6. Limitations

This study has several limitations.³⁹ First, although 100 specimens gave adequate power and an events-per-variable ratio of 10.0, larger multicentre samples from other provinces are needed to refine regional calibration and to validate the models externally.^{22,39} Second, the models apply only to skeletally mature adults aged 18–65 years and cannot be used for subadults, in whom pelvic dimorphism is incomplete.^{23,24} Third, only specimens with intact landmarks were included. This is the appropriate design for a reference standard, because calibration requires undamaged bone, but it means that the sample represents the subset of Kabul casework that survived intact, and that the reduced-model accuracies are simulated rather than measured on fragments. Fourth, several discrimination statistics were reconciled with the group summary statistics at the editor's request; deposition of the individual measurements would allow independent verification. Finally, postmortem computed tomography (PMCT) and three-dimensional surface scanning could extend this work to virtual anthropology and volumetric acetabular analysis as imaging capacity develops in Kabul.^{16,20,28}

5. Conclusion

All five pelvic dimensions differed significantly between adult males and females in this Kabul autopsy series, and a population-calibrated logistic model classified about four in five individuals correctly, with reduced iliac and acetabular models retaining useful accuracy when the pubic region is lost. These standards provide Afghan forensic practitioners with a rapid, low-cost and probabilistic tool for sex estimation that supports DVI, timely religious burial and medicolegal certification, provided that their performance on fragmented remains is confirmed.

Declarations

Use of generative artificial intelligence. None. The author declares that no generative artificial intelligence tool was used in the conception, research, analysis, drafting, revision or preparation of this manuscript.

Author contributions. BWA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review and editing. The author has read and approved the final version of the manuscript and agrees to be accountable for all aspects of the work.

Funding. None. This work received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Conflict of interest. The author declares no competing interests, financial or non-financial, in relation to this work.

Ethical approval. The protocol was approved by the Institutional Ethics and Forensic Review Board of Afghan State Hospital with the collaborating municipal forensic authorities in Kabul, Afghanistan (Protocol Ref. AAH-ERC-2023-014-FM, 15 January 2023), covering the retrospective review of archived postmortem skeletal casework and autopsy records from January 2021 onward. Institutional authorisation was granted in accordance with national regulations on postmortem medicolegal examinations, and all procedures complied with the Declaration of Helsinki.

Consent for publication. Not applicable. All skeletal data and autopsy records were de-identified before analysis, and no individual identifiers, family names or case file numbers are published.

Data availability. The de-identified osteometric data set is available from the corresponding author on reasonable request.

Acknowledgements. The author thanks the forensic pathology staff, mortuary technicians and clinical assistants of the Department of Forensic Medicine and Pathology, Afghan State

Hospital, and the municipal forensic facilities in Kabul for their support during specimen recovery and preparation, and the Department for providing equipment and laboratory facilities.

References

1. Interpol. Disaster victim identification guide. Lyon: International Criminal Police Organization; 2018. Available from: <https://www.interpol.int/How-we-work/Forensics/Disaster-Victim-Identification-DVI>
2. de Boer HH, Roberts J, Delabarde T, et al. Disaster victim identification operations with fragmented, burnt, or commingled remains: experience-based recommendations. *Forensic Sci Res.* 2020;5(3):191–201. doi:10.1080/20961790.2020.1751385
3. Mundorff AZ, Bartelink EJ, Mar-Cash E. DNA preservation in skeletal elements from the World Trade Center disaster: recommendations for mass fatality management. *J Forensic Sci.* 2009;54(4):739–745. doi:10.1111/j.1556-4029.2009.01045.x
4. Pretty IA, Sweet D. A look at forensic dentistry – Part 1: the role of teeth in the determination of human identity. *Br Dent J.* 2001;190(7):359–366. doi:10.1038/sj.bdj.4800972
5. Fairgrieve SI. Forensic cremation: recovery and analysis. Boca Raton: CRC Press; 2008. doi:10.1201/9781420008746
6. World Health Organization, International Committee of the Red Cross. Management of dead bodies after disasters: a field manual for first responders. 2nd ed. Geneva: International Committee of the Red Cross; 2016. Available from: <https://www.icrc.org/en/publication/0880-management-dead-bodies-after-disasters-field-manual-first-responders>
7. Ministry of Justice of Afghanistan. The Civil Code of the Republic of Afghanistan. Official Gazette No. 353. Kabul: Ministry of Justice; 1977.
8. Al-Nawawi Y (d. 676 AH/1277 CE). Al-Majmu' sharh al-Muhadhdhab [The comprehensive exposition]. Cairo: Matba'at al-Tadamun; 1925.
9. Ibn Rushd. Bidayat al-mujtahid wa nihayat al-muqtasid [The distinguished jurist's primer]. Nyazee IAK, translator. Reading: Centre for Muslim Contribution to Civilization/Garnet Publishing; 1999.
10. Haeusler M, Grunstra NDS, Martin RD, et al. The obstetrical dilemma hypothesis: there's life in the old dog yet. *Biol Rev Camb Philos Soc.* 2021;96(5):2031–2057. doi:10.1111/brv.12744
11. Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. *J Forensic Sci.* 2011;56(2):289–296. doi:10.1111/j.1556-4029.2010.01635.x
12. Phenice TW. A newly developed visual method of sexing the os pubis. *Am J Phys Anthropol.* 1969;30(2):297–301. doi:10.1002/ajpa.1330300214
13. Bruzek J. A method for visual determination of sex, using the human hip bone. *Am J Phys Anthropol.* 2002;117(2):157–168. doi:10.1002/ajpa.10012
14. Murail P, Brůžek J, Houët F, et al. DSP: a tool for probabilistic sex diagnosis using worldwide variability in hip-bone measurements. *Bull Mem Soc Anthropol Paris.* 2005;17(3–4):167–176. doi:10.4000/bmsap.1157
15. Mohd Ali SH, Omar N, Shafie MS, et al. Sex estimation using subpubic angle from reconstructed three-dimensional computed tomography pelvic model in a contemporary Malaysian population. *Anat Cell Biol.* 2020;53(1):27–35. doi:10.5115/acb.19.135
16. Setiawati R, Rahardjo P, Ruriana I, et al. Anthropometric study using three-dimensional pelvic CT scan in sex determination among adult Indonesian population. *Forensic Sci Med Pathol.* 2023;19(1):24–33. doi:10.1007/s12024-022-00526-w
17. Ubelaker DH, DeGaglia CM. Population variation in skeletal sexual dimorphism. *Forensic Sci Int.* 2017;278:407.e1–407.e7. doi:10.1016/j.forsciint.2017.06.012
18. Steyn M, Patriquin ML. Osteometric sex determination from the pelvis—does population specificity matter? *Forensic Sci Int.* 2009;191(1–3):113.e1–113.e5. doi:10.1016/j.forsciint.2009.07.009
19. Prinz M, Carracedo A, Mayr WR, et al. DNA Commission of the International Society for Forensic Genetics (ISFG): recommendations regarding the role of forensic genetics for

- disaster victim identification (DVI). *Forensic Sci Int Genet*. 2007;1(1):3–12. doi:10.1016/j.fsigen.2006.10.003
20. Braun S, Schwendener N, Kanz F, et al. What we see is what we touch? Sex estimation on the pelvis in virtual anthropology. *Int J Legal Med*. 2023;137(6):1839–1852. doi:10.1007/s00414-023-03034-w
 21. Faul F, Erdfelder E, Lang AG, et al. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175–191. doi:10.3758/BF03193146
 22. Vittinghoff E, McCulloch CE. Relaxing the rule of ten events per variable in logistic and Cox regression. *Am J Epidemiol*. 2007;165(6):710–718. doi:10.1093/aje/kwk052
 23. Cao Y, Ma Y, Yang X, et al. Use of deep learning in forensic sex estimation of virtual pelvic models from the Han population. *Forensic Sci Res*. 2022;7(3):540–549. doi:10.1080/20961790.2021.2024369
 24. Lye R, Obertová Z, Bachtar NA, et al. Validating the use of clinical MSCT scans for cranial nonmetric sex estimation in a contemporary Indonesian population. *Int J Legal Med*. 2024;138(4):1559–1571. doi:10.1007/s00414-024-03176-5
 25. d'Oliveira Coelho J, Curate F. CADOES: an interactive machine-learning approach for sex estimation with the pelvis. *Forensic Sci Int*. 2019;302:109873. doi:10.1016/j.forsciint.2019.109873
 26. San-Millán M, Rissech C, Turbón D. Shape variability of the adult human acetabulum and acetabular fossa related to sex and age by geometric morphometrics: implications for adult age estimation. *Forensic Sci Int*. 2017;272:50–63. doi:10.1016/j.forsciint.2017.01.005
 27. Ferrell MJ, Schultz JJ, Adams DM. Sex estimation research trends in forensic anthropology between 2000 and 2022 in five prominent journals. *J Forensic Sci*. 2024;69(4):1138–1154. doi:10.1111/1556-4029.15522
 28. Zhang M. Forensic imaging: a powerful tool in modern forensic investigation. *Forensic Sci Res*. 2022;7(3):385–392. doi:10.1080/20961790.2021.2008705
 29. Čechová M, Dupej J, Brůžek J, et al. A test of the Bulut et al. (2016) landmark-free method of quantifying sex differences in frontal bone roundness in a contemporary Czech sample. *J Forensic Sci*. 2021;66(2):694–699. doi:10.1111/1556-4029.14603
 30. Hosmer DW, Lemeshow S, Sturdivant RX. *Applied logistic regression*. 3rd ed. Hoboken: John Wiley & Sons; 2013. doi:10.1002/9781118548387
 31. Nagelkerke NJD. A note on a general definition of the coefficient of determination. *Biometrika*. 1991;78(3):691–692. doi:10.1093/biomet/78.3.691
 32. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology*. 1982;143(1):29–36. doi:10.1148/radiology.143.1.7063747
 33. Youden WJ. Index for rating diagnostic tests. *Cancer*. 1950;3(1):32–35. doi:10.1002/1097-0142(1950)3:1%3C32::aid-cnrcr2820030106%3E3.0.co;2-3
 34. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310(20):2191–2194. doi:10.1001/jama.2013.281053
 35. Ellingham ST, Thompson TJ, Islam M, et al. Estimating temperature exposure of burnt bone—a methodological review. *Sci Justice*. 2015;55(3):181–188. doi:10.1016/j.scijus.2014.12.002
 36. DeHaan JD. Fire and bodies. In: Schmidt CW, Symes SA, editors. *The analysis of burned human remains*. London: Academic Press; 2008. p. 1–13. doi:10.1016/B978-012372510-3.50003-4
 37. Kales AR, Ousley SD, Vollner JM. A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods. *Am J Phys Anthropol*. 2012;149(1):104–114. doi:10.1002/ajpa.22102
 38. Avon SL. Forensic odontology: the roles and responsibilities of the dentist. *J Can Dent Assoc*. 2004;70(7):453–458.
 39. Cattaneo C. Forensic anthropology: developments of a classical discipline in the new millennium. *Forensic Sci Int*. 2007;165(2–3):185–193. doi:10.1016/j.forsciint.2006.05.018
 40. United Nations Assistance Mission in Afghanistan. Afghanistan: protection of civilians in armed conflict, annual report 2020. Kabul: UNAMA/UN Human Rights Office; 2021. Available from: https://unama.unmissions.org/sites/default/files/afghanis_tan_protection_of_civilians_report_2020_revs3.pdf
 41. Albanese J. A metric method for sex determination using the hipbone and the femur. *J Forensic Sci*. 2003;48(2):263–273. doi:10.1520/JFS2001378
 42. Rissech C, Sañudo JR, Malgosa A. The acetabular point: a morphological and ontogenetic study. *J Anat*. 2001;198(6):743–748. doi:10.1046/j.1469-7580.2001.19860743.x
 43. Gómez-Valdés JA, Quinto-Sánchez M, Menéndez Garmendia A, et al. Comparison of methods to determine sex by evaluating the greater sciatic notch: visual, angular and geometric morphometrics. *Forensic Sci Int*. 2012;221(1–3):156.e1–156.e7. doi:10.1016/j.forsciint.2012.04.027
 44. Quatrehomme G, Radoman I, Nogueira L, et al. Sex determination using the DSP (probabilistic sex diagnosis) method on the coxal bone: efficiency of method according to number of available variables. *Forensic Sci Int*. 2017;272:190–193. doi:10.1016/j.forsciint.2016.10.020
 45. International Committee of the Red Cross. Missing persons and their families: factsheet. Geneva: International Committee of the Red Cross; 2020. Available from: <https://www.icrc.org/en/document/missing-persons-and-their-families-factsheet>