Preliminary Algerian reference data for age-at-death estimation using the pubic symphysis: a virtual CT-based sample study

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***Abstract*— Age-at-death estimation from the pubic symphysis is a cornerstone of forensic anthropological identification. The Suchey-Brooks (SB) method, although widely applied worldwide, was developed on an American reference sample and its reliability across different populations remains a subject of ongoing investigation. No national reference data exist for the Algerian population, prompting forensic practitioners to rely on foreign standards that may not adequately reflect local biological variation and secular trends.**

We conducted a prospective cross-sectional study of 340 Algerian adults (173 males, 167 females; age range 15–93 years) who underwent clinical computed tomography (CT) at the Central Hospital of Army, Algiers, between September 2022 and April 2024. Three-dimensional reconstructions of the pubic symphysis were staged according to the SB method by two experienced observers. Population-specific descriptive statistics were computed for each sex and phase, and the accuracy of the SB reference standards was assessed in a test subsample of 80 individuals (40 males, 40 females) using absolute error (AE) and relative error (RE). A Bayesian probabilistic approach was additionally applied.

Strong correlations between chronological age and SB phase were observed for both sexes (Spearman's $\rho = 0.918$; $p < 0.0001$). However, application of the original SB standards revealed substantial underestimation of age in individuals over 45 years, with total absolute errors of 14.0 and 10.7 years for males and females, respectively. Use of Algerian-specific reference values markedly reduced these errors (6.3 years for males; 5.4 years for females). Bayesian posterior probability distributions provided refined probabilistic age intervals that further improved classification accuracy, particularly for older age groups.

This study presents the first CT-based, sex-specific Algerian reference data for SB pubic symphysis aging and demonstrates that population-specific standards significantly improve age-at-death estimation accuracy. The Algerian reference data and Bayesian approach reported here should replace the original SB standards in Algerian forensic contexts, particularly for individuals over 45 years of age. Future work should expand these reference samples and explore the integration of artificial intelligence.

***Keywords*— Forensic Anthropology, Age estimation, Pubic symphysis, Suchey-Brooks method, Algerian population, CT scan, Bayesian approach, Reference sample.**

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I. INTRODUCTION

Estimation of age at death from skeletal remains is a fundamental element of the biological profile in forensic anthropology [1,2]. Among the numerous anatomical structures studied for this purpose, the pubic symphysis has received the most sustained attention due to its late maturation, clear morphological progression, and relative resistance to post-mortem trauma [1,3]. The Suchey-Brooks (SB) method, proposed by Brooks and Suchey in 1990 [1], systematizes age-related changes of the pubic symphysis into six discrete morphological phases. Each phase is associated with sex-specific mean ages, standard deviations, and 95% confidence intervals derived from a large reference sample (n = 1225) of American individuals autopsied between 1977 and 1979.

The SB method has become the most widely used technique for pubic symphyseal aging in forensic cases worldwide [4,5]. Its popularity is attributable to its methodological simplicity, well-established reliability, and the biological relevance of the pubic symphysis as an aging indicator [1,4]. A systematic review and meta-analysis confirmed the high reliability of the SB method across diverse populations (Spearman's $\rho = 0.77$ for males; Pearson's $r = 0.75$), while also identifying moderate heterogeneity among study populations [4].

Nevertheless, significant inter-population variability in the timing of pubic symphyseal morphological changes has been reported in numerous studies, limiting the transferability of the original American reference standards to other populations [3,6,7]. Factors contributing to this variability include geographical origin, secular trends, nutritional status, and socio-economic conditions [8]. Studies conducted in France [3], Australia [6], South Africa [7], Indonesia [9], Lebanon [10], and China [11] have consistently demonstrated that applying the original SB standards to non-American populations leads to systematic biases — typically overestimation in younger individuals and underestimation in older individuals — with mean absolute errors that increase substantially with age [3,6].

In Algeria, no national reference data for pubic symphyseal aging currently exist. Forensic anthropologists and forensic physicians therefore rely on foreign — predominantly American or European — standards when estimating age at death in Algerian individuals, despite these populations differing in terms of genetics, anthropometric characteristics, secular trends, and socio-economic determinants of skeletal maturation [12]. The absence of population-specific references is a recognized challenge in age estimation in North Africa and the Middle East [12,13].

The transposition of the SB method to computed tomography (CT) images represents a validated and practical advancement, enabling the construction of large virtual reference samples [5,14,15]. Studies by Telmon et al. [15], Wink [5], and Xiong et al. [11] have confirmed that three-dimensional CT

reconstructions of the pubic symphysis provide morphological information comparable to physical bone specimens, making CT-based virtual reference samples a robust and feasible approach to establishing population-specific standards.

Additionally, Bayesian probabilistic approaches have increasingly been advocated as a means to refine and improve the accuracy of age estimation from the pubic symphysis, by generating posterior probability distributions that account for prior demographic information [16,17]. These approaches provide more biologically informed and legally defensible age intervals than traditional descriptive statistics alone [16].

The aims of this study were therefore: (1) to test the applicability of the SB method on a virtual CT-based Algerian sample; (2) to establish sex-specific Algerian references for age estimation by Suchey-Brooks method; (3) to compare the accuracy of the original Suchey-Brooks standards versus Algerian-specific references in a test subsample; and (4) to apply a Bayesian probabilistic approach to generate population-specific posterior age probabilities for the Algerian population.

II. MATERIALS AND METHODS

A.Sample

We conducted a prospective cross-sectional study at the Medical Imaging Department, Central Hospital of army (CHA), Algiers, Algeria. CT examinations were collected between September 2022 and April 2024 (a 20-month period). The study sample comprised 340 living Algerian individuals of known age and sex: 173 males and 167 females, with ages ranging from 15 to 93 years (Table I). CT examinations were mainly requested in clinical contexts of abdominal or pelvic diseases. Individuals with a history of bone disease, pelvic trauma, or implants causing artifacts (e.g., hip prostheses) were excluded. All CT data were collected and recorded anonymously, retaining only the sex and age of each patient at the time of the examination.

Geographic origin was documented for each patient from hospital administrative records. The sample's distribution across Algeria's four major regions was as follows: Centre, 59.4% (202/340); East, 25.3% (86/340); West, 10.3% (35/340); South, 5 % (17/340) (Table II).

An additional test subsample of 80 individuals (40 males, 40 females) was independently selected from the same institution and used exclusively for the assessment of method accuracy, to allow a direct comparison between the original SB standards and the newly established Algerian reference values. This test sample was not included in the construction of the Algerian reference statistics.

Table I.

Descriptive statistics of the Algerian study sample.

Group	n	Mean age (years)	SD (years)	Min (years)	Max (years)
Males	173	46.4	20.1	15	93
Females	167	49.3	19.3	15	90
Total	340	47.8	19.7	15	93

Table II.

Geographic distribution of the study sample by region of origin

Region	n	%
Centre	202	59.4
East	86	25.3
West	35	10.3
South	17	5
Total	340	100

B. CT Acquisition

CT examinations were performed on a GE Revolution Evo 64-slice CT scanner (GE Healthcare, Chicago, IL, USA). Acquisition parameters were standardized: slice thickness 1.25 mm, voltage 120 kV, amperage 30–480 mAs with automatic modulation, and a soft-tissue reconstruction filter. Scans were performed in helical mode. Three-dimensional reconstructions of the pubic symphysis were generated in Volume Rendering Technique (VRT) mode, consistent with validated protocols for virtual pubic symphysis staging [5,11,14,15]. DICOM datasets were anonymized prior to staging.

C. SB Morphological Staging

The left pubic symphysis was chosen for staging following the convention adopted in comparable studies [3,6]. Each 3D CT reconstruction was staged according to the six morphological phases of the SB method [1], using the original phase descriptions and reference casts as criteria. Staging was performed by the principal observer who was blinded to the chronological age of each subject. Images were reviewed in arbitrary order. The observer could freely rotate the bone in three dimensions to optimize morphological assessment.

Intra- and interobserver reliability were evaluated on a randomized subset of 100 specimens re-staged by the principal observer two months after the initial staging (intraobserver), and by the second observer independently (interobserver). Cohen's weighted kappa coefficients were calculated to quantify agreement.

D. Statistical Analysis

For the Algerian Population Sample (APS), descriptive statistics (mean age, standard deviation, minimum and maximum) were calculated for each SB phase separately for males and females. Spearman's rank correlation coefficient (ρ) was used to evaluate the relationship between chronological age and SB phase, and Pearson's r was used to assess the correlation between chronological age and estimated age based on the SB method.

The accuracy of the original SB standards was evaluated in the test subsample using absolute error (AE = |estimated age − real age|) and relative error (RE = estimated age − real age), computed for each 10-year age class. Identical calculations were then performed using the Algerian-specific reference statistics derived from the APS.

A Bayesian (probabilistic) approach was applied to generate posterior probability distributions of belonging to each 10-year age class given sex and SB phase, based on the APS-derived frequency distributions [16,17]. All statistical analyses were performed using SPSS software version 22.

E. Ethical considerations:

The study was conducted in accordance with ethical standards and was approved by the local Scientific and Ethics Committee. Written informed consent was obtained from all participants or, for minors (<18 years), from their parents or legal guardians before the use of CT images for research purposes. Participant confidentiality was strictly preserved throughout the study.

III. RESULTS

A. Observer Reliability and Sample Characteristics

Intra- and interobserver reliabilities were excellent and substantial respectively with kappa values of 0.92 and 0.71. Errors were predominantly limited to one-stage discrepancies. All six SB phases were represented in both male and female subsamples. Within the APS, each successive phase

was associated with a significantly higher mean age, and chronological age was strongly correlated with SB phase for both sexes (Table III).

Table III.

Spearman and Pearson correlations between chronological age, SB phase, and SB estimated age in the Algerian Population Sample.

	n	Coefficient	p-value
Age vs SB Phase (Spearman ρ)			
Males	173	0.918	< 0.0001
Females	167	0.918	< 0.0001
Total	340	0.915	< 0.0001
Age vs Estimated Age (Pearson r)			
Males	173	0.900	< 0.0001
Females	167	0.918	< 0.0001
Total	340	0.908	< 0.0001

B.Algerian-Specific Descriptive Statistics by SB Phase

Table IV presents the sex-specific descriptive statistics for each SB phase in the APS. These constitute the proposed Algerian reference data for the SB method. For males, mean ages ranged from 17.9 years (Phase I) to 78.0 years (Phase VI). For females, mean ages ranged from 18.5 years (Phase I) to 73.9 years (Phase VI). Substantial overlap in age ranges between consecutive phases was observed, particularly for phases IV, V, and VI, reflecting the increasing individual variability in the rate of skeletal senescence with advancing age.

Table IV.

Sex-specific descriptive statistics (years) by SB phase for the Algerian Population Sample (n = 340).

Phase	Males (n = 173)				Females (n = 167)			
	n	Mean age	SD	Range	n	Mean age	SD	Range
I	10	17.9	2.3	15–21	11	18.5	2.3	15–22
II	25	22.6	2.4	19–30	19	24.8	3.5	20–33
III	20	30.9	3.9	22–37	16	32.4	4.9	24–40
IV	57	44.7	9.3	32–70	37	44.4	8.7	28–65
V	41	62.5	11.7	31–85	46	56.1	8.9	31–71
VI	20	78.0	7.5	64–93	38	73.9	8.7	55–90

C. Comparison with the Original Suchey-Brooks Reference Sample

Comparison of mean ages per SB phase between the APS and the original SBS (table V and VI) revealed statistically significant differences for Phases IV, V, and VI in both sexes. Mean ages for Phases IV, V, and VI were substantially higher in the APS than in the SBS, indicating that Algerian individuals attain the morphological features of these later phases at older chronological ages than the American reference population. Conversely, the mean ages for early phases (I, II and III) were broadly comparable between the two samples, although a slight tendency towards lower mean ages in the APS was noted for Phases I and II in both sexes.

These findings are consistent with the pattern reported in French [3], Australian [6], Indonesian [9], and Lebanese populations [10], and support the hypothesis that the original SB standards systematically underestimate age in older individuals from non-American populations due to population-specific differences in the tempo of skeletal senescence.

Table V.

Descriptive statistics comparison of males samples

SB Phase	SBMS				APMS				SBFS-APMS
	n	min	max	Mean age (M1)	n	min	max	Mean age (M2)	Difference (M1-M2)
I	121	14	24	18.5	10	15	21	17.9	0.6
II	81	17	36	23.4	25	19	30	22.6	0.8
III	45	20	48	28.7	20	22	37	30.9	-2.2
IV	152	22	71	35.2	57	32	70	44.7	-9.5
V	240	26	80	45.6	41	31	85	62.5	-16.9
VI	100	31	92	61.2	20	64	93	78	-16.8

SBMS: Suchey-Brooks males sample; APMS: Algerian population males sample

Table VI.

Descriptive statistics comparison of females samples

SB Phase	SBFS				APFS				SBFS-APFS
	n	min	max	Mean age (M1)	n	min	max	Mean age (M2)	Difference (M1-M2)
I	48	15	24	19.4	11	15	22	18.5	0.9
II	47	19	40	25	19	20	33	24.8	0.2
III	44	21	53	30.7	16	24	40	32.4	-1.7
IV	39	26	70	38.2	37	28	65	44.4	-6.2
V	44	25	83	48.1	46	31	71	56.1	-8
VI	51	42	87	60	38	55	90	73.9	-13.9

SBFS: Suchey-Brooks females sample; APFS: Algerian population females sample

D. Error Analysis: Original SB Standards vs. Algerian Reference Data

Table VII presents the absolute and relative errors calculated in the test subsample (40 males, 40 females) using, respectively, the original SB standards (SBS) and the Algerian-specific reference statistics (APS). For the original SB standards, both AE and RE increased substantially with age, reaching 27.6 years AE and −27.6 years RE for males over 80 years, and 23.6 years and −23.6 years for females in the same age range. In contrast, use of Algerian-specific references markedly reduced errors across all age groups, with the most pronounced improvements in individuals over 45 years. Total AE across all age groups was reduced from 14.0 to 6.3 years in males and from 10.7 to 5.4 years in females.

Table VII.

Comparison of absolute error (AE) and relative error (RE) (years) by age class in the test subsample, using original Suchey-Brooks sample (SBS) standards vs. Algerian population sample (APS) references

Age Class	n	Males – SBS		Males – APS		n	Females – SBS		Females – APS	
		AE	RE	AE	RE		AE	RE	AE	RE
20–29	5	1.6	1.4	3.0	3.0	5	2.0	2.0	3.0	2.9
30–39	7	3.0	−2.4	4.6	3.1	6	1.6	−0.4	4.3	3.5
40–49	5	6.8	−6.8	2.8	2.7	5	6.0	−6.0	2.3	0.2
50–59	6	14.6	−14.6	6.2	−1.4	8	10.7	−10.7	4.7	−3.6
60–69	6	22.9	−22.9	8.4	−8.4	6	16.4	−16.4	8.4	−8.4
70–79	6	22.2	−22.2	8.0	−8.0	5	15.4	−15.4	5.8	−2.7
> 80	5	27.6	−27.6	10.8	−10.8	5	23.6	−23.6	9.7	−9.7
Total	40	**14.0**	**−13.5**	**6.3**	**−2.4**	40	**10.7**	**−10.3**	**5.4**	**−2.6**

SBS: Suchey-Brooks Sample references; APS: Algerian Population sample references; AE: absolute error; RE: relative error. Negative RE indicates underestimation.

E. Bayesian Probabilistic Approach

Posterior probabilities of belonging to each 10-year age class given sex and SB phase are presented in Table VIII. These distributions reflect the empirical frequency distribution of individuals within each age class for each phase in the APS, weighted by the overall Algerian age distribution. For Phase I, 100% of individuals in both sexes fell within the 15–24 year age class. For Phase II, the majority of males (76%) were aged 15–24 years, with 24% aged 25–34 years. For females, the distribution was more even (53% vs. 47%), reflecting slightly greater age heterogeneity at Phase II in females. Phases IV through VI showed markedly different age distributions compared to the original SB standards, with higher posterior probabilities assigned to older age classes, particularly for Phase VI (70% probability of age > 75 years in males, 58% in females).

Table VIII.

Bayesian posterior probabilities of belonging to each 10-year age class given sex and SB phase, derived from the Algerian Population Sample.

Phase	Males – Posterior probability by age class							Females – Posterior probability by age class						
	15–24	25–34	35–44	45–54	55–64	65–74	> 75	15–24	25–34	35–44	45–54	55–64	65–74	> 75
I	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
II	0.76	0.24	0.00	0.00	0.00	0.00	0.00	0.53	0.47	0.00	0.00	0.00	0.00	0.00
III	0.10	0.70	0.20	0.00	0.00	0.00	0.00	0.13	0.56	0.31	0.00	0.00	0.00	0.00
IV	0.00	0.11	0.40	0.33	0.12	0.04	0.00	0.00	0.16	0.35	0.35	0.11	0.03	0.00
V	0.00	0.05	0.02	0.12	0.32	0.34	0.15	0.00	0.02	0.06	0.37	0.31	0.24	0.00
VI	0.00	0.00	0.00	0.00	0.10	0.20	0.70	0.00	0.00	0.00	0.00	0.16	0.26	0.58

IV. DISCUSSION

This study presents the first CT-based Algerian reference data for SB pubic symphyseal age estimation, derived from a contemporary, balanced sample of 340 individuals (173 males, 167 females) covering a wide age range (15–93 years). The strong correlations between chronological age and SB phase (Spearman's $\rho = 0.918$ for both sexes, $p < 0.0001$) confirm the applicability of the SB method to the Algerian population as a whole and validate the use of CT reconstructions for morphological staging, consistent with prior validation studies [5,11,15].

The comparison of phase-specific mean ages between the APS and the original SBS reveals a consistent pattern of inter-population difference. Algerian individuals in phases IV, V, and VI tend to be significantly older than their American counterparts who were assigned the same phase, indicating that the morphological features of advanced pubic symphyseal senescence are attained at later chronological ages in the Algerian population. This finding mirrors results from other non-American populations, including French [3], Australian [6], South African [7], Indonesian [9], and Lebanese [10] samples, and supports the well-recognized phenomenon of population-specific variation in skeletal aging [8,18].

The error analysis in the test subsample provides strong quantitative evidence of the clinical and forensic significance of these population differences. Applying the original SB standards to Algerian individuals over 45 years of age resulted in substantial systematic underestimation (negative RE), with errors reaching 27.6 years in males over 80 years. These levels of inaccuracy are forensically unacceptable and are consistent with findings in other non-American populations [3,6]. Importantly, the use of Algerian-specific reference statistics reduced total absolute errors by approximately 55% in males (from 14.0 to 6.3 years) and 49% in females (from 10.7 to 5.4 years), with the greatest improvements concentrated in the older age groups (40–49 years onwards).

The pattern of overestimation in younger individuals and underestimation in older individuals — a consistent finding across population studies of the SB method [3,6,9] — is well explained by several converging factors. First, secular trends toward earlier skeletal maturation, documented across populations with improving socio-economic conditions and nutritional status, may accelerate the attainment of early SB phases in younger cohorts [8,19]. Second, the underestimation of older individuals likely reflects both the intrinsic limitation of having only six phase means at the upper end of the age spectrum [18] and the greater biological variability of skeletal senescence in older age, as aging individuals diverge increasingly from a uniform trajectory. The recommendation by some authors to add a Phase VII to address the last decades of life [see Savall et al., 2016] appears especially pertinent to the Algerian context where Phase VI mean ages exceed 73 years.

The Bayesian probabilistic approach, applied to the APS frequency distributions, yielded posterior probability tables that provide a more nuanced and statistically defensible basis for age estimation than traditional descriptive statistics alone [16,17]. These distributions are particularly informative for older phases: for example, for a male individual staged at Phase VI, the Bayesian table assigns a 70% posterior probability to the age class > 75 years — a substantially higher and more accurate estimate than the mean ± 1 SD from the original SBS (61.2 ± 12.2 years) would suggest. Bayesian frameworks have been shown to reduce the well-known bias of age mimicry [17] and to generate posterior credible intervals consistent with Daubert standards for scientific reliability in forensic contexts [16]. These advantages make the Bayesian approach an important complement to descriptive reference tables in Algerian forensic practice.

The CT-based virtual sampling approach used in this study offers several methodological advantages over classical dry-bone studies. Clinical CT data are routinely generated in hospital settings, enabling the construction of large contemporary reference samples without the ethical constraints associated with cadaveric studies [3,5]. The GE Revolution Evo 64-slice scanner and standardized acquisition parameters used here are widely available in Algerian medical centres, facilitating the future expansion and regular updating of the reference sample. These practical advantages are increasingly recognized in the forensic anthropological literature [11,14,15].

Although the present reference sample was derived from clinical MDCT examinations of living individuals, its application can reasonably be extended to forensic PMCT examinations. While post-mortem changes such as putrefaction, intrabody gas accumulation, and the loss of surrounding soft tissues may modify image contrast and influence segmentation thresholds, these changes do not substantially alter the cortical morphology of the pubic symphyseal surface when appropriate reconstruction protocols are used. The main technical issue concerns the selection of suitable Hounsfield Unit thresholds during volume rendering, as excessively high thresholds may produce artificial cortical erosion whereas excessively low thresholds may retain non-osseous voxels. Standardized segmentation procedures and visual verification of reconstructed bone surfaces are therefore recommended to ensure faithful representation of the pubic symphysis morphology [15].

Several limitations of this study must be acknowledged. First, the study sample was drawn from the Central Hospital of the Army (CHA), a tertiary military referral institution that receives patients from across Algeria's territory rather than from a single, geographically confined civilian catchment area. Documented geographic origin confirmed recruitment from all four major regions of the country (Table II), although the Centre region was comparatively overrepresented (59.4%), a pattern consistent with the hospital's location in Algiers and, in part, with Algeria's own uneven population density, which is itself concentrated along the northern coastal regions. The sample should therefore not be regarded as strictly proportional to the national population distribution. Future studies should incorporate samples from multiple regions and civilian hospitals to further strengthen national representativeness. Second, only the left pubic symphysis was staged, although the impact of side asymmetry on SB staging remains debated in the literature. Third, ethnicity, body mass index, and socio-economic status — all of which may influence the tempo of skeletal aging — were not investigated in this study. Fourth, the comparison of CT-based staging with the original dry-bone reference sample introduces a potential inter-method reliability issue, although prior studies have demonstrated comparable staging accuracy between CT-based and physical bone assessments [11,15].

V. CONCLUSION

This study establishes the first CT-based, sex-specific Algerian reference data for the SB pubic symphysis age estimation method. The SB method is applicable to the Algerian population, but the original American reference standards produce unacceptable errors, particularly for individuals over 45 years of age. Algerian-specific reference statistics

and Bayesian posterior probability distributions significantly improve age estimation accuracy and should be adopted as the preferred approach in Algerian forensic anthropological practice. They are particularly suited for age estimation in living individuals, intact human remains, and post-mortem CT examinations in which the pubic symphysis is preserved and can be reconstructed using acquisition parameters comparable to those employed in this study. The potential of CT-based virtual sampling for the development and regular updating of population-specific standards is demonstrated, and the integration of artificial intelligence methodologies in future studies is strongly recommended.

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