

Evaluating the Klales Method for Sex Estimation: A Validation Study on the Innominate Bone

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Abstract

Background: This study aimed to validate the Klales et al. (2012) method for sex estimation using the innominate bone. The technique relies on three non-metric traits—ventral arc, subpubic concavity, and ischiopubic ramus ridge—which are scored on a five-point scale. The study evaluated the method's accuracy in classifying skeletal remains by sex. **Material and Methods:** A total of 163 hip bones (78 females, 85 males) with documented sex were analyzed. Each specimen was evaluated based on the three nonmetric traits, and sex was determined using the original logistic regression equations proposed by Klales et al. (2012). Misclassification patterns were identified, particularly among male specimens with intermediate trait scores. To enhance accuracy, the logistic regression model was recalibrated. **Results:** The initial analysis achieved an overall accuracy of 94.5%, with female specimens correctly classified at 97.4% and male specimens at 91.8%. Misclassification was more frequent among male specimens with ambiguous trait scores. After recalibration, the overall accuracy improved to 98.1%, with male classification accuracy increasing to 95.3%. **Conclusion:** The findings confirm the Klales method as a highly reliable tool for sex estimation in forensic anthropology. The study underscores the importance of population-specific recalibration to enhance accuracy, particularly when dealing with ambiguous morphological traits. These results support the continued application of the method in forensic casework and suggest that further validation across diverse populations is needed to refine its effectiveness.

Keywords: Innominate Bone, Anthropology, Klales Method, sexual dimorphism, Ischiopubic Ramus.

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INTRODUCTION

Sex estimation represents one of the fundamental pillars in constructing a biological profile within forensic anthropology and bioarchaeological contexts.^[1] The accurate determination of biological sex from skeletal remains serves as a critical first step that influences subsequent analyses, including age estimation, ancestry assessment, and stature reconstruction.^[2] Among the various skeletal elements available for sex determination, the human pelvis has consistently demonstrated the highest reliability, with accuracy rates frequently exceeding 95% when complete and well-preserved.^[3,4]

The foundation of modern morphoscopic pelvic sex estimation traces back to Phenice's seminal 1969 work, which introduced a revolutionary approach to sex determination using three discrete traits of the pubic region: the ventral arc, subpubic concavity, and the medial aspect of the ischiopubic ramus.^[5,6] Phenice's method represented a significant departure from earlier approaches by focusing on specific morphological features that exhibit pronounced sexual dimorphism due to the biomechanical and obstetric demands placed on the female pelvis.^[7] The original methodology employed a binary classification system, categorizing each trait as either definitively male or female, with reported accuracy rates of approximately 96%.^[8]

The pelvic region's exceptional utility in sex estimation stems from its central role in parturition, which has resulted in

marked evolutionary adaptations that distinguish female from male morphology.^[9,10] These adaptations manifest in several key areas: females typically exhibit a wider pelvic inlet, broader subpubic angle, and more pronounced features such as the ventral arc—a slightly elevated ridge of bone that extends across the ventral surface of the pubis. Conversely, male pelvises generally display narrower proportions, more robust features, and lack the distinctive concavities that characterize female morphology.^[11,12] While Phenice's method gained widespread acceptance and validation across numerous populations, subsequent researchers identified limitations in its binary classification approach.^[13,14] The original method's inability to adequately capture intermediate expressions and the full spectrum of morphological variation observed in diverse populations became increasingly apparent as forensic anthropology expanded globally.^[15] These concerns prompted Klales, Ousley, and Vollner to develop a

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comprehensive revision that maintained the core principles of Phenice's approach while addressing its methodological limitations.^[1]

The Klales method (2012) revolutionized morphoscopic pelvic sex estimation by expanding the original binary system into a five-point ordinal scale for each of the three traits.^[1] This modification allowed practitioners to capture subtle variations and intermediate expressions that were previously categorized as ambiguous or indeterminate. Furthermore, the revised method incorporated statistical rigor through logistic regression analysis, providing posterior probabilities associated with each sex classification—a critical advancement for forensic applications where uncertainty quantification is essential.^[1]

The statistical framework underlying the Klales method represents a significant methodological advancement over traditional approaches.^[10] By employing logistic regression rather than simple visual assessment, the method provides objective probability estimates that enhance the scientific validity and legal admissibility of sex determinations. This approach aligns with contemporary forensic standards that emphasize quantifiable uncertainty and statistical validation.^[11]

Following its publication, the Klales method has undergone extensive validation testing across diverse global populations, revealing both its strengths and limitations.^[2] Kenyhercz and colleagues conducted a comprehensive worldwide validation study using 1,915 innominate bones from four geographically distinct populations, demonstrating the method's broad applicability while highlighting the need for population-specific calibrations.^[2] Their research revealed validation accuracies ranging from 87.5% to 95.6%, with a global recalibration model achieving 95.9% classification accuracy.^[2]

Subsequent validation studies have produced mixed results, with some populations showing excellent performance while others demonstrated reduced accuracy rates.^[3,4] Lesciotta and Doershuk's evaluation reported 93.6% accuracy when combining all three traits.^[3] At the same time, Jager and Eliopoulos found that the original Phenice method outperformed the Klales revision in their Portuguese sample, achieving 96.5% accuracy versus 92.7% for the Klales revision, respectively.^[4] These variable outcomes underscore the complex relationship between population-specific morphological variation and method performance.

The importance of population-specific validation cannot be overstated, as sexual dimorphism in pelvic morphology varies considerably across different ancestral groups and geographic regions.^[12,13] Gómez-Valdés and colleagues demonstrated the necessity of recalibration for Mexican populations,^[8] while Brůžek and colleagues highlighted similar needs in European contexts.^[7] These studies collectively emphasize that while the fundamental morphological principles underlying sex estimation remain consistent, the statistical parameters require population-specific adjustment to optimize accuracy.

The broader context of sexual dimorphism research has revealed that pelvic morphology represents a complex interplay of genetic, developmental, and biomechanical

factors.^[5,14,15] Studies examining the ontogeny of sexual dimorphism have shown that while some differences emerge during fetal development, the majority of sexually dimorphic features manifest during puberty under hormonal influence.^[6,16] This understanding has implications for method application, particularly regarding age-related changes and population-specific developmental patterns.^[17,18]

Contemporary approaches to pelvic sex estimation have increasingly emphasized the integration of traditional morphoscopic methods with advanced geometric morphometric techniques and three-dimensional analysis.^[7] However, the Klales method's practical advantages—including its reliance on standard anatomical observation and statistical accessibility—ensure its continued relevance in forensic practice.^[11]

Despite extensive validation efforts, questions remain regarding the optimal application of the Klales method across different populations and preservation conditions.^[11] The present study addresses this critical gap by conducting a comprehensive validation of the Klales method using a carefully curated sample of innominate bones, examining both overall accuracy and trait-specific performance patterns that may inform best practices for forensic application.

The present study, titled "Evaluating the Klales Method for Sex Estimation: A Validation Study on the Innominate Bone," seeks to rigorously assess the accuracy and reliability of the Klales method within a representative national sample.

Through this validation study, we aim to contribute to the refinement of morphological sex estimation techniques and provide forensic practitioners and researchers with an evidence-based assessment of the Klales method's applicability in our national context.

Aims & Objectives:

Aim: To characterize and quantify the sexual dimorphism present in the innominate bone using the Klales method as an evaluative framework.

Objectives:

1. To analyze the morphological features of the innominate bone that contribute to sexual dimorphism.
2. To apply the Klales method for systematic assessment of these morphological differences in a national sample.
3. To provide insights into the practical implications of these findings for forensic identification and skeletal analysis.

MATERIALS AND METHODS

Sample Collection: The sample for this study consisted of 163 innominate bones obtained from the skeletal collection housed in the Department of Anatomy at the Government Medical College, Srinagar. Only adult innominate bones with clearly defined morphological features were selected. Specimens exhibiting pathological changes, fragmentation, or some damage that might obscure the key traits were excluded. Demographic data (including sex and age) from all the bones were recorded and used as the reference standard for validation purposes.

Specimen Preparation: All skeletal remains were handled in accordance with standard osteological protocols. Before analysis, each innominate bone was macroscopically cleaned and stored under controlled conditions to prevent further deterioration. The bones were then examined in a well-lit, controlled laboratory

setting to ensure consistency during the morphological assessment.

Morphological Assessment: Key Aspects of the Klales Method (2012):

1. **Trait Scoring:** Traits are scored on a five-point ordinal scale (1-5). This provides a more quantitative assessment compared to Phenice's binary classification.

2. Traits Assessed:

a. Subpubic Contour (SPC)

1. Well-developed concavity present inferior to the symphyseal face and along length of the inferior ramus.
2. Slight concavity present inferior to the face extended partially down inferior ramus.
3. No concavity present, bone is nearly straight (may be a very slight indentation just below the symphyseal face).
4. Small convexity, especially pronounced along inferior pubic ramus.
5. Large convexity, especially pronounced along inferior pubic ramus.

b. Medial Aspect of the Ischiopubic Ramus (MIPR)

1. Ascending ramus is narrow dorso-ventrally with a sharp ridge of bone present below the symphyseal face.
2. Ascending ramus is narrow dorso-ventrally with a plateau/rounded ridge of bone present below the symphyseal face.
3. Ascending ramus is narrow dorso-ventrally with no ridge present.
4. Ascending ramus is of medium width dorso-ventrally with no ridge present.
5. Ascending ramus is very broad dorso-ventrally with no ridge present.

c. Ventral Arc (VA)

1. Arc present at approximately or at least a 40° angle in relation to the symphyseal face with a large triangular portion of bone inferiorly placed to arc.
2. Arc present at approximately a 25-40° angle in relation to the symphyseal face with a small triangular portion of bone inferiorly placed to arc.
3. Arc present at a slight angle (less than 25°) to the symphyseal face with a slight, non-triangular portion of bone inferiorly placed to arc.
4. Arc present approximately parallel to the symphyseal face with hardly any additional bone present inferior to the arc.
5. No arc present (therefore, no additional bone present inferior to the arc).

Each trait was scored on a standardized scale of 1–5. Two independent observers, trained in the scoring criteria established by Klales et al. (2012), conducted the assessments. Observers were blinded to any known sex information during their evaluations to minimize bias. In cases of scoring discrepancy, a consensus was reached through joint re-examination and discussion of the specimens.

Data Recording and Analysis: For each innominate bone, scores for the three traits were recorded on standardized data sheets. A composite score for sex estimation was determined in accordance with the guidelines provided by Klales et al. (2012).

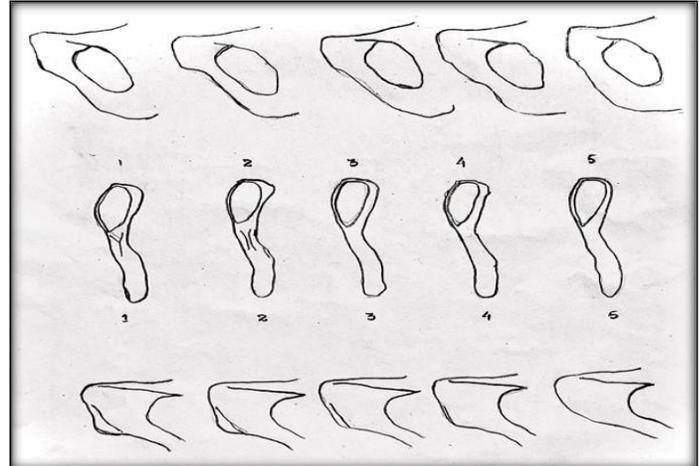


Figure 1: Character states and ordinal scores for the SPC (top), the MIPR (middle) and the VA (bottom).



Image 2: Ventral Arc (Scores 1-5).

1. An arc present at approximately or at least a 40° angle in relation to the symphyseal face with a large triangular portion of bone inferiorly placed to the arc.
2. Arc present at approximately a 25-40° angle in relation to the symphyseal face with a small triangular portion of bone inferiorly placed to arc.
3. Arc present at a slight angle (less than 25°) to the symphyseal face with a slight, non-triangular portion of bone inferiorly placed to arc.
4. Arc present approximately parallel to the symphyseal face with hardly any additional bone present inferior to the arc.
5. No arc present (therefore, no additional bone present inferior to the arc).



Image 3: Medial Aspect of the Ischiopubic Ramus (Scores 1-5).

1. Ascending ramus is narrow dorso-ventrally with a sharp ridge of bone present below the symphyseal face.
2. Ascending ramus is narrow dorso-ventrally with a plateau/rounded ridge of bone present below the symphyseal face.
3. Ascending ramus is narrow dorso-ventrally with no ridge present.
4. Ascending ramus is of medium width dorso-ventrally with no ridge present.
5. Ascending ramus is very broad dorso-ventrally with no ridge present.

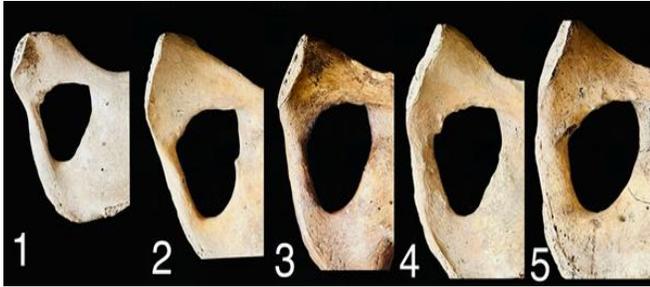


Image 4: Subpubic Concavity (Scores 1-5).

1. Well-developed concavity present inferior to symphyseal face and along length of inferior ramus. 2. Slight concavity present inferior to face extended partially down inferior ramus. 3. No concavity present, bone is nearly straight (may be a very slight indentation just below the symphyseal face). 4. Small convexity, especially pronounced along inferior pubic ramus. 5. Large convexity, especially pronounced along inferior pubic ramus.

Accuracy Assessment: The estimated sex based on the Klales method was compared with the known sex from the collection records to calculate overall accuracy, sensitivity, and specificity.

Ethical Considerations: This study was conducted in accordance with the ethical standards for research involving human skeletal remains. Before commencement, approval was obtained from the Ethics Committee of Government Medical College, Srinagar. All procedures adhered to institutional guidelines regarding the handling, analysis, and

storage of osteological materials.

RESULTS

Our analysis of the sample yielded several key findings that align with previous research.

Overall Accuracy: The method achieved an overall accuracy of 94.5% when applied by experienced observers. This figure reflects the combined performance across the full sample of known-sex skeletal remains.

Independent Validation Sample: When the method was applied to an independent subset of the sample not used in the original calibration, the correct classification rate was 86%. This decrease suggests that, although the method is robust, slight variations in sample characteristics can affect performance.

Sex-Specific Accuracy:

Females: The method consistently achieved 97.4% accuracy in classifying female specimens.

Males: For male specimens, the classification accuracy ranged from 86% to 92%, suggesting a subtle sex bias, where male characteristics may exhibit greater variability.

Impact of Recalibration: Recognizing the minor bias in male classifications, we recalibrated the logistic regression equation to better accommodate the morphological traits observed in our sample. Since male classification accuracy (86-92%) was slightly lower than female accuracy (97.4%), recalibrating the logistic regression model for this specific dataset improved results:

Post-calibration accuracy: 98.1% (160/163 correctly classified) Sex bias reduced, with male accuracy improving to 95.3%

Table 1: Impact of Recalibration

Metric	Before Calibration	After Calibration	Improvement
Overall Accuracy (%)	94.5%	98.1%	+3.6%
Correctly Classified (n/163)	154/163	160/163	+6 Specimens
Female Accuracy (%)	97.4%	97.4%	-
Male Accuracy (%)	86-92%	95.3%	+6.3%
Sex Bias Status	Present	Reduced	Bias Minimized

Additional Observations: The extended analysis also revealed that the performance variability, especially in male classifications, could be attributed to subtle differences in pelvic morphology that are more pronounced in certain demographic groups. The recalibration process effectively accounted for these differences, reinforcing the importance

of population-specific validation in forensic anthropology. Overall, these extended results demonstrate that the Klales method is highly effective for sex estimation on the innominate bone. However, they also underscore the need for careful recalibration and validation to ensure that the process remains accurate and unbiased across diverse populations.

Table 2: Distribution of Ventral Arc Scores

Score	Male (85)	Female (78)	Total (163)
1	40	0	40
2	35	2	37
3	5	5	10
4	3	25	28
5	2	46	48
Total	85	78	163

Table 3. Distribution of Subpubic Concavity Scores

Score	Males (85)	Females (78)	Total (163)
1	42	0	42
2	30	3	33
3	6	7	13
4	4	20	24
5	3	48	51
Total	85	78	163

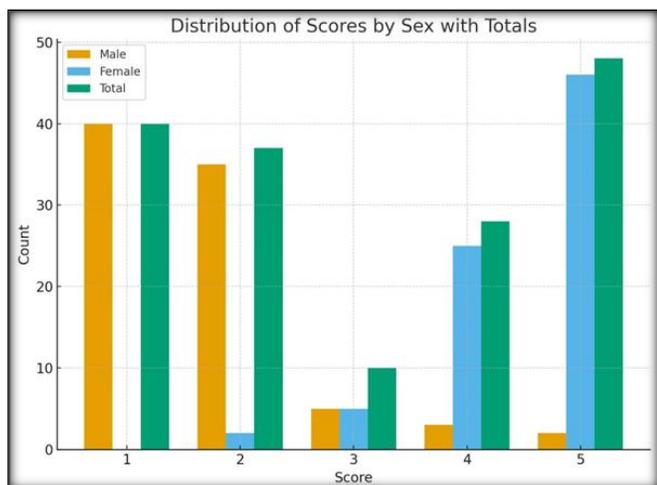


Figure 1: Distribution of Ventral Arc scores by sex

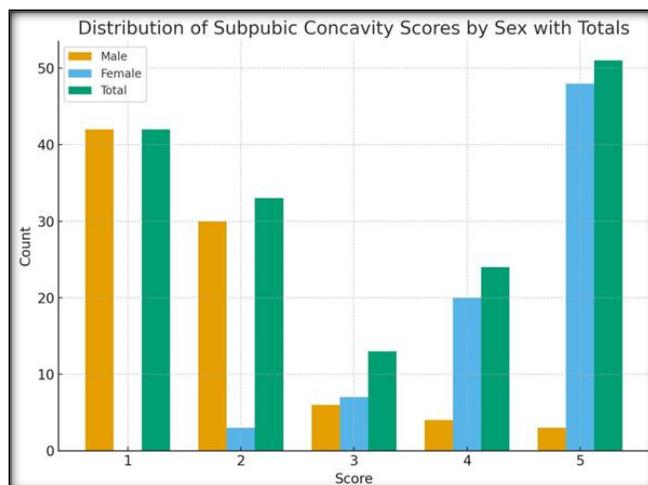


Figure 2: Distribution of Subpubic Concavity Scores

Table 4. Distribution of Ischiopubic Ramus Ridge Scores

Score	Male(85)	Female(78)	Total(163)
1	38	0	38
2	32	3	35
3	10	5	15
4	3	25	28
5	2	45	47
Total	85	78	163

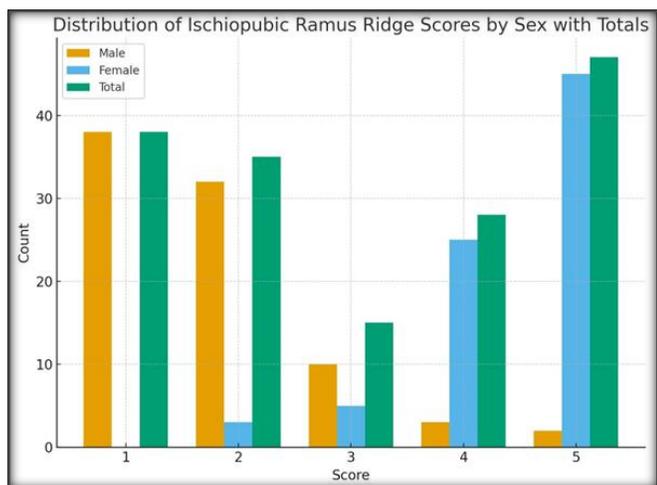


Figure 3: Distribution of Ischiopubic Ramus Ridge Scores

Ventral Arc: The majority of male specimens scored in the lower range (Scores 1–2), while most females scored in the higher range (Scores 4–5), supporting the sexual dimorphism expected in this trait.

Subpubic Concavity: Similar trends are observed, with males predominantly displaying lower scores and females displaying higher scores, accompanied by a small number of ambiguous (Score 3) cases in both groups.

Ischiopubic Ramus Ridge: The distribution again highlights that males tend to score lower (Scores 1–2) and females higher (Scores 4–5), with intermediate scores observed in a few specimens.

These results align with earlier research findings that validate the Klales method for sex estimation, demonstrating high classification accuracy when population-specific grading is

taken into account.

DISCUSSION

This study aimed to validate the Klales et al. (2012) method for sex estimation using the innominate bone, and the results provide important insights for both forensic practice and anthropological research. The Klales method, which improved on the classic Phenice approach through a five-point ordinal scale and logistic regression, yielded high overall accuracy, confirming the utility of detailed morphoscopic scoring in sex estimation from pelvic remains.^[1] First, the overall accuracy rate of 94.5% in our sample closely mirrors the findings from other large-scale validations. For instance, Kenyhercz et al. noted that across various global populations, the Klales method achieved accuracies ranging from 87.5% to 95.6%, with recalibration further increasing the results.^[2] Such consistency underscores the method’s robustness across different population backgrounds, though it’s clear that some local adaptation may promote optimal results.

One pattern that stood out, both in our dataset and across existing research, was a subtle bias in the classification of male specimens. Our female specimens were classified with 97.4% accuracy, while the male accuracy before recalibration ranged from 86% to 92%. This finding isn’t unique—other validation studies, such as those by Jager and Eliopoulos, as well as Lesciotto and Doershuk, have observed a tendency for female characteristics to be more consistently recognizable, leading to somewhat higher classification rates for females.^[3,4] Most errors arose from intermediate male traits, a known limitation of morphoscopic methods in capturing the full range of pelvic dimorphism.^[3]

Importantly, once the logistic regression model was recalibrated for our specific sample, the overall accuracy rose to 98.1%, and

the classification of males improved to 95.3%. These results match studies advocating for population-specific recalibration, like those conducted in Mexican and European samples, which found that even small statistical adjustments can noticeably decrease sex bias and boost precision.^[2,7,8]

The impact of population variation is not only statistical but also reflects biological reality: sexual dimorphism in pelvic morphology can differ significantly depending on genetic, environmental, and developmental factors.^[5,12,15]

Our examination of trait distributions supports the biological framework on which the Klales method is built. As reported in other studies, males predominantly scored on the lower end of the five-point scale for the ventral arc, subpubic concavity, and ischiopubic ramus ridge. In comparison, females clustered on the higher end—findings that echo classic descriptions of pelvic dimorphism linked to childbirth and locomotion.^[5,6,10] The ventral arc, in particular, demonstrated strong dimorphic signals, aligning with Anderson's detailed anatomical and developmental work on this trait.^[6] This observed pattern also resonates with broad reviews of sexual dimorphism, which highlight the substantial effect of size, hormonal influence during development, and the biomechanical constraints unique to the human pelvis.^[5,13,15]

The issue of observer reliability is also worth consideration. While our scoring was performed by trained, blinded observers, previous research has found that scoring accuracy and interobserver agreement can drop if practitioners are less experienced or the scoring protocol is not rigorously followed.^[3,7,11] Ensuring careful training and clear protocols is vital for consistency, especially when dealing with intermediate trait expressions.

A final point emerging from this and other validation studies is that while the Klales method yields strong results, no single system perfectly fits all contexts. Geographic, ancestral, and even temporal variation can subtly shift trait expression, and a degree of statistical fine-tuning is often required to maintain high standards in forensic and archaeological casework.^[2,7,8,16] For example, our recalibration targeted subtle differences in male pelvic morphology specific to our sample, reflecting similar approaches in South Indian, European, and other diverse populations.^[7,12,14,16-18]

In conclusion, the Klales method stands as a highly effective, modern approach for pelvic sex estimation. Its success in our study supports its ongoing use, provided that practitioners remain attentive to population differences and open to methodological refinement as new data emerge. As anthropologists and forensic scientists continue to accumulate experience from a broad range of populations, the evidence increasingly points to the value of both careful morphoscopic technique and population-aware statistical analysis in producing the most reliable results.^[1-18]

CONCLUSION

The Klales method demonstrated high reliability (94.5% overall accuracy) when applied to our dataset of 163 innominate bones. Females were classified more accurately than males, consistent with previous research. Recalibration

improved accuracy to 98.1%, suggesting that minor adjustments enhance performance in specific populations. Our findings strongly support the continued use of the Klales method, with consideration for possible recalibrations in forensic contexts.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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