forensic sciences

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# Integrating Nasal Anthropometry with Multivariate Analyses to Examine Forensic Population Differentiation Between Malaysian and Indonesian Adults

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**Abstract**

Background/Objectives: Nasal morphology is an important craniofacial feature in forensic anthropology for examining population-level variation and informing biological profiling in living individuals. Despite genetic, historical, and cultural similarities between Malaysian and Indonesian populations, population-specific nasal anthropometric data remain limited. This study integrates nasal anthropometry with multivariate analytical approaches to examine population- and sex-related variation in nasal morphology among Malaysian and Indonesian adults. Methods: A cross-sectional anthropometric study was conducted among Malaysian and Indonesian adults. Nasal breadth and nasal height were measured using standardised techniques, and the nasal index was calculated. Univariate analyses were performed to assess population- and sex-related differences. Multivariate analyses, including principal component analysis (PCA), hierarchical cluster analysis (HCA), and partial least squares (PLS), were applied to eleven nasal parameters and the nasal index to evaluate patterns of population differentiation. Results: Malaysian participants predominantly exhibited leptorrhine nasal types, whereas mesorrhine nasal types were more prevalent among Indonesian participants. Significant differences were observed in nasal height and nasal index between populations, while nasal breadth did not differ significantly. Sex-related variation was evident, with males generally exhibiting larger nasal dimensions and higher nasal indices than females. Multivariate analyses demonstrated clear population separation, with modelling indicating that population group contributed more strongly to morphological differentiation than sex. Conclusions: The findings provide population-specific soft-tissue nasal data for Malaysian and Indonesian groups and support the use of multivariate analytical frameworks in forensic anthropological research.

**Keywords:** anthropology; craniofacial; morphometry; multivariate; nasal index; profiling

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Academic Editor: Radoslav Beňuš

Received: 7 January 2026
Revised: 23 January 2026
Accepted: 6 February 2026
Published: 8 February 2026



## 1. Introduction

Anthropometric evaluation of human body characteristics, both qualitative and quantitative, has long been used to establish standardised reference proportions for biological profiling. Such assessments support the estimation of key attributes, including age [1], ancestry or population affiliation [2], sex [3], and stature [4]. Understanding variation in human physiology is essential for scientific investigation, as it informs accurate diagnosis, treatment planning, and the categorisation of individuals based on measurable anatomical traits [5,6]. As a systematic approach to measuring human body dimensions, anthropometry remains a foundational tool for examining such variation across populations.

The application of anthropometry spans multiple disciplines, including medicine [7], forensic science [8], and genetics [9]. Within forensic contexts, anthropometric data play a particularly important role in human identification, especially when conventional identifiers are unavailable or incomplete. Facial anthropometric studies have therefore gained increasing attention, as facial structures demonstrate pronounced morphological variability across populations and between sexes. Such variability has made facial measurements valuable in fields such as reconstructive surgery, forensic analysis, and genetic counselling [10].

Among facial features, the nose occupies a central anatomical position and exhibits substantial morphological diversity. Nasal anthropometry focuses on the measurement and analysis of nasal structures, providing foundational data for understanding population-specific craniofacial variation [11]. The nasal index, derived from nasal breadth and height, is widely used to classify nasal types and support population-level comparisons in forensic anthropology. Previous studies have demonstrated that nasal dimensions and indices vary significantly between ethnic and geographical groups, reinforcing the importance of population-specific reference data for forensic interpretation [2,11–14].

In Southeast Asia, Malaysians and Indonesians represent closely related populations with shared geographical proximity and historical connections [15,16]. Despite this shared background, existing anthropometric research suggests that measurable craniofacial differences may still be present between these groups [17]. However, nasal morphology in these populations has largely been examined using univariate statistical approaches [12,18,19], which may not fully capture the complex multivariate structure of biological data.

Multivariate techniques offer complementary analytical tools for exploring relationships among multiple correlated variables [20,21]. When integrated with anthropometric measurements, these methods enable objective pattern recognition and enhanced interpretation without imposing predefined group assumptions. Despite their established use in other forensic and biomedical applications, these approaches remain underutilised in nasal anthropometry, particularly in studies involving Southeast Asian populations.

Accordingly, the present study integrates nasal anthropometry with multivariate analyses to investigate population- and sex-related differences in nasal morphology between Malaysian and Indonesian adults. By combining univariate statistical assessment with multivariate exploratory and supervised techniques, this study aims to evaluate the forensic relevance of nasal measurements for population differentiation and provide robust population-specific reference data suitable for forensic anthropological applications.

## 2. Methods

### 2.1. Study Design and Participants

A cross-sectional anthropometric study was conducted among adult Malaysian and Indonesian participants. Convenience and snowball sampling techniques were employed to facilitate participant recruitment within the study locations, consistent with non-probability sampling approaches commonly used in anthropometric and population-based research [22,23].

https://doi.org/10.3390/forensicsci6010014

For conceptual clarity and consistency, the term *sex* is used throughout this study to refer to biological differences between male and female participants, while population group is used to describe biologically informed grouping based on shared ancestry or population-level characteristics rather than socially constructed racial categories.

Participants were recruited from the Petaling district of Malaysia and Surabaya, Indonesia. The study population comprised Malaysian Malays and individuals from several Indonesian ethnic groups, including Javanese, Madura, Medan, and Padang. A total of 212 participants were included in the analysis, consisting of 103 Malaysians (48.6%) and 109 Indonesians (51.4%).

Among the Malaysian participants, 58 were males and 45 were females. The Indonesian sample comprised 71 males and 38 females. This distribution provided representation of both sexes within each population group, enabling sex-related variation in nasal morphology to be examined and interpreted within the context of the available sample.

Regarding age distribution, the age range for Malaysian males was 18 to 74 years, while Malaysian females ranged from 19 to 67 years. Indonesian males and females both ranged from 18 to 75 years of age. The mean age of Malaysian males was 35.27 years (SD = 15.20), and Malaysian females had a mean age of 31.94 years (SD = 13.68). For the Indonesian group, the mean age of males was 35.15 years (SD = 13.69), while females had a mean age of 39.95 years (SD = 14.49).

Eligibility criteria were defined to ensure the assessment of natural nasal morphology. Inclusion criteria were adults aged 18 years and above who self-identified as Malaysian Malay or Indonesian and reported ethnic consistency up to the third-generation grandparents. Only individuals who provided informed consent were included. Exclusion criteria comprised mixed ancestry within three generations, prior cosmetic nasal surgery, recent nasal trauma, nasal piercings or medical treatments affecting nasal structure, and visible nasal deformities. Individuals under 18 years of age were excluded to avoid the inclusion of incompletely developed nasal structures.

Ethical approval for the study was obtained from the Management and Science University (MSU) (Approval No. MSU-RMC-02/FR01/05/L1/048). All participants were provided with verbal and written information regarding the study objectives and procedures. The written informed consent was obtained prior to data collection. Participant confidentiality was maintained through anonymisation and secure data handling procedures.

### *2.2. Anthropometric Measurements*

Nasal anthropometric data were collected using a computerised digital Vernier calliper (Mitutoyo Absolute Digimatic, Utsunomiya, Japan), selected for its high precision and ability to record measurements to the nearest fraction of a millimetre. All measurements were conducted by a single trained observer to minimise inter-observer variability. The calliper was calibrated prior to each measurement session in accordance with the manufacturer's instructions to ensure measurement accuracy and consistency.

#### 2.2.1. Measurement Reliability and Observer Consistency

Prior to the commencement of formal data collection, an intra-observer reliability assessment was conducted to evaluate measurement precision and investigator proficiency [24]. A pilot reliability study was performed on a subset of participants ($n$ = 20), representing approximately 10% of the final sample size ($n$ = 212). These participants were not included in the subsequent analytical dataset.

Facial landmarks were identified and measured by the same investigator on two separate occasions under identical conditions, with a washout period of two weeks between measurement sessions to minimise recall bias. Intra-observer error was quantified using the

Technical Error of Measurement (TEM), relative TEM (%TEM), and intraclass correlation coefficients (ICC; two-way mixed-effects model, absolute agreement).

Across all measured variables, TEM values ranged from 0.7 to 1.9 mm, with relative TEM (%TEM) values below 3.5%. Intraclass correlation coefficients demonstrated high repeatability, with ICC values ranging from 0.91 to 0.98. Landmarks recognised as more challenging to identify on living individuals, including nasion, also demonstrated acceptable repeatability (ICC > 0.90).

These results indicate that the investigator was able to consistently identify craniofacial landmarks and acquire measurements with sufficient precision and accuracy, supporting the reliability of the subsequent formal data collection.

#### 2.2.2. Data Collection

Participants were seated comfortably in a well-lit and controlled environment. The head was positioned in the anatomical orientation, with the Frankfort horizontal plane aligned parallel to the floor and the face directed anteriorly. Participants were instructed to maintain a neutral facial expression and to remove any accessories, such as glasses or face coverings, that could interfere with the identification of anatomical landmarks. Hair was secured away from the face where necessary to allow unobstructed access to the nasal region.

Nasal breadth and nasal height were used to calculate the nasal index following the standard method described by Dhulqarnain et al. [25]. Nasal breadth was measured as the straight horizontal distance between the right and left alae, while nasal height was measured as the vertical distance from the nasion to the subnasale. The nasal index was calculated using the following formula:

$$\text{Nasal index} = \left(\frac{\text{Nasal breadth}}{\text{Nasal height}}\right) \times 100 \quad (1)$$

Based on nasal height, nasal breadth, and nasal index values, nasal types were classified according to established criteria reported by Dhulqarnain et al. [25] and Rohith et al. [26], as summarised in Table 1.

**Table 1.** Classification of nasal types based on nasal index values.

| Category | Nose Size | Nasal Index Value |
|---|---|---|
| Hyperleptorrhine | Long narrow nose | 40–54.9 |
| Leptorrhine | Moderately narrow nose | <70 |
| Mesorrhine | Moderate or medium size | 70–84.9 |
| Platyrrhine | Moderately wide nose | 85–99.9 |
| Hyperplatyrrhine | Very wide nose | ≥100 |

For multivariate analyses, 11 nasal morphology parameters were measured following the procedure described by Basjuri et al. [17]. These parameters comprised key linear distances and angular measurements of the nasal region and are summarised in Table 2. The measurement landmarks for these parameters are illustrated in Figure 1. To enhance measurement reliability, each parameter was measured three times for each participant, with the calliper removed and repositioned between measurements. The mean of the three readings was calculated and recorded for analysis.

**Table 2.** Definition of nasal morphology parameters used for multivariate analyses.

| Parameter | Description |
|---|---|
| Parameter 1 | Biocular width (distance between the right and left exocanthion points) |
| Parameter 2 | Intercanthal width (distance between the right and left endocanthion points) |
| Parameter 3 | Nasal bridge width |
| Parameter 4 | Alar width (left) |
| Parameter 5 | Nasal height (soft-tissue nasion to subnasale) |
| Parameter 6 | Alar width (right) |
| Parameter 7 | Nasofrontal angle (measured at the soft-tissue nasion) |
| Parameter 8 | Subnasale |
| Parameter 9 | Nasal projection (distance from the alar base to pronasale) |
| Parameter 10 | Nasal dorsum length (distance from nasion to pronasale) |
| Parameter 11 | Nasal tip angle |

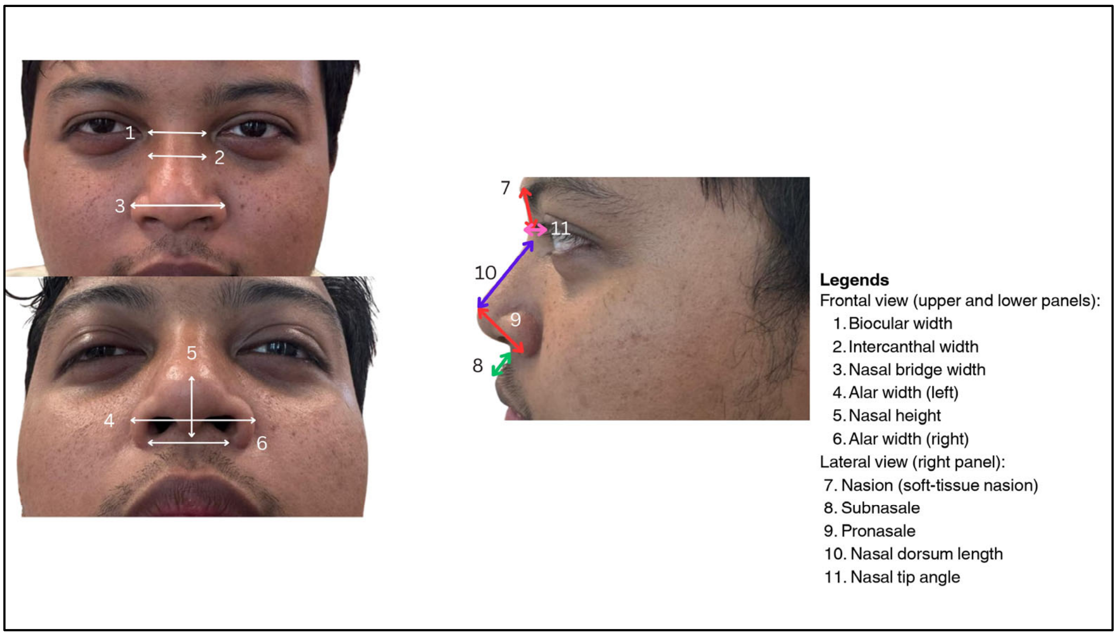


**Figure 1.** Nasal morphology measurement landmarks.

Although several of the landmarks employed in this study, including nasion, are classically defined as skeletal Type I landmarks, their identification in the present study was conducted using established soft-tissue anthropometric conventions appropriate for living individuals. In this context, nasion was identified as the point of maximum concavity at the root of the nose in the mid-sagittal plane, corresponding to the surface projection of the underlying naso-frontal junction, rather than direct visualisation of the skeletal suture. All landmark identification was therefore based on external morphological features and surface anatomy, in accordance with standardised anthropometric protocols for living subjects.

### *2.3. Statistical Analysis*

Data analysis was performed using descriptive and inferential statistical procedures appropriate to the nasal anthropometric variables examined in this study. Nasal breadth, nasal height, and nasal index were summarised using descriptive statistics, including mean, standard deviation, minimum, and maximum values, for Malaysian and Indonesian participants. Analyses were also stratified by sex to evaluate sexual dimorphism.

Frequency and percentage distributions were calculated to classify nasal morphology into standard nose types based on nasal index categories: hyperleptorrhine, leptorrhine, mesorrhine, platyrrhine, and hyperplatyrrhine. This classification was used to examine the distribution of nasal types within and between the two populations.

Comparative analyses were conducted to assess differences in nasal breadth, nasal height, and nasal index between Malaysian and Indonesian participants, as well as between male and female groups. Appropriate independent-sample statistical tests were applied, with statistical significance set at $p < 0.05$. Where significant overall differences were observed, Tukey's post hoc multiple comparison test was employed to identify specific pairwise differences among Malaysian males, Malaysian females, Indonesian males, and Indonesian females at a 95% confidence level.

### *2.4. Multivariate Analyses*

Multivariate analyses were applied to explore patterns within the nasal morphology dataset beyond univariate statistical comparisons. The multivariate dataset comprised measurements from approximately 11 nasal parameters together with the nasal index for all participants. Multivariate analyses were conducted using OriginPro 2025 software.

Principal component analysis (PCA) was performed on the correlation matrix of the multivariate data to reduce dimensionality and to examine relationships among variables. Eigenvalues were calculated, and components with eigenvalues greater than 1 were retained for further evaluation. PCA score plots were generated to visualise the distribution of observations, while loading plots were used to assess the contribution of individual variables to the principal components.

Hierarchical cluster analysis (HCA) was conducted to examine similarity patterns among the nasal parameters. A dendrogram was generated to identify natural groupings of variables based on their multivariate relationships.

Partial least squares (PLS) analysis was subsequently performed as a supervised multivariate technique to evaluate variable importance in relation to the predefined response variables. Model performance was assessed using cross-validation, and the predicted residual sum of squares (PRESS) was used to determine the optimal number of factors. The proportion of variance explained by each factor was calculated for both predictor and response variables. Variable importance was further assessed using the Variable Importance in Projection (VIP) scores to identify parameters contributing most strongly to the model.

## 3. Results

### *3.1. Nasal Index-Based Analysis*

This section presents the descriptive and inferential analyses of nasal index–related variables among Malaysian and Indonesian populations. The nasal index was examined as a classical anthropometric indicator to characterise nasal morphology, evaluate population-level differences, and assess sexual dimorphism. Analyses include the distribution of nasal types, comparisons of nasal breadth, nasal height, and nasal index between populations and sexes, as well as post hoc evaluations of interaction effects. These results provide a foundational univariate framework for interpreting nasal morphological variation prior to multivariate analyses.

#### 3.1.1. Distribution of Nasal Types Based on Nasal Index

A total of 212 participants were assessed for nasal index classification, comprising 103 Malaysians and 109 Indonesians. The frequency distribution of nasal types based on nasal index measurements is presented in Table 3.

https://doi.org/10.3390/forensicsci6010014

**Table 3.** Frequency distribution of nasal types among Malaysian and Indonesian populations based on nasal index measurements.

| Nose Shape | Populations | | | |
|---|---|---|---|---|
| | Malaysians | | Indonesians | |
| | *n* | % | *n* | % |
| Hyperleptorrhine | 7 | 6.8 | 0 | 0 |
| Leptorrhine | 62 | 60.2 | 39 | 35.8 |
| Mesorrhine | 33 | 32.0 | 62 | 56.9 |
| Platyrrhine | 1 | 1.0 | 8 | 7.3 |
| Hyperplatyrrhine | 0 | 0 | 0 | 0 |

In the Malaysian population, the leptorrhine nasal type was the most prevalent, accounting for 60.2% of individuals, followed by mesorrhine (32.0%), hyperleptorrhine (6.8%), and platyrrhine (1.0%). In contrast, the Indonesian population predominantly exhibited mesorrhine nasal types (56.9%), followed by leptorrhine (35.8%) and platyrrhine (7.3%). Hyperleptorrhine nasal type was not observed among Indonesian participants.

Overall, the Malaysian population encompassed all nasal shape categories except hyperplatyrrhine, whereas the Indonesian population exhibited all categories except hyperleptorrhine and hyperplatyrrhine. These distribution patterns demonstrate population-level variation in nasal morphology between the two groups.

### 3.1.2. Sex-Based Distribution of Nasal Types

The distribution of nasal types stratified by sex within the Malaysian and Indonesian populations is summarised in Table 4. Within each population, broadly similar patterns of nasal type distribution were observed between males and females.

**Table 4.** Distribution of nose shape based on sex in both Malaysian and Indonesian populations.

| Nose Shape | Sex | | | |
|---|---|---|---|---|
| | Male | | Female | |
| | Malaysian | Indonesian | Malaysian | Indonesian |
| Hyperleptorrhine | 4 (6.9%) | 0 (0%) | 3 (6.7%) | 0 (0%) |
| Leptorrhine | 40 (69.0%) | 28 (39.4%) | 22 (48.9%) | 11 (28.9%) |
| Mesorrhine | 14 (24.1%) | 40 (56.3%) | 19 (42.2%) | 22 (57.9%) |
| Platyrrhine | 0 (0%) | 3 (4.2%) | 1 (2.2%) | 5 (13.2%) |
| Total | 58 (100%) | 71 (100%) | 45 (100%) | 38 (100%) |

Among Malaysian participants, the leptorrhine nasal type was the most prevalent in both males (69.0%) and females (48.9%). This was followed by the mesorrhine type, which accounted for 24.1% of Malaysian males and 42.2% of Malaysian females. Hyperleptorrhine noses were less frequent in both sexes, while the platyrrhine type was rare and observed only among Malaysian females (2.2%).

In the Indonesian population, the mesorrhine nasal type predominated in both males (56.3%) and females (57.9%). This was followed by the leptorrhine type, which accounted for 39.4% of Indonesian males and 28.9% of Indonesian females. The platyrrhine type was present in both sexes but remained less common, whereas hyperleptorrhine nasal types were not observed among Indonesian participants.

Overall, these findings indicate consistent sex-related distribution patterns within each population, while preserving clear population-level differences in dominant nasal types between Malaysian and Indonesian groups.

#### 3.1.3. Comparison of Nasal Measurements Between Populations

Descriptive and inferential statistical analyses of nasal breadth, nasal height, and nasal index between Malaysian and Indonesian populations are presented in Table 5. Mean nasal breadth values were similar between Malaysians (39.48 ± 4.56 mm) and Indonesians (39.69 ± 3.56 mm), with no statistically significant difference observed ($p = 0.710$).

**Table 5.** Statistical analysis of nasal parameters in Malaysian and Indonesian populations.

| Measurement | Populations | | *p*-Value |
|---|---|---|---|
| | Malaysians (*n* = 103) | Indonesians (*n* = 109) | |
| Breadth (mm) | | | |
| Mean | 39.48 | 39.69 | 0.710 |
| SD | 4.56 | 3.56 | |
| Min | 30.05 | 32.60 | |
| Max | 55.79 | 47.55 | |
| Height (mm) | | | |
| Mean | 59.20 | 54.68 | 0.000 |
| SD | 9.33 | 5.23 | |
| Min | 45.57 | 41.68 | |
| Max | 93.69 | 66.65 | |
| Nasal Index | | | |
| Mean | 67.44 | 73.06 | 0.000 |
| SD | 7.79 | 8.02 | |
| Min | 40.57 | 56.52 | |
| Max | 87.38 | 95.09 | |

In contrast, nasal height was significantly greater among Malaysians (59.20 ± 9.33 mm) compared to Indonesians (54.68 ± 5.23 mm) ($p < 0.001$). The nasal index was significantly higher in Indonesians (73.06 ± 8.02) than in Malaysians (67.44 ± 7.79) ($p < 0.001$).

These results indicate that population differences were evident for nasal height and nasal index, whereas nasal breadth did not differ significantly between the two populations.

#### 3.1.4. Sex Differences in Nasal Measurements

Sex-based comparisons of nasal breadth, nasal height, and nasal index for both populations are presented in Table 6. Malaysian males exhibited the highest mean nasal breadth (41.12 ± 4.84 mm), followed by Indonesian males, Indonesian females, and Malaysian females. A similar trend was observed for nasal height, with Malaysian males showing the highest mean value (62.82 ± 10.43 mm).

For nasal index, Indonesian females recorded the highest mean value (73.74 ± 8.57), followed by Indonesian males, Malaysian females, and Malaysian males. Statistical analysis revealed significant differences in nasal breadth, nasal height, and nasal index between males and females across both populations ($p < 0.001$).

**Table 6.** Descriptive statistical analysis of nasal index of males and females in Malaysia and Indonesia populations.

| Measurement | Sex | | | | *p*-Value |
|---|---|---|---|---|---|
| | Malaysia | | Indonesia | | |
| | Male ($n$ = 58) | Female ($n$ = 45) | Male ($n$ = 71) | Female ($n$ = 38) | |
| Breadth (mm) | | | | | |
| Mean | 41.12 | 37.52 | 40.66 | 37.93 | 0.000 |
| SD | 4.84 | 3.29 | 3.53 | 2.92 | |
| Min | 32.00 | 30.05 | 32.73 | 32.60 | |
| Max | 55.79 | 45.33 | 47.55 | 45.60 | |
| Height (mm) | | | | | |
| Mean | 62.82 | 54.88 | 56.25 | 51.86 | 0.000 |
| SD | 10.43 | 5.28 | 4.75 | 4.92 | |
| Min | 45.57 | 75.86 | 45.96 | 41.68 | |
| Max | 48.57 | 93.69 | 66.65 | 62.29 | |
| Nasal Index | | | | | |
| Mean | 66.26 | 68.84 | 72.68 | 73.74 | 0.000 |
| SD | 7.60 | 7.86 | 7.74 | 8.57 | |
| Min | 40.57 | 52.00 | 57.96 | 56.52 | |
| Max | 84.25 | 87.38 | 95.09 | 94.55 | |

#### 3.1.5. Post Hoc Analysis of Sex and Population Interactions

Tukey's post hoc multiple comparison test was performed to examine pairwise differences among Malaysian males, Malaysian females, Indonesian males, and Indonesian females (Table 7). For nasal breadth, significant differences were observed between Indonesian males and Indonesian females, Indonesian males and Malaysian females, Indonesian females and Malaysian males, and Malaysian males and Malaysian females ($p < 0.05$).

**Table 7.** Tukey's post hoc test for nasal breadth, nasal height, and nasal index among sex groups of Malaysian and Indonesian populations.

| Interaction | | Significant Value at 95% Confidence Interval | | |
|---|---|---|---|---|
| | | Nasal Breadth | Nasal Height | Nasal Index |
| Indonesian males | Indonesian females | 0.002 | 0.008 | 0.907 |
| | Malaysian males | 0.907 | 0.000 | 0.000 |
| | Malaysian females | 0.000 | 0.716 | 0.051 |
| Indonesian females | Indonesian males | 0.002 | 0.008 | 0.907 |
| | Malaysian males | 0.000 | 0.00 | 0.000 |
| | Malaysian females | 0.958 | 0.176 | 0.023 |
| Malaysian males | Indonesian males | 0.907 | 0.000 | 0.000 |
| | Indonesia females | 0.000 | 0.000 | 0.000 |
| | Malaysian females | 0.000 | 0.000 | 0.353 |
| Malaysian females | Indonesian females | 0.000 | 0.716 | 0.051 |
| | Indonesian females | 0.958 | 0.176 | 0.023 |
| | Malaysian males | 0.000 | 0.000 | 0.353 |

For nasal height, significant differences were identified in multiple pairwise comparisons involving Malaysian males, while comparisons between Indonesian males and Malaysian females, as well as Indonesian females and Malaysian females, were not statistically significant. Regarding nasal index, significant differences were observed primarily in comparisons involving Malaysian males and Indonesian participants, whereas several sex-matched comparisons did not show significant differences.

### *3.2. Multivariate Analysis of Nasal Morphology*

Multivariate statistical analyses were applied to the combined nasal morphology dataset to explore patterns of variation that could not be fully captured through univariate nasal index–based comparisons. Using the complete set of approximately 11 nasal morphology parameters together with the nasal index, PCA, HCA, and PLS analysis were employed to examine the overall variance structure of the dataset, assess multivariate similarity patterns, and evaluate the relative contribution of population group and sex to nasal morphological variation.

#### 3.2.1. PCA

PCA was applied to the multivariate nasal morphology dataset to explore underlying patterns of covariation among the measured parameters. PCA was performed using the correlation matrix to account for differences in measurement scales across variables. The correlation matrix used for PCA is presented in Table 8.

**Table 8.** Correlation matrix of nasal morphology parameters and nasal index used for principal component analysis.

| Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Nasal Index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.0672 | 0.00775 | −0.03647 | −0.06893 | −0.00403 | −0.1339 | −0.00305 | −0.04524 | −0.02482 | −0.18017 | 0.07735 |
| 2 | 0.0672 | 1 | 0.49324 | 0.38813 | 0.42786 | 0.39238 | 0.19022 | 0.5333 | 0.39476 | 0.34833 | 0.21028 | −0.0476 |
| 3 | 0.00775 | 0.49324 | 1 | 0.79538 | 0.41419 | 0.6435 | 0.19756 | 0.44493 | 0.57523 | 0.44742 | 0.25129 | 0.33876 |
| 4 | −0.03647 | 0.38813 | 0.79538 | 1 | 0.1615 | 0.53699 | 0.19997 | 0.31255 | 0.5492 | 0.38144 | 0.25702 | 0.34024 |
| 5 | −0.06893 | 0.42786 | 0.41419 | 0.1615 | 1 | 0.51977 | 0.06847 | 0.6606 | 0.49835 | 0.48561 | −0.00701 | −0.52535 |
| 6 | −0.00403 | 0.39238 | 0.6435 | 0.53699 | 0.51977 | 1 | 0.17658 | 0.52519 | 0.50342 | 0.31991 | 0.07605 | 0.06111 |
| 7 | −0.1339 | 0.19022 | 0.19756 | 0.19997 | 0.06847 | 0.17658 | 1 | 0.11716 | 0.16681 | 0.01983 | 0.16631 | 0.10213 |
| 8 | −0.00305 | 0.5333 | 0.44493 | 0.31255 | 0.6606 | 0.52519 | 0.11716 | 1 | 0.4392 | 0.34722 | 0.0959 | −0.22926 |
| 9 | −0.04524 | 0.39476 | 0.57523 | 0.5492 | 0.49835 | 0.50342 | 0.16681 | 0.4392 | 1 | 0.56464 | 0.2262 | −0.16602 |
| 10 | −0.02482 | 0.34833 | 0.44742 | 0.38144 | 0.48561 | 0.31991 | 0.01983 | 0.34722 | 0.56464 | 1 | 0.29932 | −0.56319 |
| 11 | −0.18017 | 0.21028 | 0.25129 | 0.25702 | −0.00701 | 0.07605 | 0.16631 | 0.0959 | 0.2262 | 0.29932 | 1 | 0.00834 |
| Nasal Index | 0.07735 | −0.0476 | 0.33876 | 0.34024 | −0.52535 | 0.06111 | 0.10213 | −0.22926 | −0.16602 | −0.56319 | 0.00834 | 1 |

The correlation structure indicated a combination of positive and negative associations among nasal parameters. Several inverse relationships were observed, including negative correlations between Parameter 1 and Parameters 4 to 11, as well as between the nasal index and selected parameters such as Parameters 2, 5, 8, 9, and 10. In contrast, many other parameter pairs exhibited positive correlations, reflecting direct associations among multiple linear and angular nasal measurements. This mixed correlation structure supports the use of PCA as an exploratory tool to reduce dimensionality and to summarise shared patterns of variation within the nasal morphology dataset.

Eigenvalue analysis of the correlation matrix identified four principal components with eigenvalues greater than 1 (Table 9). Together, these components accounted for 72.59% of the total variance in the nasal morphology dataset. The first principal component explained 37.01% of the variance, followed by the second (16.44%), third (10.64%), and fourth (8.49%) components. Each subsequent component contributed less than 10% of the total variance.

**Table 9.** Eigenvalues and percentage of variance explained by principal components derived from the correlation matrix of nasal morphology variables.

| No. | Eigenvalue | Percentage of Variance | Cumulative |
|---|---|---|---|
| 1 | 4.44101 | 37.01% | 37.01% |
| 2 | 1.97321 | 16.44% | 53.45% |
| 3 | 1.27706 | 10.64% | 64.09% |
| 4 | 1.01915 | 8.49% | 72.59% |
| 5 | 0.8613 | 7.18% | 79.76% |
| 6 | 0.7229 | 6.02% | 85.79% |
| 7 | 0.50574 | 4.21% | 90.00% |
| 8 | 0.39175 | 3.26% | 93.27% |
| 9 | 0.34174 | 2.85% | 96.12% |
| 10 | 0.28642 | 2.39% | 98.50% |
| 11 | 0.17016 | 1.42% | 99.92% |
| 12 | 0.00956 | 0.08% | 100.00% |

The first two principal components together accounted for 53.45% of the total variance and were therefore selected for visualisation in the PCA score plots. These components capture the dominant multivariate patterns present in the dataset and provide a reduced-dimensional representation suitable for exploratory assessment of population- and sex-related variation in nasal morphology. Overall, the eigenvalue structure indicates the presence of structured multivariate relationships among the measured nasal parameters, supporting further examination using complementary multivariate statistical techniques.

The PCA loading plot (Figure 2) illustrates the contribution and direction of the nasal morphology parameters and the nasal index with respect to the first two principal components (PC1 and PC2). Most linear nasal measurements, including Parameters 2, 3, 4, 6, and 9, show positive loadings along PC1, indicating that this component primarily captures overall nasal size and proportional relationships among linear dimensions.

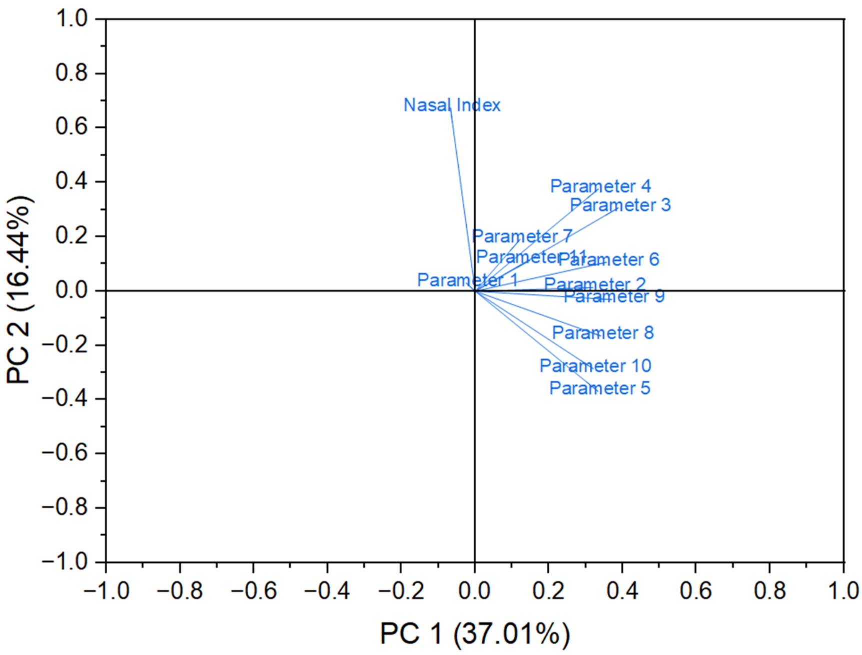


**Figure 2.** PCA loading plot of nasal morphology parameters.

In contrast, the nasal index exhibits a strong positive loading along PC2, with a comparatively weaker association with PC1. This suggests that PC2 is largely influenced by relative nasal proportions rather than absolute size-related measurements. Parameters associated with nasal angles and projection, such as Parameters 5, 8, and 10, display negative loadings along PC2, indicating an inverse relationship with the nasal index on this axis.

The loading structure indicates that PC1 represents a general morphological dimension dominated by linear nasal measurements, whereas PC2 reflects variation related to nasal proportionality, particularly as captured by the nasal index. This separation supports the use of PCA as an effective exploratory tool for identifying multivariate patterns within nasal morphology data.

Meanwhile, the PCA score plots illustrating population group and sex distributions are shown in Figure 3a,b, respectively. The distribution of participants along Principal Component 1 (PC1, 37.01%) and Principal Component 2 (PC2, 16.44%) indicates that individuals from the Indonesian population group tend to be more concentrated along PC2, whereas Malaysian participants display a broader dispersion across both components, particularly along PC1.

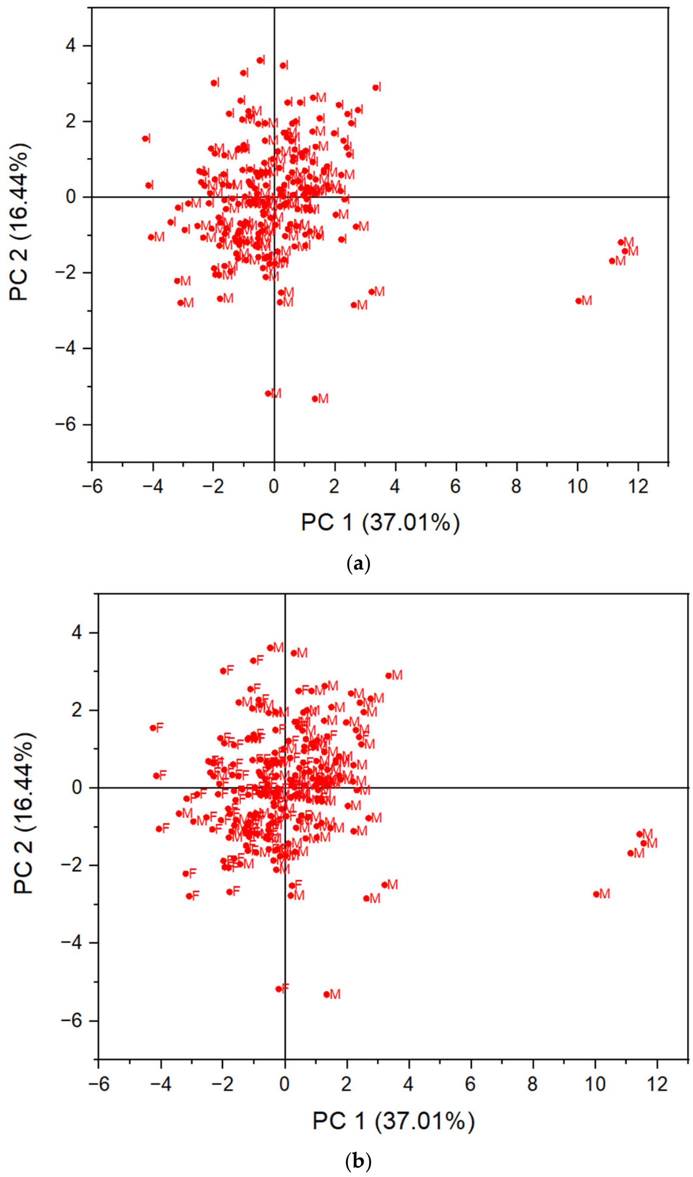


**Figure 3.** PCA score plot distribution of (**a**) population group [I = Indonesia, M = Malaysia] and (**b**) sex [M = male, F = female].

With respect to sex, females show a tendency to cluster more closely along PC2, while males exhibit greater dispersion along PC1. These distribution patterns suggest that variation associated with population group is more strongly reflected along PC2, whereas variation related to sex is more prominently aligned with PC1. Although some overlap between groups is evident, the score plots reveal discernible multivariate trends associated with both population group and sex in nasal morphology.

### 3.2.2. HCA

HCA was conducted to examine similarity patterns among the nasal morphology parameters. The resulting dendrogram (Figure 4) illustrates the hierarchical relationships between variables based on their multivariate similarity.

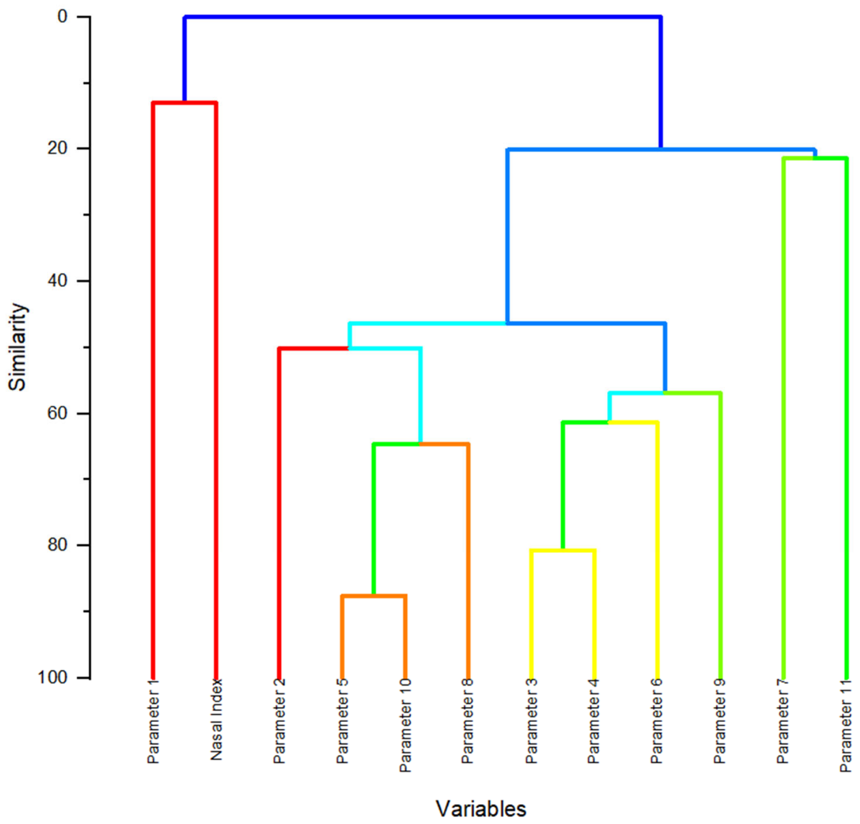


**Figure 4.** Dendrogram showing the hierarchical clustering of nasal morphology parameters. Note: Different colours in the dendrogram indicate different clustering relationships.

Two primary clusters were identified. The first cluster, highlighted in red, comprised Parameter 1 (endocanthion point) and the nasal index, indicating a high degree of similarity between these variables. This suggests that these measurements share a comparable variance structure within the dataset and may capture related aspects of nasal morphology.

The second major cluster, shown in blue, included Parameters 2 (nasal bony width), 3 (interalar distance), 4 (bialar base distance), 6 (bony nasal distance measurement), 7 (nasofrontal angle), and 9 (nasal wing to pronasal distance). These variables exhibited relatively high similarity with one another, reflecting closely associated multivariate behaviour across the sample.

The remaining parameters, including Parameter 5 (nasal base to pronasal distance), Parameter 8 (nasolabial angle), Parameter 10 (nasion to pronasal distance), and Parameter 11 (nasal projection), formed smaller, distinct clusters, indicating lower similarity with the primary variable groups. This pattern suggests that these measurements capture more independent aspects of nasal morphology.

Overall, the HCA results support the presence of structured relationships among nasal parameters and complement the PCA findings by highlighting groups of variables that exhibit shared multivariate characteristics.

#### 3.2.3. PLS

The presence of correlated variables within the nasal morphology dataset, as indicated by the PCA and HCA, justified the application of PLS regression as a supervised multivariate technique. PLS was employed to evaluate the relationship between the multivariate nasal parameters and the predefined response variables while reducing data dimensionality.

Model optimisation was assessed using cross-validation, and the predicted residual sum of squares (PRESS) values are presented in Table 10. The PRESS profile indicated that a two-factor model was optimal, with the lowest root mean PRESS value of 0.95895 observed for Factor 2. This result suggests adequate model stability and predictive performance for subsequent interpretation.

**Table 10.** PRESS values for PLS model cross-validation.

| Factor | Root Mean PRESS |
|---|---|
| 0 | 1.00474 |
| 1 | 0.97307 |
| 2 | 0.95895 |

The proportion of variance explained by each PLS factor is summarised in Table 11. Factor 1 accounted for 47.89% of the variance in the X block and 7.69% of the variance in the Y response, while Factor 2 explained an additional 52.11% of the X variance and 2.93% of the Y variance. Collectively, the first two factors explained 100% of the variance in the predictor variables and 10.63% of the variance in the response variables.

**Table 11.** Variance explained by each factor for X and Y effects in the PLS model.

| Number of Factors | Variance Explained for X Effects (%) | Cumulative X Variance (%) | Variance Explained for Y Responses (%) | Cumulative Y Variance (%) |
|---|---|---|---|---|
| 1 | 47.89 | 47.89 | 7.69 | 7.69 |
| 2 | 52.11 | 100 | 2.93 | 10.63 |

The variance explained profile indicates that the first two PLS factors capture the dominant structure of the multivariate nasal morphology data and are therefore sufficient for subsequent model interpretation. These factors represent the primary multivariate patterns linking the nasal parameters to the predefined response variables in the study.

To further assess the contribution of individual variables, Variable Importance in Projection (VIP) scores were derived from the PLS model (Figure 5). VIP values indicate the relative importance of each predictor in explaining variation captured by the model, with higher values reflecting greater contribution. The results showed that population group exhibited consistently higher VIP values than sex, indicating a stronger influence on the multivariate structure of the nasal morphology dataset. In contrast, sex displayed lower VIP scores, suggesting a more limited contribution to the overall model. These findings indicate that population-related variation contributes more substantially to nasal morphological differentiation than sex-related variation within the present dataset.

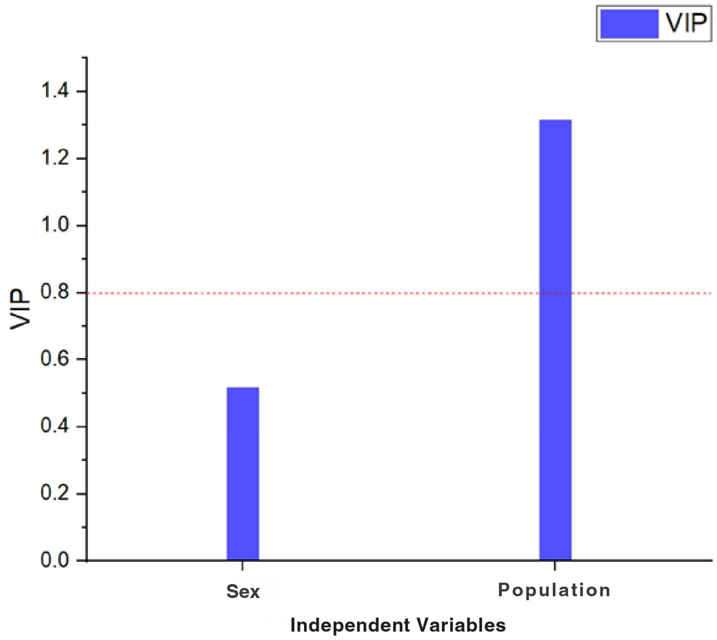


**Figure 5.** VIP plot of variables in the PLS model.

## 4. Discussion

### *4.1. Interpretation of Results*

This study investigated nasal morphological variation between Malaysian and Indonesian populations using multivariate analyses, revealing clear population-specific differences in nasal shape and dimensions, as well as secondary influences related to sex. The combined results of PCA, HCA, and PLS analyses provide consistent evidence that population group represents the primary source of variation in nasal morphology within the studied dataset.

The distribution of nasal shapes based on the nasal index indicated clear differences between the two populations. Malaysians predominantly exhibited leptorrhine noses, whereas mesorrhine noses were more common in Indonesians. These findings align with previous studies [27–29], which highlight geographic and genetic factors contributing to nasal shape variation among different ethnic groups. The absence of certain nasal shape categories (such as hyperplatyrrhine in Malaysians and hyperleptorrhine in Indonesians) further supports the notion that distinct racial characteristics influence the development of nasal features [30,31].

The observed sexual dimorphism, with males showing significantly larger nasal dimensions than females, is consistent with existing anthropometric studies [3,14]. This reinforces the importance of considering sex in nasal morphology studies, as males and females exhibit consistent differences in craniofacial dimensions across populations.

### *4.2. Comparison with Previous Studies*

The findings of this study are consistent with previous research on craniofacial variation, particularly with respect to nasal morphology, which has been shown to vary systematically across populations and ancestral groups [29,32]. Population-level differences in nasal form, including variation in nasal index and the relative predominance of leptorrhine and mesorrhine nasal types, have been widely documented, including among Southeast Asian populations [10,26]. In the present study, Malaysian participants predominantly exhibited leptorrhine nasal characteristics, whereas Indonesian participants showed a higher prevalence of mesorrhine nasal types. These findings are consistent with those reported by Marini et al. [33], who similarly identified mesorrhine nasal morphology as dominant within Indonesian populations. Taken together, these comparisons support the interpretation that population-related variation in nasal morphology reflects a combination of shared ancestry and environmental influences and is reproducible across independent studies and analytical approaches.

In addition to population-level variation, the present study also identified sex-related differences in nasal morphology, with males generally exhibiting larger nasal dimensions than females. This pattern is consistent with previous anthropometric studies reporting greater nasal height and breadth in males across diverse populations [17,26,34]. Similar sex-related trends have been documented by Patel et al. [35] in a study of young Gujarati adults, where males demonstrated significantly higher nasal index values and broader nasal dimensions compared to females, despite variation in predominant nasal types between sexes. These findings support the interpretation that sex contributes to nasal morphological variation, although its influence is typically secondary to population or ancestry-related factors. The consistency of sex-related differences across geographically and ancestrally distinct groups suggests that such dimorphism reflects broader patterns of craniofacial growth and size dimorphism rather than population-specific nasal form [14,36].

The present findings further align with established forensic anthropological understanding that population-related variation plays a more prominent role than sex in shaping nasal morphology. While sex-related differences in nasal dimensions have been reported, nasal morphology has long been recognised as more informative for population and ancestry assessment than for sex estimation [37]. In the present study, multivariate analyses demonstrated that population group accounted for a greater proportion of morphological variation than sex among Malaysian and Indonesian participants.

These results are consistent with previous work highlighting the value of multivariate analytical frameworks for examining complex craniofacial traits. Studies employing PCA- and PLS-based approaches have shown that nasal and facial morphology are strongly influenced by population history, ancestry, and environmental context, often exceeding the effects attributable to sex alone [38]. Similarly, Butaric and Klocke [39] demonstrated that nasal morphological variation across populations reflects broader adaptive and population-specific patterns related to climate and ancestry rather than isolated sex-based differences. In this context, the present study supports existing literature indicating that multivariate methods provide a more comprehensive characterisation of nasal morphology than univariate metrics alone, particularly for forensic identification and biological profiling.

### *4.3. Implications for Forensic Science*

The findings of this study have relevance for forensic anthropology and biological profiling, particularly in relation to the interpretation of population-level variation in nasal morphology among living individuals. The observed differences between population groups indicate that nasal anthropometric traits may contribute to the broader assessment of ancestry in forensic contexts when soft-tissue nasal form is preserved, and other lines of evidence are limited or unavailable. However, the present results should be regarded as providing population-specific soft-tissue morphological data rather than immediately applicable forensic standards.

The application of multivariate analytical techniques, including PCA and PLS, enabled the simultaneous evaluation of multiple nasal parameters and facilitated assessment of their relative contributions to morphological variation. In the present study, these approaches demonstrated that population group accounted for a greater proportion of variation than sex, supporting their utility as exploratory analytical tools for examining complex craniofacial datasets and informing future model development.

Importantly, the present study is based exclusively on nasal anthropometric measurements obtained from living individuals and therefore reflects soft-tissue morphology rather than underlying skeletal anatomy. As such, the findings are directly applicable only to living or recently deceased individuals in whom soft-tissue nasal features are preserved. Application of these results to fully skeletonised remains would be inappropriate, as skeletal nasal morphology cannot be reliably inferred from soft-tissue measurements without direct analysis of cranial skeletal material or virtual skeletal datasets, such as cranial CT scans.

In this context, the present findings provide a structured foundation for future research aimed at developing population-specific reference datasets and classification models based on nasal morphology. The construction of discriminant functions or other forensic tools would require further investigation, including independent validation samples, expanded population coverage, and direct analysis of skeletal or virtual cranial data. Future studies integrating soft-tissue and skeletal approaches may help clarify the extent to which population-level patterns observed in living individuals are reflected in skeletal nasal anatomy.

### *4.4. Future Research Directions*

The present study provides population-specific insights into nasal soft-tissue morphology among living individuals; however, several avenues for future research may further strengthen and extend these findings. One important direction is the inclusion of additional craniofacial soft-tissue parameters, such as orbital dimensions, maxillary width, and facial angles, which may offer a more comprehensive representation of facial morphology and improve the analytical resolution of population-level variation.

Future studies would also benefit from expanding the sample size and incorporating a broader range of populations. Inclusion of additional Southeast Asian groups, as well as populations from other geographic regions, would allow for external validation of observed patterns and support more generalisable interpretations of nasal morphological variation. Such expansion is essential before any population-specific reference frameworks can be meaningfully developed.

Integration of morphological data with genetic information represents another promising research direction. Combining nasal anthropometry with genomic ancestry data may provide deeper insight into the relative contributions of genetic inheritance and environmental factors to nasal shape variation. However, such integrative approaches should be pursued within a research framework rather than as immediate forensic applications.

Importantly, future research should distinguish clearly between soft-tissue and skeletal analyses. While the present study focuses on nasal morphology in living individuals, investigation of skeletal nasal variation would require direct analysis of skeletal collections or virtual skeletal data, such as cranial CT scans. Comparative studies examining the correspondence between soft-tissue and skeletal nasal morphology may help clarify the extent to which population-level patterns observed in living subjects are reflected in skeletal anatomy.

In summary, future work should prioritise expanded population coverage, additional craniofacial variables, and appropriate validation strategies, while maintaining a clear distinction between soft-tissue and skeletal approaches. Such efforts will contribute to a more robust and methodologically sound understanding of nasal morphology within forensic anthropology and related disciplines.

**Author Contributions:** Conceptualization, A.Z.W. and M.K.B.; methodology, M.K.B. and A.Z.W.; software, M.J.M.Y. and E.S.R.A.; formal analysis, M.K.B., M.J.M.Y. and M.R.A.R.A.; investigation, M.K.B.; resources, M.K.B.; data curation, M.K.B.; writing—original draft preparation, M.K.B., M.J.M.Y. and E.S.R.A.; writing—review and editing, A.Z.W., M.J.M.Y., E.S.R.A. and M.R.A.R.A.; visualisation, M.J.M.Y.; supervision, A.Z.W. and M.J.M.Y.; project administration, A.Z.W.; funding acquisition, M.J.M.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Management and Science University (MSU) Seed Grant, grant number SG-019-022023-FHLS.

**Institutional Review Board Statement:** Ethical approval for the study was obtained from the Management and Science University (MSU) (Approval No. MSU-RMC-02/FR01/05/L1/048, approval date 30 November 2020). The study was conducted in accordance with the Declaration of Helsinki.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the participants to publish this paper.

**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

**Acknowledgments:** The authors would like to thank MSU for providing the resources and funding to support this study under the MSU Seed Grant (grant number SG-019-022023-FHLS). Special thanks to the participants from Malaysia and Indonesia for their cooperation and valuable contributions to the research. We also wish to acknowledge the assistance of the local communities and individuals who have facilitated the data collection process. Their support was invaluable in ensuring the success of this study.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| HCA | Hierarchical Cluster Analysis |
| ICC | Intraclass Correlation Coefficients |
| PCA | Principal Component Analysis |
| PLS | Partial Least Squares |
| PRESS | Predicted Residual Sum of Squares |
| SD | standard deviation |
| TEM | Technical Error of Measurement |
| VIP | Variable Importance in Projection |

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