Makara Journal of Science, 22/1 (2018), 7-16
doi: 10.7454/mss.v22i1.7422

# Craniofacial Shape of Arfak People Based on Geometric Morphometric Features

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Received October 25, 2016 | Accepted February 1, 2018

## Abstract

Face and cranial (craniofacial) shape is highly specific to the individual; therefore, craniofacial shape is often used to identify individuals and to analyze variability in the human population. Previous studies, consisting only of verbal descriptions, suggested that the cranial shape of the Papuan people was highly variable. Despite their usefulness, verbal descriptions cannot fully demonstrate common and local variation in cranial shape. They also cannot be used to extract the general trend of variation or to group face shapes based on their similarity. Here we attempt to apply geometric analysis, a method of shape analysis, to measure facial anatomical structural landmarks of Papuan people. The craniofacial shape of Papuan people was constructed from those of Arfak people based on 16 anatomic landmarks on the lateral side. Arfak is one of the traditional Papuan tribes in Manokwari, West Papua Province. Our result showed great variation in craniofacial shapes among the Arfak. The nose, chin, and mandible differed significantly, whereas other parts of the face were relatively stable and showed small variations. These differences reflected variations in the facial growth rate. The high level of diversity thus indicates that some parts of the face have higher plasticity in their growth pattern than others.

## Abstrak

**Bentuk Kraniofasial Orang Arfak berdasarkan Karakteristik Morfometrika Geometri**. Bentuk wajah dan kranial (craniofacial) setiap individu adalah spesifik; sehingga kraniofasial sering digunakan dalam proses identifikasi individu dan untuk menganalisis variabilitas populasi manusia. Studi sebelumnya hanya berdasarkan deskripsi verbal, menunjukkan bahwa cranial orang Papua bervariasi. Meskipun bermanfaat, deskripsi secara verbal tidak dapat secara utuh menggambarkan variasi secara lokal dan umum bentuk cranial. Deskripsi secara verbal juga tidak dapat mengekstrak kecenderungan umum variasi dan mengelompokkan bentuk wajah berdasarkan kemiripan. Dalam artikel ini kami mencoba untuk menggunakan analisis geometri, yaitu suatu metode analisis bentuk untuk mengukur struktur landmark anatomi wajah orang Papua. Bentuk kraniofasial orang Papua dikonstruksi dari suku Arfak berdasarkan 16 titik anatomi landmark sisi lateral. Suku Arfak merupakan salah satu suku tradisional di daerah Manokwari Provinsi Papua Barat. Hasil penelitian kami menunjukkan variasi yang besar pada bentuk kraniofasial orang Arfak. Hidung, dagu dan mandibula menunjukkan perbedaan yang signifikan dibandingkan bagian wajah lainnya yang lebih stabil dan sedikit variasi. Perbedaan ini menggambarkan laju pertumbuhan wajah yang berbeda. Oleh karena itu, perbedaan yang nyata itu mengindikasikan bahwa bagian wajah itu lebih plastisitas dalam pola pertumbuhannya dibandingkan bagian wajah lainnya.

***Keywords***: *craniofacial, Arfak tribe, landmark, relative warp, non-uniform*

## Introduction

Papua (originally called Netherlands New Guinea, later renamed Irian Jaya) covers half of the western part of New Guinea. In Papua there are approximately 269 languages [1] and thus a possible 269 tribes. They are considered to belong to the Australoid race. Arfak is one of the tribes that inhabit in Manokwari, West Papua Province. The Arfak people have a semi-nomadic life-style with a semi-permanent residence. Their livelihood depends on hunting, gathering, and subsistence farming with shifting cultivation [2-4]. The Arfak tribe is divided into four subtribes, namely Hattam, Meyah, Sougb, and Moile [2,3].

Craniofacial shape is highly specific to the individual and is therefore often used to make a unique identification and to analyze variability in human populations. Face shape is influenced by genetic and environmental factors [5,6]. Therefore, several analytical studies of the face and head have already been carried out related to genetic and environmental factors such as ethnicity, sexual dimorphism, attractiveness, skull fossils, ontogenetic development, secular trends, and health [6,12,31,34,36-38].

Studies related to human craniofacial shape are rarely performed on Indonesian people. Previous studies have examined the face shape of Batak, Sundanese, and Betawi people [7-12]. These studies showed a low level of variation in the face shape of Indonesian people. Skull homogeneity in the African and minimum variation in facial character within and between sexes in a tribe from the Philippines were also reported by Bruner et al. [5], Bruner & Manzi [13], and Anies at al. [31]. However, Papuan people and their ancestors had cranial and mandibular variation, which have already been identified in verbal accounts by Verneau [14] and Bulbeck & Connor [15]. Therefore, additional information is needed to support previous studies related to craniofacial variation in Papuan people using alternate methods. This study evaluates the craniofacial morphological characteristics of Papuan people more comprehensively based on facial anatomical structures using a geometric morphometrics package.

Geometric morphometrics, or landmark morphometrics, is a relatively recent development in the study of human and animal morphology. The advantage of this method is that a difference in shape can be detected by an accurate statistical analysis of a rather small number of samples. It can obtain superior results from image visualization and capture shape change information better than traditional morphometric measurements, and shape differences can be visualized directly as illustrations or computer animations. This method starts with the digitization of landmark coordinates on the structure. Then, the influence of variation related to size, location, and orientation of objects is eliminated mathematically, so that the differences only express shape variation [16,32,33]. This study aims to characterize the craniofacial variability of Arfak men and women and to study the distribution pattern of craniofacial morphology.

## Materials and Methods

**Data collection.** The study was conducted from September 2010 to April 2011 in Manokwari, West Papua Province. This study was carried out using photographs of the faces of males and females of the Arfak tribe. The people were also interviewed to determine the identities and tribal origins of the two previous generations.

**Collecting facial images.** The facial image of the subject was recorded using an Olympus C-750 digital camera with a telescopic lens and a Canon DS126071 with an optical lens of focal length >50 mm. The distance from the face to the photographic equipment was approximately 3–4 m to minimize perspective errors. Photographs were taken against a white background.

**Digitization of face shape.** The best face photograph of each subject was chosen. There are 16 lateral anatomic landmarks used in the analysis of face shape in Figure 1 (Table 1). Cartesian coordinates of landmark anatomy of each individual were digitized manually with tpsDig software. Digitization was performed five times for each individual to minimize digitization errors. The distribution of landmark positions and the accuracy of the results of digitization were observed with tpsRelW software.

**Data analysis.** To obtain information on general face shape and its local variations, we used three methods of geometric morphometrics, Generalized Procrustes Analysis (GPA) [16,17]. Thin Plate Spline (TPS), and Relative Warp Analysis [18]. These methods are used to calculate the average shape, analyze shape variation, and summarize the variation in the non-uniform component of shape variation, respectively. Face variations were grouped based on their similarity using the neighbor-joining method [19] in the analysis phylogeny and evolutions (APE) package [20]. Overall calculations were performed using the R program [21].

GPA method is used to remove all information related to the size, rotation, and position of each image. First, the GPA method calculates the centroid of the landmark coordinates. The centroid is the average of the "x"


**Figure 1. Face Digitation of Lateral Face**

**Table 1. Description of Landmark Anatomy of Lateral Face**

| Number | Description |
|---|---|
| 1 | Most lateral point of the forehead (*glabella*) |
| 2 | Innermost point on the nose ridge within the eye region (*nasion*) |
| 3 | Maximum point of the nose (*pronasal*) |
| 4 | Lowest point between the nose tip and the upper lip (*subnasale*) |
| 5 | Midpoint of the upper lip (*vermilion* atas) |
| 6 | Most lateral point where the upper and lower lip meet (*cheilion*) |
| 7 | Midpoint of the lower lip (*vermilion* bawah) |
| 8 | Minimum point between vermilion lower side and gnathion |
| 9 | Lowest point of the chin (*gnathion*) |
| 10 | Most lateral point of the nose (*alare*) |
| 11 | Cheek bone (*zygomatic*) |
| 12 | Lateral hinge when the eyelid closes (*exochantion*) |
| 13 | Outer aspect of the eyebrow |
| 14 | Maximum point of upper auditory canal |
| 15 | Minimum point of lower auditory canal |
| 16 | The maximum curvature point at the angle of the mandible (*gonion*) |

coordinate and "y" coordinate of all anatomic landmarks. Then each specimen is scaled to unit centroid size. Each face is then rotated to minimize the total squared distances between homolog landmarks in different specimens. Furthermore, the average coordinates of each landmark are determined [16,17,22]. These coordinates are used as data for the TPS method. Visualization of general facial images is shown using tpsSuper software [23]. This study uses the average shape as a reference, under the assumption that the average shape of Arfak craniofacial is a common shape of their ancestors.

Pairwise comparisons are carried out by mapping the anatomic landmark of reference to the homologous anatomic landmark of each face using the Thin Plate Spline (TPS) method. Deformation shows the magnitude and direction of variation between two shapes. These deformation processes use the tpsSplin software [24].

TPS decomposes the differences in shape between the uniform (affine or linear) and non-uniform (non-affine) components, both of which can be displayed as grid deformation. Uniform components will maintain parallel lines on the grid deformation; this reflects the changes in global shape that occur on all anatomic landmarks because of differences in size, orientation, or location between two shapes. Non-uniform components reflect changes in the specific areas of certain anatomic landmarks and thus show local differences [18,16]. Non-uniform components can be decomposed into several partial warps. The level of deformation of a reference to such a shape is expressed as a shape space metric called bending energy [25]. Using the analogy of bending a thin sheet of metal, two close anatomic landmarks will require greater energy to displace them than two landmarks that are much further from each other. Uniform deformation does not require bending energy (i.e., bending energy = 0), whereas the non-uniform components require greater energy on a smaller scale [18]. This study used non-uniform deformation because these shapes reflect local variations; thus, we can determine which part of the anatomic landmark is the most variable.

To summarize face shape variations in non-uniform components, principal component analysis (often called an analysis of relative warps (RWs) when applied to morphometric data) was performed on a matrix of partial warp scores. When a RW is orthogonal to another, they are uncorrelated. The first RW carries the largest proportion of the variance, and subsequent RWs carry smaller proportions. Therefore, the first RW can be used to extract the general trend of variation. All calculations were carried out with TPSRelW software [26].

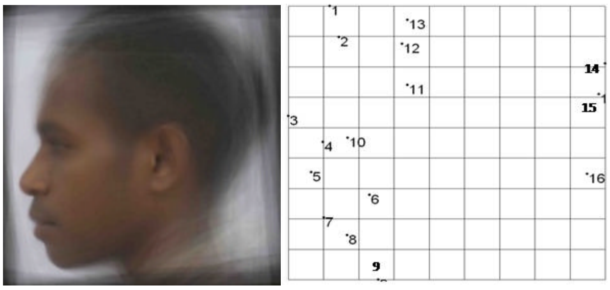
One can interpret the results as forming a hyperdimensional space containing the face of each individual, and the distance between individuals reflects the dissimilarity between them. A Euclidian distance matrix is used as the data for grouping face shape based on its similarity using the neighbor-joining cluster method [19] in the analysis phylogeny and evolutions (APE) package [20].

## Results and Discussion

**General craniofacial shape of the Arfak tribe.** The general face shape of Arfak men and women consists of a consensus face. The general face constructed from 37 men and 43 women was based on 16 anatomic landmarks on the lateral aspect. Face visualization, grid deformation, and the landmark coordinates of the general face of Arfak people from the lateral aspect are shown in Figures 2 and 3.

The general head shape of Arfak men and women is an elongated (*dolichocephalic*) shape (Figures 2 and 3). The *dolichocephalic* head shape was determined on the basis of a larger vertical than horizontal head diameter. This study supports the Verneau [14] classification of head shape of the Papuan race as *dolichocephalic.* These categories refer to the skulls of Arfak people and Doreri people identified by De Quatrefages and Hamy [14].

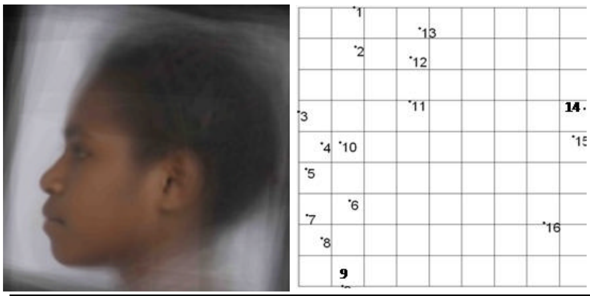
**Craniofacial variation.** The Arfak people exhibit varied craniofacial shapes, which are shown on the non-uniform components deformation grid that describes local changes (Figure 3). This study supports the word



| No. | Landmark Coordinates | | No. | Landmark Coordinates | |
|---|---|---|---|---|---|
| | X | Y | | X | Y |
| 1 | −0.07 | 0.28 | 9 | −0.10 | −0.31 |
| 2 | −0.07 | 0.19 | 10 | −0.10 | −0.01 |
| 3 | −0.18 | 0.06 | 11 | 0.04 | 0.08 |
| 4 | −0.14 | −0.01 | 12 | 0.04 | 0.17 |
| 5 | −0.17 | −0.06 | 13 | 0.06 | 0.23 |
| 6 | −0.08 | −0.13 | 14 | 0.39 | 0.06 |
| 7 | −0.17 | −0.16 | 15 | 0.37 | 0.00 |
| 8 | −0.14 | −0.21 | 16 | 0.31 | −0.18 |

No = landmark number as Figure 1, Table 1

**Figure 2. General Craniofacial Visualization, Deformation Grid, and Landmark Coordinates of Arfak Men on the Lateral Aspect, Constructed from a Composite Face of 37 Men based on 16 Landmarks**



| No. | Landmark Coordinates | | No. | Landmark Coordinates | |
|---|---|---|---|---|---|
| | X | Y | | X | Y |
| 1 | −0.07 | 0.28 | 9 | −0.10 | −0.31 |
| 2 | −0.07 | 0.19 | 10 | −0.10 | −0.01 |
| 3 | −0.18 | 0.06 | 11 | 0.04 | 0.08 |
| 4 | −0.14 | −0.01 | 12 | 0.04 | 0.17 |
| 5 | −0.17 | −0.06 | 13 | 0.06 | 0.23 |
| 6 | −0.08 | −0.13 | 14 | 0.39 | 0.06 |
| 7 | −0.17 | −0.16 | 15 | 0.37 | 0.00 |
| 8 | −0.14 | −0.21 | 16 | 0.31 | −0.18 |

No = landmark number as Figure 1, Table 1

**Gambar 3. General Face Visualization, Deformation Grid, and Landmark Coordinates of Arfak Women Constructed from a Composite Image of 43 Women based on 16 Landmarks on the Lateral Aspect**

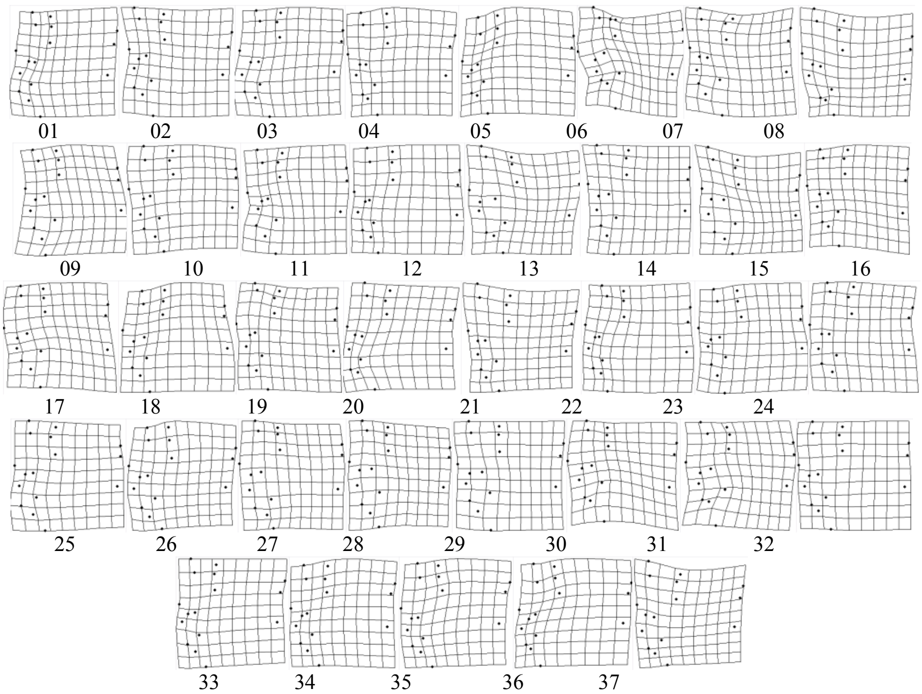



**Figure 4. Variation in Lateral Face of Men based on Grid Deformation (1–37: Number of People)**

of Lawes [28], who observed cranial shape variation among the Papuan people. The variation in craniofacial shape of 37 and 43 Arfak men and women, respectively, is shown in Figures 4 and 5. These figures show local variation in craniofacial shape based on the non-uniform deformation grid.

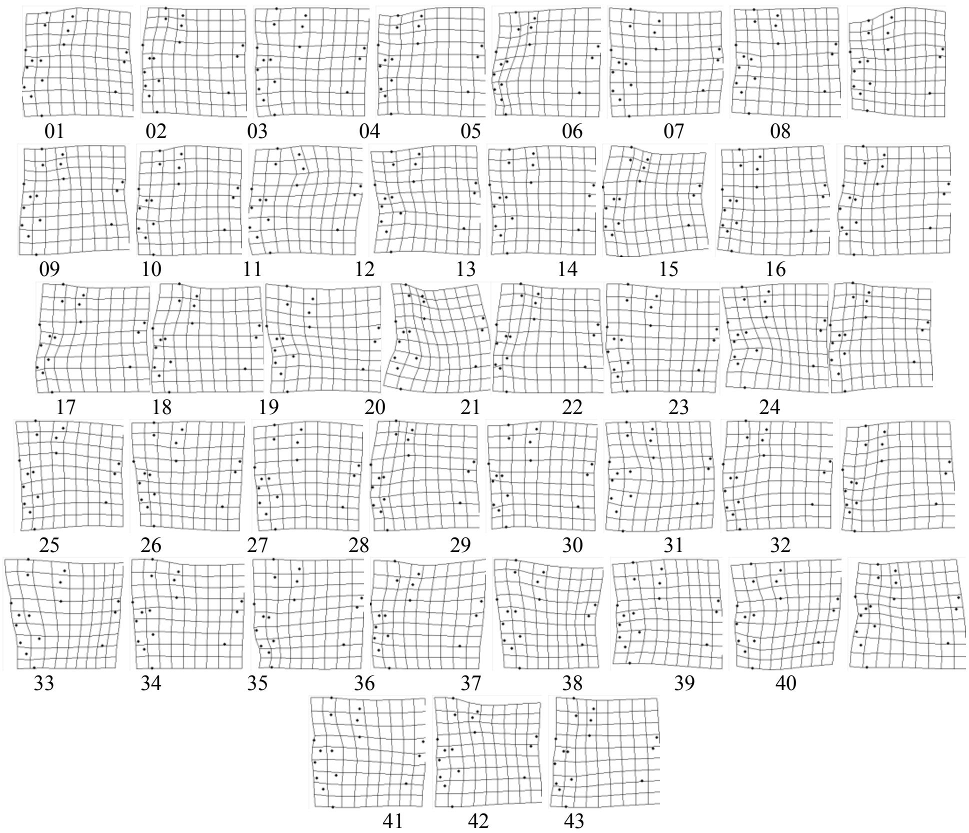



**Figure 5. Variation in Lateral Face of Women based on Grid Deformation (1–43: Number of People)**

To summarize the overall face shape variation in terms of non-uniform components resulting from 16 landmarks on the lateral aspect, the partial warp score, and RW score were determined. Both scores were used to analyze shape variability by the PCA method. Facial morphology variations formed morphological space (28 RW lateral face of men and women). The RW value is calculated based on the average shape of each individual. The percentage variability expressed by each RW component decreased gradually from the first to the last component. Therefore, some components of the first RW can explain the variability in the large proportions.

Figure 6 shows a comparison between RW1 and other components of lateral face of Arfak men. Comparison between the RW1 component and the fourth RW components on the first row and column showed the ellipsoid shape distribution pattern. The RW1 component usually carried information about size, whereas other components carried information about shape [27]. In contrast, comparison of RW2 to other RW on the second row and column to the fifth row and column showed the rounded shape distribution pattern. The same result is also shown in comparisons of RW3, RW4, and RW5.

Neighbor-joining cluster analysis based on Euclidean distances describes a small number of people clustered together according to similar faces (Figure 7). Individuals in a similar face group have a close Euclidean distance from one another. Grouping of similar lateral faces only formed one group subtype.

The Arfak tribe face shape showed variation in typology based on facial anatomical structures using GPA, deformation, and RW analysis. The diversity in facial shape based on landmark coordinate data support the cranial diversity of the Papuan race, which have been described verbally by Lawes [28].

The lateral face subtype of Arfak men showed 14 and 15 anatomic landmarks moving in the inferio-anterior direction close to the anatomy of the $16^{th}$ landmark (Gonion). The $16^{th}$ anatomic landmark did not show movement; therefore, the jaw shape is similar to the general shape. This facial subtype looks narrow. It showed the first, second, and third anatomic landmarks moving in the inferio-posterior direction. The movement of the fifth anatomic landmark in the anterior direction greater than the sixth and seventh anatomic landmarks produced a prognathic maxillary jaw shape and small lips.

Neighbor-joining analysis of craniofacial shape in women formed four groups with similar faces (Figure 7), while others showed differences in face shape. Each group of similar faces consisted of 6–8 people. The lateral face of Arfak women showed differences between each

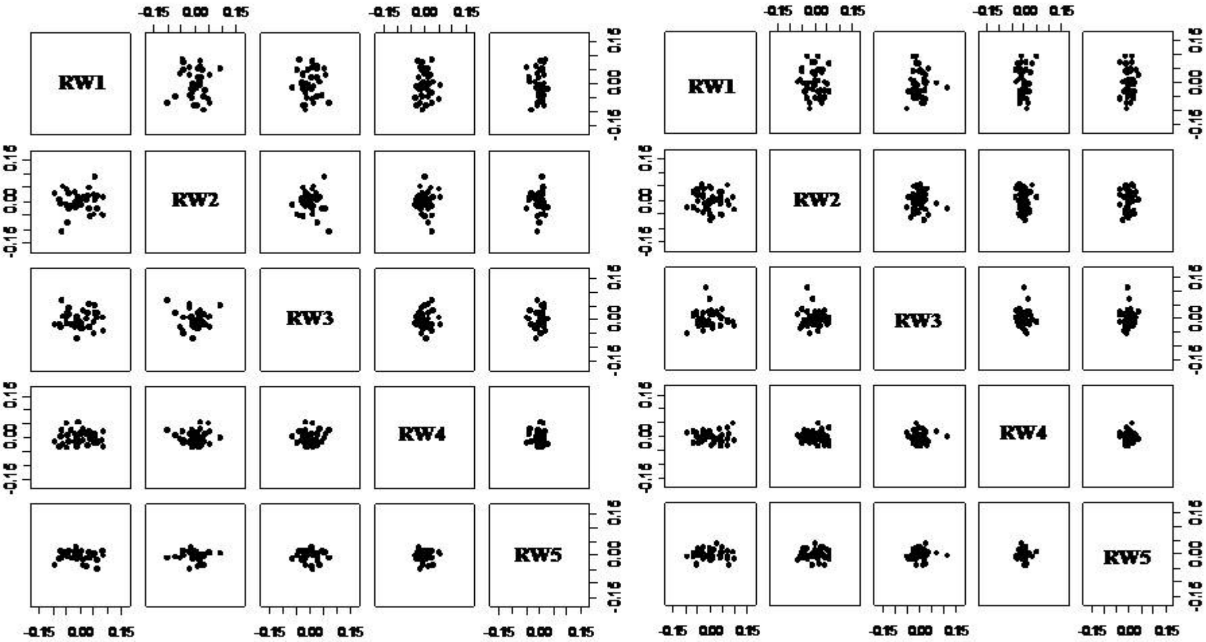
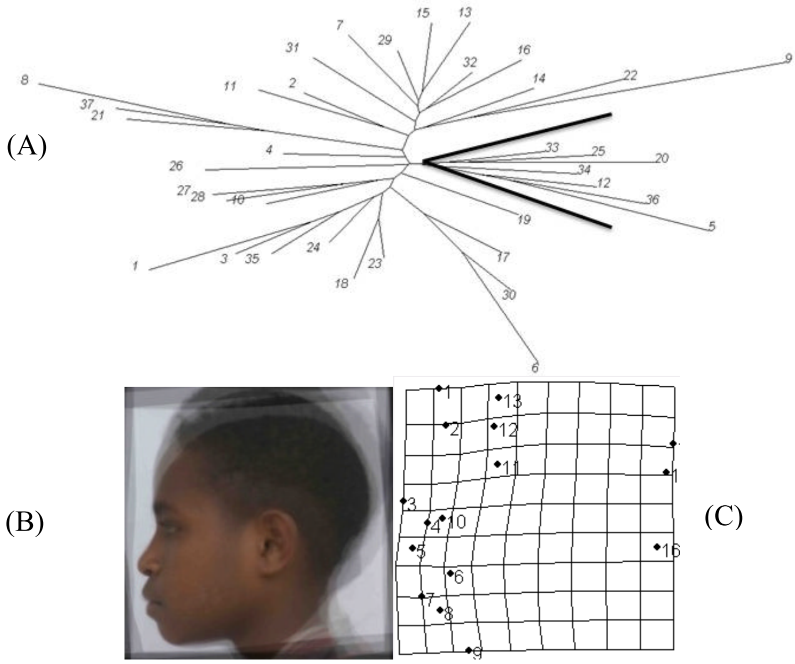



**Figure 6. Comparison of RW1 to RW5 on the Lateral Face of Men (Left) and Women (Right)**




(D)

| No. | *Landmark Coordinates* X | Y | No. | *Landmark Coordinates* X | Y |
|---|---|---|---|---|---|
| 1 | −0.11 | 0.26 | 9 | −0.04 | −0.32 |
| 2 | −0.10 | 0.18 | 10 | −0.10 | −0.02 |
| 3 | −0.18 | 0.02 | 11 | 0.02 | 0.09 |
| 4 | −0.13 | −0.03 | 12 | 0.00 | 0.18 |
| 5 | −0.16 | −0.09 | 13 | 0.01 | 0.24 |
| 6 | −0.08 | −0.15 | 14 | 0.38 | 0.12 |
| 7 | −0.14 | −0.19 | 15 | 0.37 | 0.06 |
| 8 | −0.10 | −0.23 | 16 | 0.35 | −0.11 |

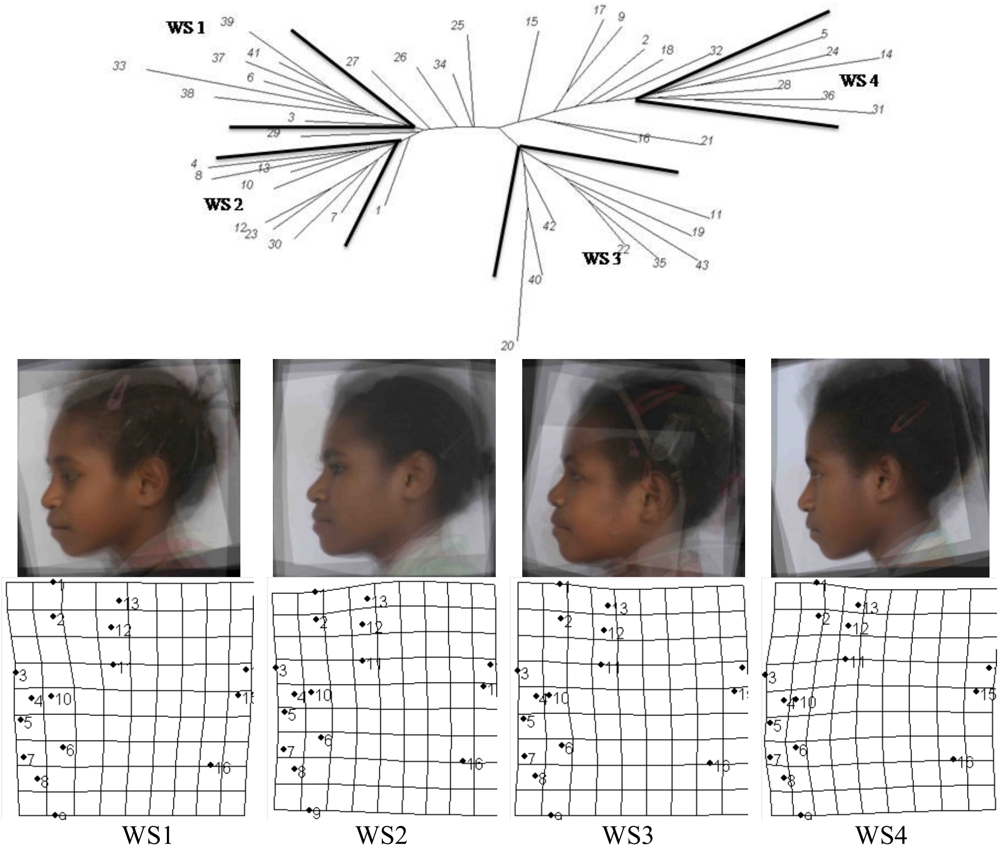
**Figure 7. The Unrooted Network of Similar Lateral Faces of Arfak Men with the Neighbor-joining Method (A), Image Visualization (B), Deformation Grid to General Shape (C), and Landmark Coordinates (D)**

subtype (Figure 8). The WS1 subtype was characterized by a short and prominent forehead, short nose, and cheekbones and chin similar to the general shape, while the WS2 subtype had the highest and most prominent forehead among subtypes, a short nose, a prognathic mandible, cheek bones similar to those of the WS1 subtypes, and the shortest chin of all subtypes. The WS3 subtype had the shortest but least prominent forehead among all subtypes. Their nose and chin were similar to the general shape, and their cheek bones were short. The WS4 subtype was characterized by a high and less prominent forehead than others, prognathism of the maxilla and mandible, high cheek bones, and a short nose and chin.

(A)

(B)

(C)




(D)

| No. | WS1 Coordinates | | No. | WS2 Coordinates | | No. | WS3 Coordinates | | No. | WS4 Coordinates | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | Y | | X | Y | | X | Y | | X | Y |
| 1 | −0.14 | 0.25 | 1 | −0.10 | 0.24 | 1 | −0.10 | 0.29 | 1 | −0.13 | 0.28 |
| 2 | −0.13 | 0.17 | 2 | −0.10 | 0.17 | 2 | −0.09 | 0.20 | 2 | −0.10 | 0.19 |
| 3 | −0.20 | 0.02 | 3 | −0.19 | 0.03 | 3 | −0.19 | 0.06 | 3 | −0.18 | 0.00 |
| 4 | −0.15 | −0.04 | 4 | −0.14 | −0.03 | 4 | −0.13 | −0.01 | 4 | −0.12 | −0.05 |
| 5 | −0.17 | −0.09 | 5 | −0.16 | −0.08 | 5 | −0.16 | −0.07 | 5 | −0.13 | −0.12 |
| 6 | −0.05 | −0.14 | 6 | −0.06 | −0.14 | 6 | −0.06 | −0.13 | 6 | −0.05 | −0.16 |
| 7 | −0.14 | −0.18 | 7 | −0.16 | −0.18 | 7 | −0.15 | −0.16 | 7 | −0.10 | −0.21 |
| 8 | −0.10 | −0.23 | 8 | −0.12 | −0.23 | 8 | −0.12 | −0.22 | 8 | −0.05 | −0.26 |
| 9 | −0.03 | −0.30 | 9 | −0.08 | −0.33 | 9 | −0.08 | −0.32 | 9 | 0.02 | −0.35 |
| 10 | −0.10 | −0.02 | 10 | −0.09 | −0.02 | 10 | −0.10 | −0.00 | 10 | −0.09 | −0.04 |
| 11 | 0.04 | 0.08 | 11 | 0.04 | 0.08 | 11 | 0.03 | 0.07 | 11 | −0.00 | 0.10 |
| 12 | 0.02 | 0.17 | 12 | 0.03 | 0.18 | 12 | 0.03 | 0.17 | 12 | −0.03 | 0.19 |
| 13 | 0.03 | 0.23 | 13 | 0.04 | 0.24 | 13 | 0.03 | 0.23 | 13 | −0.02 | 0.25 |
| 14 | 0.39 | 0.13 | 14 | 0.39 | 0.13 | 14 | 0.39 | 0.07 | 14 | 0.34 | 0.17 |
| 15 | 0.38 | 0.07 | 15 | 0.37 | 0.07 | 15 | 0.37 | 0.00 | 15 | 0.33 | 0.10 |
| 16 | 0.34 | −0.11 | 16 | 0.33 | −0.13 | 16 | 0.33 | −0.18 | 16 | 0.33 | −0.09 |

**Gambar 8. The Unrooted Network of Similar Lateral Faces of Arfak Women with the Neighbor-joining Method (A), Image Visualization (B), Deformation Grid to General Shape (C), and Landmark Coordinates (D)**

The RW component showed the relationship of face shape similarity. The ellipsoid-shaped distribution of individuals in RW1 versus RW2, RW3, RW4, and RW5 describing face morphology variation patterns are varied and polarized. Variability expressed by RW1 carried information about the size, whereas information about the form was expressed by other RW. This study differed from research conducted by Bruner and Manzi [13] and Bruner et al. [5], who studied the shapes and sizes of skulls from African populations using PCA analysis from data obtained by the GPA method. Their study showed homogeneous and non-polarized face variability.

Based on face variations exhibited by RW1 components, the nose, chin, and mandible had significant differences compared with other parts of the face, which were relatively stable and exhibited small variations. This difference described the growth rate of faces as different from each other. Analysis by morphometric geometry of the craniofacial shapes of Indonesian people showed that the mandible and chin had plasticity in their facial growth patterns [7,11,12]. This means the craniofacial parts adapt separately to mechanical and functional changes. Thus, the great diversity in nose, chin, and mandible found in this study indicates that those parts are more plastic than others. Based on a study by Fang et al. [35], the largest differences in facial dimensions between different ethnic populations are found in forehead height, interocular distance, and nasal width, using traditional morphometrics.

Diversity in the mandible was also found among human fossils discovered in Watinglo, northern coast of Papua New Guinea (about 10,000 years ago). Morphologically, the mandible shape from the Watinglo fossil showed similarity with the mandible from present-day Australian Aboriginal and Melanesian people but differed from the mandible shape of Coobol Creek and Kow Swamp fossils [15].

Craniofacial variation of the Arfak tribe might be a result of mixing with immigrant people. Lawes [28] concluded that populations who remain in mountain areas are native Papuan people, whereas those in coastal areas are immigrants. The population in coastal areas has a light brown skin color, whereas the population in mountain areas has a darker skin color. Wallace [29] also distinguished Dorey people (now Manokwari) as the immigrant population who live in coastal areas, whereas Arfak people are the native population who live in mountain areas. In addition, the Wonggor clan ancestors came from the Biak region according to Mr. Wonggor, Kepala Kampung Anggra Village in Arfak mountain areas (Wonggor, 2011 personal communication). Craven & de Fretes [30] also state that the mountain population consists of a mixture Arfak subtribes with migrants from other parts of Papua and Indonesia. Based on a survey of the Manokwari coastal area, there are some dominant tribes, such as Arfak, Biak, Serui, and Buton. Mountain areas, such as Anggra village, are still relatively dominated by the Arfak tribe, especially from the Moile subtribe.

Face shapes of several tribes in Indonesia, namely Kampung Naga [9], Batak [10], and Betawi [11], showed that both marriage patterns, endogamy and exogamy, are unaffected by the formation of facial variations. The Arfak tribe have a mixture of marriage patterns between subtribes. Marriage patterns and mixing of subtribes might be a cause of variation in facial shape.

## Conclusions

The craniofacial shape of Papuan people is found to be varied based on the morphometric geometric method. An ellipsoid-shaped distribution, which described craniofacial morphology patterns, was varied and polarized. The nose, chin, and mandible have significant differences compared with other parts of the face, which are relatively stable and exhibit small variations. This difference described the growth rate of parts of the face as different from each other. This means the craniofacial parts adapt separately to mechanical and functional changes.

## Acknowledgments

I would like to acknowledge the Indonesian Ministry of Education, Directorate General of Higher Education (DIKTI) for the Scholarship grant Post-graduate Study (BPPS) during periods 2007 to 2010 and for the people who have given their participating in this study.

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