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Ethnic Differences in Tweed's Facial Triangle: A Comparative Study between Sudanese and the Major Racial Classes

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ABSTRACT

Aim: *This study evaluated Tweed's facial triangle in various racial groups, including Sudanese, Black African, Black American, East Asian, and Caucasian populations with normal occlusion.*

Material and Method: *Using 29 cephalometric radiographs from Sudanese patients aged 18-25 with class I malocclusion.*

Result: *The analysis revealed significant differences in facial angles among these groups. Notably, increased proclination of lower incisors was observed in Sudanese, Arabs, East Asians, and African-descended populations.*

Conclusion: *The findings highlight the importance of incorporating ethnic-specific cephalometric norms into orthodontic practice for accurate diagnosis and effective treatment planning.*

Keywords
Cephalometric, Tweed's Facial Triangle, Races, Orthodontic treatment.

Background and Introduction

Cephalometric radiography is primarily used to describe facial skeletal morphology and growth, predict future growth, plan treatments, and evaluate treatment outcomes. This involves digitally or manually determining skeletal and dental relationships using specific points for linear and angular measurements. These measurements can then be compared to reference values from different racial groups. Various analyses have shown differences across racial and ethnic groups [1-8].

Tweed's Facial Triangle is indeed a significant tool in orthodontics for diagnosis, classification, and prognosis. It emphasizes the relationship between the lower incisor's inclination and the Frankfort horizontal plane, which is critical for determining the balance and harmony of the facial profile. Further, Tweed introduced the Frankfort mandibular plane angle (FMA), which is formed between the mandibular and Frankfort planes. He measured this angle directly on patients, lateral cephalometric radiographs, and photographs. Using the FMA, Tweed could predict the prognosis of orthodontic cases. He defined prognosis as achieving, or nearly achieving, four key orthodontic objectives: optimal facial aesthetics, lasting results, an efficient chewing function, and the longevity of the dentition [9]. Furthermore, Tweed initially attributed his students' struggles with achieving facial esthetics to inexperience [10]. However, after attending a cephalometric course, he reevaluated four cases with pleasing esthetics and, through radiographic analysis, developed a new diagnostic method. This method involved creating a triangle formed by the mandibular plane, the Frankfort plane, and a line from the apex to the incisal edge of the mandibular central incisor. This led to the establishment of the Frankfort-mandibular incisor angle (FMIA) and the completion of the Tweed diagnostic facial triangle [10].

Furthermore, Tweed [11] initially suggested that the lower incisors should ideally be positioned at a 90-degree angle to the lower border of the mandible, with a permissible variation of 5 degrees. His conclusion was based on an extensive study of his practice, where he used sectioned plaster casts of the lower arch. He observed that patients with desirable facial aesthetics typically had lower incisors that were "upright over basal bone" [11].

According to Tweed's guidelines:

- If the FMA is 30º or greater, the FMIA should be 65º.
- If the FMA is 25º ± 4º, the FMIA should be 68º.
- If the FMA is lower than 20º, the IMPA should not exceed 94º.

These relationships help in determining the correct positioning of the lower incisors relative to the skeletal structure, which is crucial for achieving a balanced and stable orthodontic result. Margolis, as well as Speidel and Stoner [12,13], conducted independent cephalometric studies that provided partial support for Tweed's assumptions regarding the positioning of the lower incisors. Their research demonstrated that in cases of normal occlusion, the average inclination of the lower incisors relative to the lower border of the mandible was close to 90 degrees. Their finding was significant as it aligned with Tweed's principles and offered empirical evidence that supported his approach to diagnosing and treating malocclusions. Specifically, it reassured Tweed that his emphasis on the angular relationship between the lower incisors and various craniofacial planes, such as the Frankfort horizontal plane, was valid and applicable in clinical settings. These studies helped to confirm that maintaining specific angular relationships, like those Tweed advocated, could lead to more stable and esthetically pleasing orthodontic results.

Lwasawa et al. conducted a study involving 36 Japanese adults (18 men and 18 women) with normal occlusion and balanced facial features to examine their soft tissues using cephalographic analysis. From this group, 20 subjects were selected and compared with 20 Class II, Division 1, and 20 Class III patients to develop a diagnostic guide for the Tweed triangle. The study found average measurements of 27.28° for FMA, 95.50° for IMPA, and 57.22° for FMIA. The researchers concluded that an FMIA of 57° is suitable for diagnosing Japanese patients but suggested adjusting this value based on the FMA [14].

Zhu et al. [15] studied the facial characteristics of 20 male and 23 female Chinese adults with skeletal class I malocclusion, utilizing Steiner, Downs, Northwestern analysis, and Tweed triangle parameters. The findings indicated that Chinese adults generally have a more forwardly positioned maxilla and mandible, along with a smaller facial height, compared to Japanese and Caucasians. The recorded Tweed triangle values were FMA (25.40 ± 56.1) and IMPA (96.21 ± 9.5). The study also noted that the occlusal plane in Chinese individuals is less inclined than in Japanese individuals, suggesting that orthodontic treatment for skeletal class I malocclusion may be easier in Japanese patients compared to their Chinese counterparts.

Nahidh et al. [16] studied 95 dental students with normal occlusion and found gender-based differences in cephalometric measurements. Males had a higher, though not significantly different, Wits appraisal and Frankfort-mandibular plane angle compared to females, while females had a higher Frankfort-mandibular incisor angle. Both genders showed greater lower incisor proclination than Tweed's standard, with a similar Frankfort-mandibular plane angle. The study established normal values for Wits appraisal and the Tweed Triangle, noting that females' Wits appraisal was closer to Jacobson's standard, while it was higher in males.

As mentioned earlier. [1-11] [14-16] the Tweed facial triangle, a widely recognized cephalometric analysis in orthodontics, evaluates the relationships between the lower incisor, mandible, and cranial base. Research on the three major racial classes [Caucasian, Oriental, and Black] reveals significant differences that reflect the distinct craniofacial characteristics of each group. These angles are essential for assessing facial profile, dental inclinations, and vertical growth patterns. Each major class has its characteristic as follows:

Caucasian Populations

- **FMA (Frankfort Mandibular Plane Angle):** Caucasian individuals often have a moderate FMA, indicating a balanced vertical growth pattern.
- **IMPA (Incisor Mandibular Plane Angle):** The IMPA tends to be moderate as well, reflecting a relatively standard incisor inclination.
- **FMIA (Frankfort Mandibular Incisor Angle):** The FMIA in Caucasians is typically within a range that indicates neither excessive nor minimal protrusion of the lower incisors, leading to a balanced facial profile.

Oriental (East Asian) Populations

- **FMA:** Asians often exhibit a higher FMA, indicating a more vertical growth pattern and a tendency towards a more obtuse mandibular plane angle.
- **IMPA:** The IMPA tends to be higher in Asian populations, suggesting a more pronounced labial inclination of the lower incisors. This is often associated with the flatter facial profile seen in many Asian groups.
- **FMIA:** The FMIA is usually lower, reflecting the higher IMPA and the more forward position of the lower incisors in relation to the Frankfort horizontal plane.

Black (African or African-descended) Populations

- **FMA:** African and African-descended populations often exhibit a lower FMA, indicating a more horizontal mandibular plane and a tendency towards a less vertical growth pattern.
- **IMPA:** The IMPA is generally lower in this group, reflecting a more upright or even lingual inclination of the lower incisors. This is associated with a more prominent chin and a strong mandibular profile.
- **FMIA:** The FMIA tends to be higher, reflecting the more

upright position of the lower incisors and the more pronounced facial convexity typical of this group.

- Further, the findings from several studies on the three major racial classes reveal distinct variations in craniofacial morphology as follows:
- **Asian Populations:** Studies have shown that Asian individuals often have a more prominent maxilla and a flatter nasal profile compared to Caucasians. These characteristics may lead to different cephalometric norms, particularly in measurements related to the anteroposterior position of the jaws.
- **African and African-American Populations:** These groups tend to have a more protrusive maxillary and mandibular dentition, with greater lip protrusion and a more convex facial profile. This can influence norms related to dental and skeletal relationships, especially in the assessment of overjet and facial convexity.
- **Arabic Populations:** Research on Arabic populations often highlights a combination of characteristics seen in both European and African groups, with some unique traits. This suggests that cephalometric norms should be carefully tailored to reflect these specific features.
- **African-Brazilian Populations:** African-Brazilian individuals share some craniofacial characteristics with African and African American populations but also exhibit distinct traits due to the admixture with European and Native American ancestries.

Implications of Tweed Facial Triangle Differences

1. **Diagnosis and Treatment Planning:** The differences in the Tweed facial triangle angles among these racial groups highlight the importance of using ethnic-specific norms in orthodontic diagnosis and treatment planning. For instance, an IMPA considered normal in one group might indicate a need for orthodontic intervention in another.
2. **Facial Aesthetics:** The variation in these angles also impacts the perceived facial aesthetics within different ethnic groups. Understanding these differences is crucial for orthodontists aiming to achieve a facial balance that aligns with the patient's ethnic norms and personal aesthetic goals.
3. **Orthodontic Outcomes:** Tailoring orthodontic treatment to respect these variations can lead to more successful outcomes, both functionally and aesthetically, as it ensures that the treatment objectives are in harmony with the patient's natural craniofacial structure.

Aims

This study aims to assess significant differences between the mean values of Tweed's facial angles in the Sudanese sample and Tweed's original norms. Additionally, it compares these findings with those from previously published studies on the three major racial classes. (Caucasian, Oriental and Black).

Material and Method

Subjects

The sample size consisted of Twenty-nine (29) pretreatment lateral cephalographs of adult Sudanese patients with age range 18 to 25 years old seeking orthodontic treatment at the orthodontic department clinic. The selection was based on the following criteria:

1– Patients between the ages of 18 and 25 years old.
2– Having skeletal and dental Class 1 prior to treatment.
3– The availability of pretreatment lateral cephalographs of high quality taken by the same cephalostat with the lips relaxed and the teeth in occlusion.
4– There were no congenital abnormalities, jaw injuries, fractures, or major facial asymmetry in any of the instances.

A written informed consent form was signed by each participant.

Method

A well-trained technician captured the radiographs from a distance of 5 feet, with patients looking straight into a mirror.

All lateral cephalographs were digitally traced by a single operator using the *Web Ceph* application. And the three angles that form Tweed's facial triangle were drawn and measured to the nearest 0.5°:

- FMIA (Frankfort Mandibular Incisor Angle) measures the angle between the Frankfort horizontal plane and the long axis of the lower incisor
- FMA (Frankfort Mandibular Plane Angle) measures the angle between the Frankfort horizontal plane and the mandibular plane.
- IMPA (Incisor Mandibular Plane Angle) measures the angle between the mandibular plane and the long axis of the lower incisor (Figure 1).

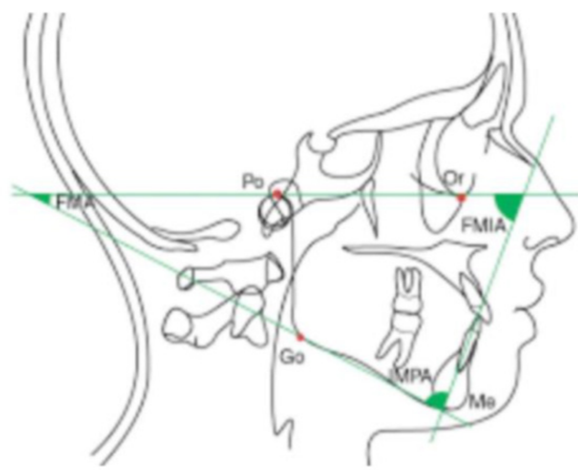

Figure 1: The Tweed facial triangle: FMIA, FMA and IMPA angles.

Statistical Analysis

The data was analyzed using Microsoft Excel. Descriptive statistics, including mean and standard deviation, were calculated. For analytical purposes, Student's t-test was employed to assess significant differences between the mean values of Tweed's facial angles in the Sudanese sample and Tweed's Norms. Additionally, comparisons were made with previously published studies on the three major racial classes as well as in Arabs. A significance level of $p < 0.05$ was used.

Results

The error of the method was evaluated by taking double measurements at least one week apart on five randomly selected cephalograms. The t-test results showed no statistically significant differences between the two sets of readings.

Comparison Between Sudanese and Caucasian Racial Groups

Table 1: Comparison of Tweed triangle values between Sudanese and Tweed Norms (Caucasian).

Variable	Class I Sudanese			Class I Tweed Norms			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	68.60	5.0	100	0.0001	Ext. Sig
FMA	25.73	5.8	29	24.90	5.0	100	0.5058	NS
IMPA	95.92	8.2	29	86.60	5.8	100	0.0001	Ext. Sig

P> 0.05 NS: Not significant. P< 0.0001: Ext.Sig: Extremely Significant.

Table 1 exhibits extremely statistically significant differences in the FMIA and IMPA angles between the Sudanese sample and the Caucasian norms, whereas no significant difference was observed for the FMA angle.

Table 2: Comparison of Tweed triangle mean values between Sudanese and White American [Merrifield 1966].

Variable	Class I Sudanese			Class I White American			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	65.70	5.0	40	0.0008	Ext. Sig
FMA	25.73	5.8	29	27.10	5,0	40	0.2994	N. S
IMPA	95.92	8.2	29	87.20	5,8	40	0.0001	Ext. Sig

P> 0.05 NS: Not significant. P< 0.0001 Ext. Sig: Extremely significant.

Reference: Merrifield LL The profile line as an aid in critically evaluating facial esthetics. Am J Orthod 1966; 52(11):804-22`

Table 2 shows extremely statistically significant differences in the FMIA and IMPA angles between the Sudanese sample and the White American (Caucasian) whereas no significant difference was observed for the FMA angle.

Comparison Between Sudanese and Oriental Racial Groups

Table 3: Comparison of Tweed triangle values between Sudanese and Japanese.

Variable	Class I Sudanese			Class I Japanese			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	57.22	3.9	20	0.0903	N. S
FMA	25.73	5.8	29	27.28	3.1	20	0.2812	N. S
IMPA	95.92	8.2	29	95.50	3.1	20	0.9819	N. S

P> 0.05 NS: Not significant.

Table 3 describes no statistically significant differences observed between the Sudanese and Japanese populations when comparing the FMIA, FMA, and IMPA angles of the Tweed facial triangle.

Table 4: Comparison of Tweed triangle values between Sudanese and Chinese.

Variable	Class I Sudanese			Class I Chinese			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	58.39	3.9	43	0.1476	N. S
FMA	25.73	5.8	29	25.40	6.1	43	0.8191	N. S
IMPA	95.92	8.2	29	96.21	9.5	43	0.9870	N. S

P> 0.05 NS: Not significant.

Table 4 demonstrates no statistically significant differences observed between the Sudanese and Chinese populations when comparing the FMIA, FMA, and IMPA angles of the Tweed facial triangle.

Table 5: Comparison of Tweed triangle values between Sudanese and Chinese.

Variable	Class I Sudanese			Class I Korean			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	62.11	4.4	47	0.0903	N. S
FMA	25.73	5.8	29	23.85	5.1	47	0.2812	N. S
IMPA	95.92	8.2	29	94.04	6.5	47	0.9819	N. S

P> 0.05 NS: Not significant.

Table 5 reveals no statistically significant differences observed between the Sudanese and Korean populations when comparing the FMIA, FMA, and IMPA angles of the Tweed facial triangle.

Comparison Between Sudanese and Arabs Racial Groups

Table 6: Comparison of Tweed triangle values between Sudanese and Qatari.

Variable	Class I Sudanese			Class I Qatari			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	52.00	8.8	43	0.0001	Ext. Sig
FMA	25.73	5.8	29	33.50	6.2	43	0.0001	Ext. Sig
IMPA	95.92	8.2	29	94.50	6.8	43	0.4267	N. S

P> 0.05 NS: Not significant. P< 0.0001: Ext.Sig: Extremely Significant.

Table 6 depicts extremely statistically significant differences between the Sudanese and Qatari populations when comparing the FMIA and FMA angles of the Tweed facial triangle. However, no statistically significant difference was observed when comparing the IMPA angle.

Table 7: Comparison of Tweed triangle values between Sudanese and Saudi.

Variable	Class I Sudanese			Class I Saudi			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	51.50	8.9	50	0.0001	Ext Sig
FMA	25.73	5.8	29	35.40	5.8	50	0.0001	Ext Sig
IMPA	95.92	8.2	29	93.10	8.6	50	0.1572	N. S

P> 0.05 NS: Not significant. P< 0.0001: Ext.Sig: Extremely Significant.

Table 7 illustrates extremely statistically significant differences between the Sudanese and Saudi populations when comparing the FMIA and FMA angles of the Tweed facial triangle. However, no statistically significant difference was observed when comparing the IMPA angle.

Comparison Between Sudanese and Black Racial Groups

Table 8: Comparison of Tweed triangle values between Sudanese and Nigerian.

Variable	Class I Sudanese			Class I Nigerian			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	54.08	5.1	100	0.0001	Ext Sig
FMA	25.73	5.8	29	23.26	4.8	100	0.0217	Sig
IMPA	95.92	8.2	29	103.47	6.3	100	0.0001	Ext. Sig

P< 0.05 Sig.: Significant. P< 0.0001 Ext, Sig: Extremely Significant

Table 8 displays extremely statistically significant differences observed between the Sudanese and Nigerian populations when comparing the FMIA and IMPA angles of the Tweed facial triangle. Additionally, there was a statistically significant difference at the 5% level when comparing the FMA angle.

Table 9: Comparison of Tweed triangle values between Sudanese and

Variable	Class I Sudanese			Class I Black Brazilian			Statistical result	
	Mean	SD	N	Mean	SD	N	P-value	Sig level
FMIA	60.35	7.4	29	50.90	8.3	37	0.0001	Ext Sig
FMA	25.73	5.8	29	29.12	6.9	37	0.0377	Sig
IMPA	95.92	8.2	29	99.88	4.4	37	0.0144	Sig

P< 0.05 Sig: Significant. P< 0.0001 Ext. Sig: Extremely Significant.

Table 9 defines extremely statistically significant differences observed between the Sudanese and Black Brazilian populations when comparing the FMIA angle of the Tweed facial triangle. Additionally, there were statistically significant differences at the 5% level when comparing the FMA and IMPA angles.

Discussion

To achieve an accurate diagnosis and prognosis, as well as to offer a precise and appropriate treatment plan, orthodontic treatments have traditionally been guided by objectives established during the clinical examination. These objectives focus on three primary areas: occlusal function, periodontal health, and facial aesthetics. By thoroughly assessing each of these aspects, orthodontists can tailor treatment plans to meet the individual needs of patients, ensuring both functional and aesthetic outcomes that contribute to overall oral health and patient satisfaction.

Numerous studies have documented dentoalveolar variations across different ethnic populations, including Asian, Arabic, African, African American, and African-Brazilian groups. These variations suggest that cephalometric norms used to assess craniofacial relationships may differ across these groups. Therefore, it is important to consider ethnic-specific norms when evaluating cephalometric data for accurate diagnosis and treatment planning in orthodontics and related fields.

Tweed highlighted that the primary goals of orthodontic treatment are to achieve facial balance and harmony, ensure post-treatment stability of the dentition, maintain healthy oral tissues, and establish an efficient chewing mechanism. Consequently, research has focused on the soft-tissue changes associated with tooth movement [17]. Further, Tweed's Facial Triangle is an orthodontic tool for diagnosis and treatment planning. Tweed emphasized that specific values for the FMA, FMIA, and IMPA angles are key to improving facial aesthetics and achieving stable results, particularly suggesting that lower incisors should be inclined at 90º ± 5º relative to the basal bone. Accurate assessment of the IMPA value, ideally within 94 degrees, is crucial for effective orthodontic treatment [18,19]. Many studies have examined differences in standard cephalometric measurements across various racial and ethnic groups. Much of this research focuses on comparisons between Caucasians and non-Caucasian groups, including Japanese, Chinese, Koreans (Oriental), Nigerians Africans, African Americans, (Black) and Arabs. The findings generally show that Black and Oriental groups tend to have the most protrusive dentition, while Caucasians typically exhibit the most retrusive dentition. This observation was also reflected in the results of the current study [14,15,20,21].

The current study's findings deviated from Tweed's recommendations. The mean values for FMIA (60.35° ± 7.4°) and IMPA (95.921° ± 8.2°) were significantly higher than Tweed's norms, while the FMA angle (25.73° ± 5.8°) showed no notable difference. This indicates more proclined lower incisors and a lower FMIA angle, with no significant change in the FMA angle. Moreover, the study found that the mean values of Tweed facial triangles were consistent with those of Japanese, Chinese, and Korean populations, showing no statistically significant differences. However, a definitive conclusion about classifying Sudanese individuals within the East Asian racial group cannot be made without a larger and more representative sample [14,15].

In contrast, significant to extremely significant differences in Tweed facial triangle mean values were observed when compared to Nigerian and Black Brazilian populations, with significance levels ranging from P<0.05 to P<0.0001. Additionally, when comparing Sudanese individuals to Qatari and Saudi (Arabs) populations, the study found extremely statistically significant differences in FMIA and IMPA angles (P<0.001) but no significant difference in the FMA angle [20,21].

The analyses of the three major racial classes have shown significant differences in the FMIA, FMA, and IMPA angles, indicating that aesthetic criteria for one group may not be applicable to another. Each ethnic group has unique physical traits and social standards for facial aesthetics, making inter-ethnic comparisons challenging. These variations underscore the need to consider ethnic differences in orthodontic diagnosis and treatment planning [14-16,20,21]. The close alignment between visual and cephalometric averages across all three angles indicates that cephalometric analysis is a reliable method for evaluating these relationships in patients. While individual variation exists, the angles generally cluster around their respective averages, reinforcing their utility in orthodontic diagnosis and treatment planning. This consistency of these measurements underscores the importance of using a larger, representative sample to draw firm definitive conclusions, particularly when assessing the statistical significance of differences across populations. Based on the current study, the absence of statistically significant differences in Tweed's facial triangle mean values between the Sudanese population and populations from Japan, China, and Korea suggests that the Sudanese might be classified within the Oriental racial group. This finding is exciting given that the Sudanese are typically characterized by a combination of Afro-Arab ethnic features. To reach a more definitive conclusion regarding the racial classification of the Sudanese, it is essential to conduct a study with a larger and more representative sample drawn from various regions of Sudan.

Conclusion

The Tweed facial triangle varies significantly among the Caucasian, Oriental (Asian), and Black (African-descended) populations. The Sudanese population may align more closely with the Oriental racial group than expected, given their mixed Afro-Arab ethnicity. This highlights the complexity of racial classification based on cephalometric data alone. However, the current sample size may limit the strength of this conclusion. A larger, more diverse sample from across Sudan would provide a stronger basis for determining whether these findings hold true across the broader Sudanese population. Additionally, incorporating ethnic-specific cephalometric norms and genetic data could offer a more comprehensive understanding of the Sudanese population's racial classification as well as ensure accurate diagnosis, appropriate treatment planning, and socially sensitive patient care.

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