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BONE AGE ESTIMATION USING THE MATURATION PROCESS OF THE LATERAL CLAVICULAR EPIPHYSIS AMONG THE BLACK SOUTH AFRICAN POPULATION: A RETROSPECTIVE RADIOLOGICAL STUDY
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BONE AGE ESTIMATION USING THE MATURATION PROCESS OF THE LATERAL CLAVICULAR EPIPHYSIS AMONG THE BLACK SOUTH AFRICAN POPULATION: A RETROSPECTIVE RADIOLOGICAL STUDY

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ABSTRACT

***Objective*: To estimate the age of living individuals through radiological analysis of the ossification process of the lateral clavicular epiphysis, evaluate the sex dimorphism and population-specific variations within the Black South African population.**
***Materials and Methods*: This was a cross-sectional study where 771 clear chest radiographs showing acromioclavicular joints were retrospectively collected from select radiological departments in KwaZulu Natal province of South Africa. The appearance of the maturation centers was examined and recorded in line with the 3 phases of maturation of the lateral clavicular epiphysis. The hospital radiologist was engaged as an inter-observer reviewer who cross examined and confirmed each of the stages of the maturation process. Regression analysis was employed to assess linearity by plotting the mean variation between chronological age and actual age for every respondent against their age distribution.**
***Results*: It was observed that the age range for the total population was 14-24 years in stage 1, 14-26 years in stage 2, and 17-30 years in stage 3. Stages 2 and 3 were the most widely distributed along the age set. The ossification stages of the lateral clavicular epiphysis in this group were 32.7% ($^{252}/_{771}$) in stage 1, 24.3% ($^{187}/_{771}$) in stage 2, and 43.1% ($^{332}/_{771}$) in stage 3. The chronological age in the current cohort was approximated with a margin of error of ±1.46 years using linear regression analysis. Furthermore, it was observed that there was a greater tendency to overestimate the actual age by 0.19 years among the current population group using Bland Altman's plot.**
***Conclusion*: The fusion process of the lateral clavicular epiphysis may be used to approximate age, especially in individuals without birth records. To improve reliability, the lateral clavicular epiphysis may be used in combination with other**

skeletal indicators, such as the development of the iliac crest and the fusion of the distal femur, for forensic accuracy.

INTRODUCTION

The need for readily available age estimation techniques in African countries cannot be ignored given the increasing surge of migrants with no valid identification documents and inadequate access to government services for proper birth registrations. Without proper documentation, a minor may be subjected to legal processes preserved for adults and vice versa, which can lead to severe consequences such as wrongful prosecution or denial of necessary services that are age-specific. The bone age maturation process has proved to be a useful marker for age estimation, especially among children and young adults.

Historically, research on estimating age via the clavicle has focused heavily on the medial (sternal) end, primarily because it is the last long bone epiphysis to fuse in the human body. In contrast, the acromial (lateral) end has been largely overlooked, despite its potential utility [1].

Medial fusion has limitations in some cases, particularly where computed tomography (CT) imaging is unavailable, when there is significant tissue overlap, or when skeletal remains are fragmented. In contrast, lateral epiphysis fusion may offer complementary information. Langley's findings suggest that the lateral epiphysis begins to fuse in late adolescence and completes fusion shortly thereafter, providing additional data points within the critical developmental window of 17–24 years [2]. Moreover, morphological variation in lateral fusion appears minimal between sexes, which simplifies its integration into age estimation frameworks.

Historically, the acromial end of the clavicular epiphysis has not been well explored by researchers in the early 19th century. It did not appear to have bony nodules used as markers in the ossification process like those of the medial epiphysis. However, the small nodules of the lateral epiphysis were later observed to slide medially towards the sternal end and later fuse with the shaft. This made it difficult to identify the ossification process of lateral epiphysis [3]. The first study on the maturation of the lateral clavicular epiphysis was done by Stevenson on lemurs, although he was unable to complete his work due to lack of adequate samples [4]. Stevenson discovered that the difficulty in identifying the fusion of the lateral epiphysis on dry clavicles was because the epiphyseal plates glazed over the shaft making it a component of the diaphysis [4].

Existing sources state that the lateral epiphysis unites by the age of 19 to 20 years and quickly ossifies within a few months after the onset [5-7]. In some cases, this epiphyseal plate presents a small detached chip of bone, while in other instances, it just slides on top of the diaphysis, making it difficult to observe separately. Due to this, some authors suggested that no ossification process exists on the lateral clavicular epiphysis [3].

Todd and D' Errico carried out an intensive survey of the lateral clavicular epiphysis and published a chart showing the fusion process of the lateral epiphysis [3]. They noted that the minimum age of complete fusion takes place by 19 years in all the clavicles in their study. However, they also observed that it was difficult to locate the lateral epiphysis in the process of fusion and thus called for more studies with a large sample size. In comparison, between the maturation processes of the medial and lateral epiphyses, Stevenson observed that the medial epiphysis ossified much slower over 10 years, while the lateral epiphysis ossified within a 5-year period or shorter [4].

This was attributed to the fact that the medial epiphysis underwent membranous ossification while the lateral developed through endochondral ossification. Before the discovery of techniques for assessing bone age, Fawcett confirmed the existence of the lateral and medial epiphysis after observing that failure of the union of the two centers leads to two separate bone masses [8]. This was due to non-ossification of the pre-cartilaginous bridge connecting the sternal and acromial segments with one another during the 19 mm stage of embryonic development. The bony connection is for a long period normally not observable. Bassed noted that even though the lateral clavicular epiphysis has not been well studied, it contributes valuable information in forensic age estimation, especially in deciding whether an individual has attained the age of social and criminal responsibility (18 years) [9].

Langley recently demonstrated and scored the process of fusion of the lateral epiphysis into 3 distinct phases viz: (i) stage 1: no fusion, (ii) stage 2: partial fusion, and (iii) stage 3: complete fusion [2]. This staging system was adapted from the same scoring system applied by Todd and D'Errico[4] and Webb and Suchey during the evaluation of the lateral epiphyseal plates using dry bones [10].

However, unlike the medial epiphysis, there is no internationally recognized standard of grading the ossification of the lateral epiphysis. Langley's staging system was thus applied in the current X-ray studies as follows; Stage 1: No fusion. Stage 2: Partial fusion (continuing fusion), Stage 3: Complete fusion (Figure I) [2]. Langley observed that most epiphyseal plates complete fusion by 18 years and thus could help determine if one has reached the age of 18 years when combined with other age assessment techniques [2].

MATERIALS AND METHODS

This was a cross-sectional study where 771 clear chest radiographs showing acromioclavicular joints were retrospectively collected within a period of three months. The X-rays were collected from the radiological department of KwaZulu Natal Regional hospital, KwaZulu Natal province of South Africa (ZA). This was after the hospital gatekeepers' permission, and ethical approval was obtained through the Institutional Biomedical Ethics Committee (BREC REF 266/14).

Selection criteria: For clear joint observation, coherent images with an anteroposterior (PA) view, adequate exposure, no bone or joint pathology, and without soft tissue overlaps were selected for the study. Only radiographs of black South African (ZA) patients aged between 14 and 30 years were collected to ensure homogeneity. Chest X-rays showing right and left acromioclavicular joints were selected for the study to determine the symmetry (or lack of) in the development of the clavicle. The X-rays selected were then sorted in the data bank, uploaded for further examination using Picture Archiving and Communication System (PACS) software, where contrast and image resolution could be adjusted. The uploaded data was then subjected to the stated selection criteria, and then a systemic random sampling process was initiated until 771 radiographs were selected for the study.

The processed images were made anonymous by deleting the patient's name, age, and other hospital identifiers. Serial numbers were then allocated to all the 771 digital X-rays for reference purposes. The blinding process was intended to reduce bias during age determination. The chronological (actual) age of each serialized digital X-ray was acquired from the patient's records and stored together with the serial numbers; this value will later be compared with the estimated age derived from the maturation process of the lateral epiphysis.

Each digital X-ray was then examined using PACS software to determine the maturation patterns of the lateral clavicular epiphysis. The appearance of the maturation centers was recorded in line with the 3 phases of maturation proposed by Langley [2]. Each stage was then allocated to the subscribed expected age group (Figure 1). The hospital radiologist was engaged as an inter-observer reviewer who cross examined and confirmed each of the stages of the maturation process. The X rays are then assigned to either of the three stages as shown in figure 1. Each stage corresponds to an age range prescribed i.e. stage one is assigned between 12 to 16 years, stage two between 16 and 18 years and stage 3 between 17 and 30 years. Assigning the exact age depends on the extent of fusion and sex.

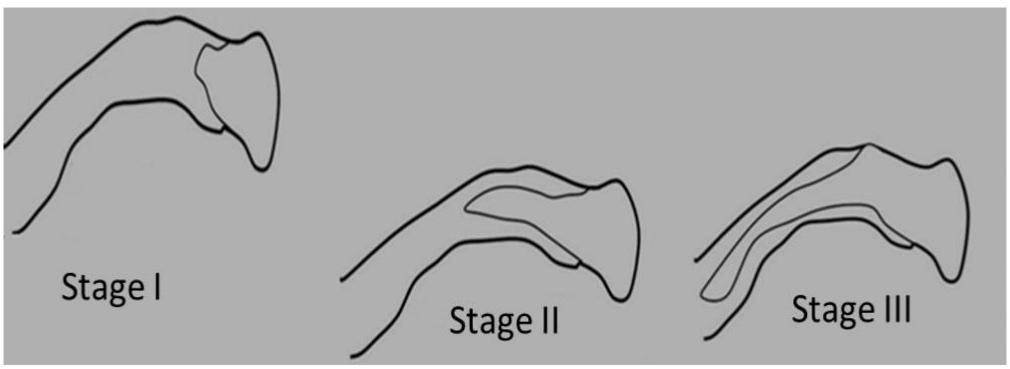

Figure I: An illustration of the 3 stages of the fusion process of the acromioclavicular epiphysis. Stage I: No union, stage II: Partial union, stage III: Showing an inactive surface with degenerative changes, porosity, and epiphyseal lipping towards the acromial end, a: glazing/sliding of the metaphysis towards the acromial end.

Interobserver variability and reproducibility

To assess the reproducibility of the study, a total of 119 X-rays were randomly selected for interobserver review by choosing every seventh radiograph from the sample. The two independent assessors were provided with serialized data entry forms that excluded chronological age, along with a three-stage scoring sheet. They also received brief training on how to evaluate age based on the maturation of the lateral epiphyseal plates.

The results from the independent observers were then analyzed using Fleiss' kappa to determine the level of agreement between the observers and the primary investigator. The two radiologists achieved a kappa value of 0.68 (95% CI: 0.55–0.81), indicating substantial agreement in staging the epiphyseal maturation process, consistent with the scale proposed by Landis and Koch [11]. When the ordinal nature of the data was accounted for using quadratic weighting, the agreement increased to 0.88, reflecting nearly perfect reliability. Most discrepancies occurred between adjacent stages, likely due to the continuous nature of skeletal development.

Data Analysis

Raw data entry, cleaning, and analysis were done using IBM SPSS Statistics (Version 29.0) for Windows 11. Descriptive information was presented as mean, median, mean ± standard deviation (SD), and percentiles. Regression models are used to figure out a person's age by looking at the relationship between their chronological age and the ossification stages (1–3) of the lateral clavicular epiphysis (LCE) in the digital radiographs. Logistic regression figures out how likely it is that someone will get older past a certain point, while linear regression figures out how old someone will be based on their stage. A p value of ≤ 0.05 at a CI of 95% was regarded as statistically significant. A Bland Altman's (BA) plot was drawn to compare and evaluate the agreement between the CA and EA. This plot also provided the limits of agreements between the two measurements.

RESULTS

Frequency distribution of the samples within the stages

Among the ZA population (n=771), the age range was 14-24 years in stage 1, 14-26 years in stage 2, and 17-30 years in stage 3. Stages 2 and 3 were the most widely distributed along the age set. The ossification stages of the lateral clavicular epiphysis in this group were 32.7% ($^{252}/_{771}$) in stage 1, 24.3% ($^{187}/_{771}$) in stage 2, and 43.1% ($^{332}/_{771}$) in stage 3 (Table I).

Table I

Ossification stages of the lateral epiphysis in the South African population

LC	**Male**		**Female**		**Total**	
Stages	**n**	**%**	**n**	**%**	**n**	**%**
Stage 1: No fusion	143	18.5%	109	14.2%	252	32.6%
Stage 2: Partial fusion	75	9.8%	112	14.5%	187	24.3%
Stage 3: Complete fusion	156	20.2%	176	22.8%	332	43.1%
Total	374	48.5%	397	51.5%	771	100%

Ossification stages of the lateral epiphysis in the South African population

In the South African population (n=771), stage 1 was observed at a mean age of 17.80 ± 2.66 years with an age range of 14-24 years. Stage 2 was 21.54 ± 2.95 years with an age range of 14-26 years, while stage 3 was 27.19 ± 2.29 years with an age range of 17-30 years (Table II).

Table II

Mean age of the lateral clavicular epiphysis ossification stages in the South African population

Stages	**n**	**Mean**	**Min-Max**	**Median**
Stage 1	252	17.80±2.66	14-24	18.00
Stage 2	187	21.54±2.95	14-26	23.00
Stage 3	332	27.19±2.29	17-30	27.00

Stage 1: The no visible fusion stage was observed in 32.7% ($^{252}/_{771}$) of the South African population group, 18.5% ($^{143}/_{771}$) were males, while 14.1% ($^{109}/_{771}$) were females. The age range was 14-24 and 15-22 years in male and female patients, respectively (Figure II).
(ii) Stage 2: Partial fusion was observed in 24.3% ($^{187}/_{771}$) of the South African population group, 9.7% ($^{75}/_{771}$) were males, while 14.5% ($^{112}/_{771}$) were females. The age range was 16-26 among males and 14-25 years among females (Figure II).
(iii) Stage 3: complete fusion: Stage 3 ossification was observed in 43.1% ($^{332}/_{771}$) of the South African population group. The age range was between 23-30 years in both sexes (Figure II).

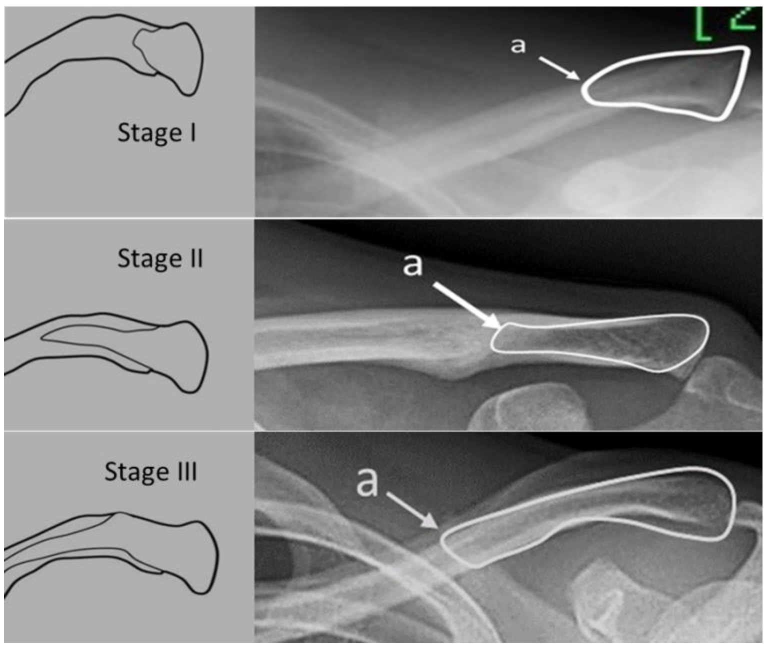

Figure II: Ossification of the lateral clavicular epiphysis showing Stage 1: no fusion, Stage 2: partial fusion; Stage 3: degenerative changes, porosity, and epiphyseal lipping towards the acromial end
Key: a= glazing/sliding of the metaphysis towards the acromial end

Sex difference in the lateral epiphysis
The mean age at which stage 1 was observed was 18.09 ± 2.90 in males and 17.41 ± 2.27 in females (p-value = 0.003). Stage 2 was observed at 21.92 ± 2.59 and 21.29 ± 3.16 years for male and female patients, respectively (p-value = 0.00). Complete fusion (stage 3) of the lateral clavicle was recorded at a mean age of 27.20 ± 2.23 and 27.18 ± 2.36 years in males and females, respectively (p = 0.00) (Table III).

Table III
Sex difference of the lateral epiphyseal ends among the ZA population

LC	Sex	n	Mean	SD	Min-Max	Median	p-value
Stage 1	Male	143	18.09	2.90	14-24	18.00	0.003
	Female	109	17.41	2.27	14-22	17.00	
Stage 2	Male	75	21.92	2.59	16-26	23.00	p < 0.001
	Female	112	21.29	3.16	14-25	22.00	

Stage 3	Male	156	27.20	2.23	19-30	28.00	0.029
	Female	176	27.18	2.36	17-30	27.00	

Key: LC—Lateral Clavicle, SD- Standard Deviation

The mean variation between CA and EA among the ZA population
The mean estimated age with the observed standard error of mean (SEM) for every radiograph was presented against the CA among the ZA. The minimum observed age difference was 4 years, while the maximum observed age difference was 7 years. Age 30 had the lowest error rate during age estimation at 0.61 years, while age 19 had the highest error rate of 1.69 years (Table IV).

Table IV
The mean observed variation between CA and EA in the ZA population

CA	n	Range	Mean EA	SD	SEM
14	41	4	15.27	1.09	0.91
15	33	4	16.15	1.17	1.41
16	38	4	15.89	1.33	0.87
17	41	5	16.85	1.57	1.51
18	38	5	18.61	1.40	1.68
19	30	4	19.10	1.26	1.69
20	30	5	19.83	1.36	0.89
21	44	6	20.93	1.91	0.69
22	52	6	21.62	1.96	0.87
23	52	5	23.52	1.33	0.79
24	54	5	24.67	1.28	0.91
25	52	7	25.52	1.27	0.81
26	57	5	26.53	1.15	0.59
27	44	5	27.57	1.54	0.94
28	57	4	28.89	1.17	0.79
29	54	4	29.00	1.16	0.95
30	54	4	29.44	1.07	0.61

Key: EA – Estimated age, SD- Standard Deviation, SEM- Standard error of the mean

Linear regression test for relationship comparing the CA and EA among the ZA population
Regression analysis was employed to assess linearity by plotting the mean variation between CA and EA for every respondent against their age distribution, thereby evaluating the extent of divergence from chronological age (SEM). The SEM among the ZA population was ±1.46 years at a 95% confidence interval (CI) (Figure III). Therefore, the chronological age in the South African population was approximated with a margin of error of ±1.46 years.

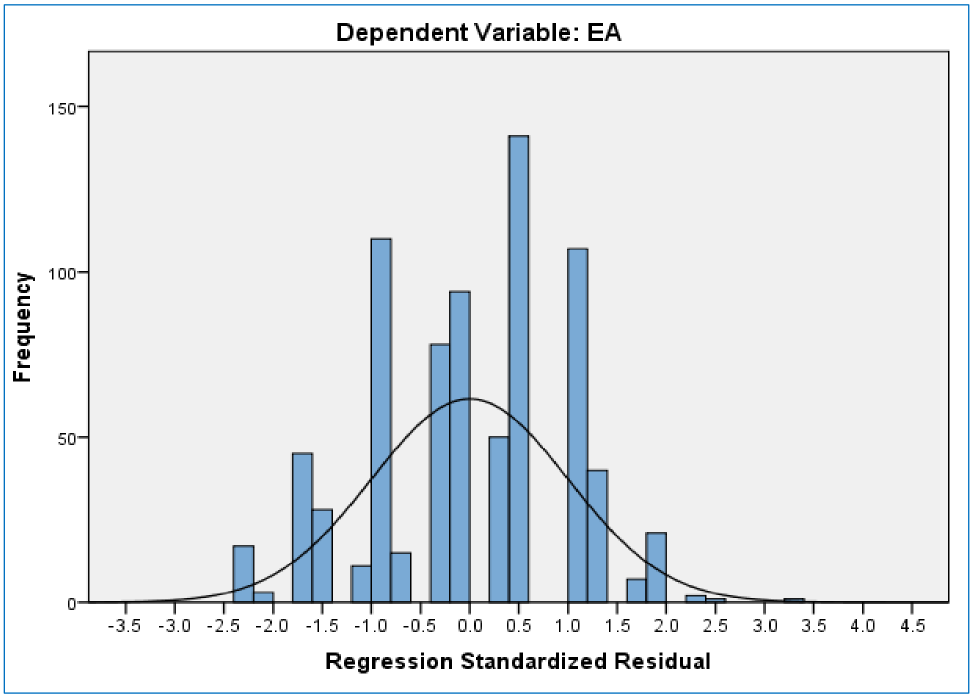

Figure III: Linear regression histogram reporting deviations between CA as compared with EA among the ZA population.

A Bland-Altman (BA) plot testing the limits of agreements of EA in the South African population

The mean variation observed when comparing CA with EA was presented on the BA's graph. A negative number (in years) indicates that the chronological age (actual age) has been underestimated, whereas a positive number (in years) reflects an overestimation. Hence for the ZA sample (n = 771), the limit of agreement was 0.19 years. This suggests a greater tendency to overestimate the actual age by 0.19 years among the current population group (Figure IV).

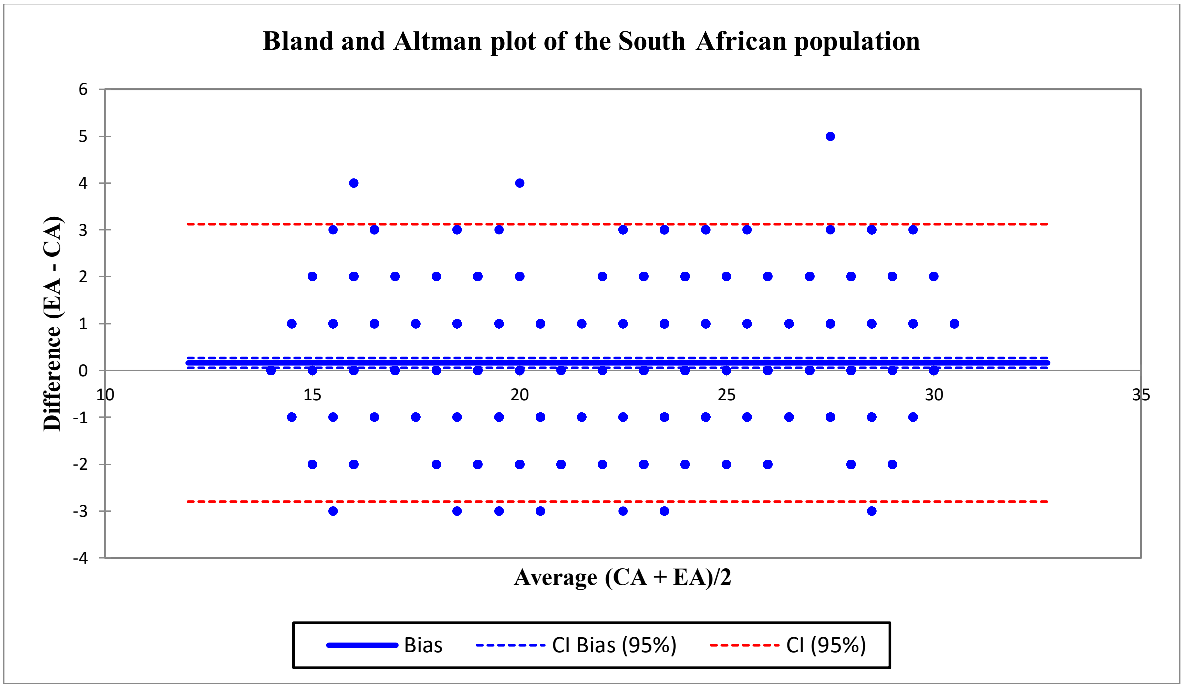

Figure IV: The BA plot for comparing the mean variation of CA with EA in the ZA population (the blue line above zero years represents the over estimation limit).

Trendlines comparing the EA in males, females, and the actual age

Trend lines depicting the relationship between CA and EA of males and females along the age interval were plotted. It was observed that the ZA population below the age of 22 years had a wide EA difference from the actual age (SEM = 1.5 ± 1.01and 1.4 ± 1.91 years in males and females). Above 22 years, the trendlines become closer, representing a more accurate age assessment for those in their late twenties (SEM of 0.9 ± 0.4 and 1.1 ± 0.47 years in males and females) from age 23 to 30 (Figure V).

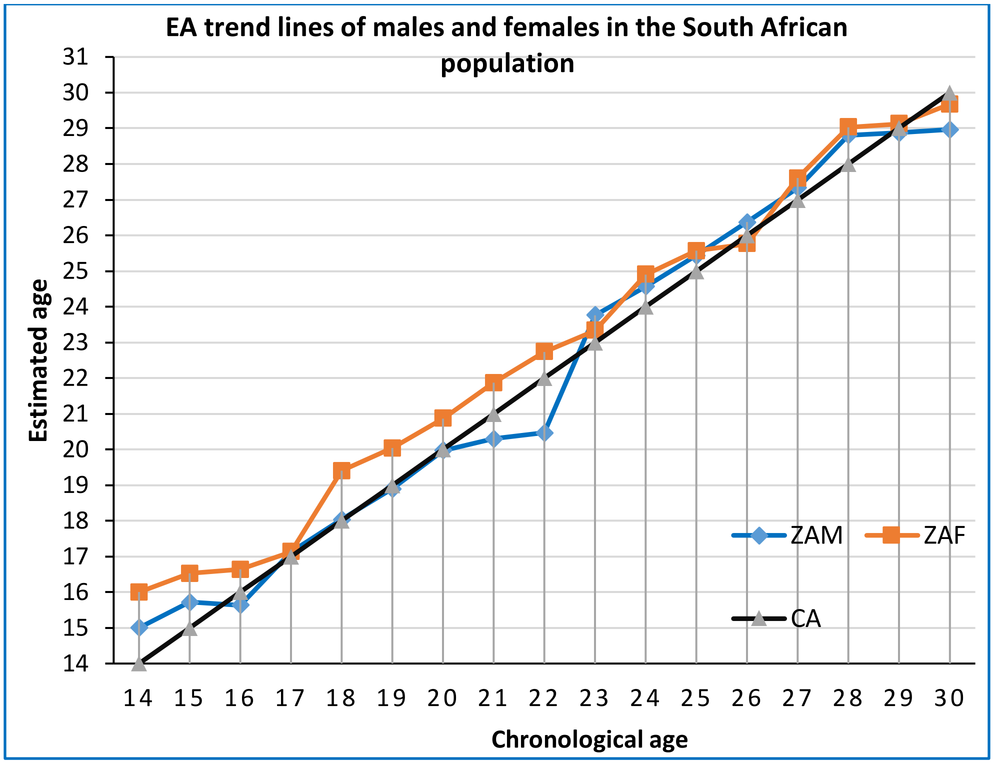

Figure V: relationship trendline between CA and EA in the ZA population.
Key: ZAM = South African male population, ZAF = South African female population, CA = chronological age.

DISCUSSION

In the previous studies, it was stated that complete fusion of the lateral epiphysis began from 18 years and above [2, 5, 12, 13]. The South African population noted an early age of 17 years in stage 3, contrary to this report. However, this was only observed in three female patients. Langley also noted a similar case in three 17-year-old males. Therefore, the incidence of finding stage 3 to be below 17 years is not significant enough to affect the results of age estimation [2]. The slow pace of development for these specific cases may have been due to variations in the maturation process of bones that is different from one individual to another.

In their research, Stull reported a standard error of -3 years and +2 years for the estimation of age in children under 12 years [14]. Their study utilized dry bone analyses to determine age at death. Conversely, Lakha noted an error margin of ±3 years for the South African demographic between the ages of 6 to 24 years, employing X-rays to examine the epiphysis of the hip and knee joints. For the present study, the epiphyseal plates of the clavicle were utilized to estimate the age of living individuals [15]. The regression analysis recorded a narrow gap in males at a SEM of ±1.45 years, while a wider gap was reported in the female South African population at a SEM of ±1.47 years.

Unlike the bones used above, the clavicle provides a chronological pattern of ossification that can easily be monitored. This leads to improved precision in the results for the same population group. These results also varied with those of Bassed et al., who observed a wider SEM of ±1.80 years in males and ±1.49 years in the Australian female population using CT imaging modality [9].

Baude reported a SEM of 1.2 years in a South African population below the age of 17 years using radiographs of the hand and wrist (G&P method) [16]. Therefore, it is apparent that the modality of examination could affect the outcome of age estimation evaluated.

Using the Bland-Altman plot to estimate the limits of agreement between EA and CA, it was more likely to overpredict the age of South African males at 0.19 years and females at 0.90 years. This indicated that it is more likely to overpredict the age of the South African female patients during age determination as compared to their male counterparts. In addition, it was noted that the level of accuracy increases gradually towards the 3rd decade of life in both sexes.

This overestimation probably stems from differences in the variation in biological development of bones. In general, females reach skeletal maturity earlier than males because puberty begins sooner for females, and estrogen accelerates the fusion of epiphyseal plates. If an age-assessment model does not properly account for this accelerated maturation, it may treat both males and females with the same fusion stage (as seen in Stage 3) as being the same age. As a result, the model may assign the female an age that actually corresponds to a male at that stage, which leads to an overestimation of her true chronological age (actual age).

With respect to the South African cohorts, 2.59% of the patients had a maturation gap between the right and left clavicular epiphysis. The incidence was, however, not statistically significant ($p > 0.05$). Furthermore, the occurrence of asymmetry was higher in the females than in the male patients. These maturation gaps were most commonly observed at stages 1 and 2. Nonetheless, it was not possible to determine which side matured faster than the other, as earlier maturation could be observed on both the right and left clavicles.

In the South African population, the error of estimating the chronological age in males was more precise (±1.45 years) than in females (±1.47 years). It was also observed that it is more likely to overestimate the age of the South African female patients by 0.9 years than their male counterparts. In addition, the results demonstrated that the level of accuracy in age estimation increases gradually towards the 3rd decade of life in both sexes. As compared to the Caucasian population, which has for long been regarded as the standard model for bone age estimation, Schmeling observed a higher error range of two (2) years among European cohorts using traditional X-rays [7]. However; Franklin did the same study using dry bone samples; he observed a much wider margin of error of estimated age as compared to the current findings [17]. This may have been attributed to the modern radiological techniques applied on the current study, or a shift in socio-economic standing of the current population, which is believed to also influence biological maturity of bones.

In the ZA legal setting, the age of reaching adulthood and legal responsibility is 18 years. Therefore, the risk of identifying a minor as an adult may cause adverse complications in the judicial system, such as wrongful convictions or inappropriate sentencing, which can have long-lasting effects on the individual's life. It would then be prudent to include the observed error margin of 1.4 years in favour of the undocumented individual and a 0.9-year bias to accommodate sex differences. For a female whose EA is at 18.0 years, the actual age (CA) could mathematically be as low as 15.6 years when accounting for both the MAE and the observed overestimation bias using this model.

CONCLUSION

Lateral epiphyseal plates proved valuable for determining the age of young adults even though the results were less accurate as compared to the sternal end of the clavicle when used in the living. The determined age should therefore be regarded as estimates, not exact ages, as observed in the field of forensic sciences. In forensic practice, an age estimation margin of error of approximately ±1.5 years is typically considered acceptable for youths and young adults, particularly in legal cases where age cutoffs such as 18 or 21 years are crucial. Still, sex-related bias needs to be taken seriously, since even a one-year difference can have significant consequences in medico-legal settings, such as affecting the outcome of legal decisions regarding age-related rights and responsibilities.

It was more likely to overestimate age among females as compared to males. This emphasizes sex dimorphism and population-specific biological growth patterns that cannot be ignored during age estimation. Therefore, it is clear that there is a need to employ sex-specific analytic models, provide prediction intervals, and calibrate estimates for each population group when assessing the age of living individuals. If used in combination with other age assessment matrices, the lateral clavicular epiphysis may have complementary and confirmatory benefits in identifying undocumented persons for medico-legal purposes.

Limitations of the study

The study used references of the three-stage classification system derived from the Caucasian population (Western hemisphere) while the study subjects were of Black African population. This may cause bias in determining age.

Author contribution: The corresponding author (Domnic Marera) is responsible for study conception and design, data collection, data analysis, and manuscript preparation.

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