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Predictive Models for Sex and Stature Estimation using Foot Anthropometric Dimensions among Indigenes of Cross River State

[1]Ogan CA, [2,4]Babatunde LB, [2,3]Salawu, AA, [1]Edet RN, [1,2*]Ikpa, JO
[1]Department of Anatomy and Forensic Anthropology, Faculty Of Basic Medical Sciences Cross River University of Technology (Crutech), Calabar – Nigeria
[2]Department of Anatomy, College Of Medicine, University of Lagos. Lagos State, Nigeria
[3]Department of General Surgery Lagos University Teaching Hospital Luth
[4]Medical Services Branch, Nigerian Air Force, Abuja Nigeria

Corresponding Author: Ikpa JO
E-mail: jamesonahikpa@gmail.com; +2347089418231

ABSTRACT
The Estimation Of Sex And Stature Is Important In Establishing A Biological Profile For Personal Identification For Medico-Legal Purposes, Mostly When Body Parts Are Found Dismembered Or Mutilated. This Study Aimed To Measure Anthropometric Foot Parameters Of Adult Male And Female Cross River State Indigenes, To Investigate The Possibility Of Using Anthropometric Foot Dimensions To Estimate Sex And Stature. The Study Comprised 249 Subjects (129 Males And 120 Females) Who Have Both Paternal And Maternal Origin In Cross River State Were Included In This Study. To Ascertain Their Origin, They Were Asked Verbally. The Participants Included Were Aged, 18–65 Years Who Volunteered And Satisfied The Inclusion Criteria. Following Institutional Approval, Anthropometric Measurements Of Stature, Foot Length (FL), Foot Width (FW), Bi-Malleolar Width (BMW) Were Taken. The Data Was Analyzed For Descriptive And Inferential Statistics Using The SPSS Statistical Package Version 20.0. The Results Of The Present Study Recorded Mean Stature Values Were; 176.49 ± 7.4 Cm For Males, 166.36 ± 7.1 Cm For Females, And 171.42 ± 8.9 Cm For The Pooled Sample. Independent T-Test Exhibited Statistically Significant Gender Differences ($P<0.05$) For All The Parameters, With The Males Having Consistently Higher Values Than The Females. Paired T Test Revealed The Existence Bilateral Asymmetry On Bi-Malleolar Width Foot Width And Foot Length ($P < 0.05$). Significant Positive Correlation Coefficients Of Stature With The Foot Length And Width Dimensions Were Found To Range From 0.307to 0.485 In The Study. Logistic Regression Models Were Created For Predicting Gender, Single And Multiple Linear Regression Models Were Also Created For Stature Estimation. This Study Provides Standards For Stature Estimation Using The Lower Limb Measurements Among Cross River State Indigenes.

Keywords: Sex, Stature, Foot Anthropometric Measurements, Predictive Models, Cross River State Indigenes.

INTRODUCTION
In the practice of forensic sciences, predicting or establishing the identity of the dead is the starting point for experts in this field. Anthropometric data have for years been used to estimate the possible sex, age or stature of a whole or fragmented body parts from different populations.[1,2] The scope of forensic anthropology is building the biological profile of an Individual from skeletal remains. This process involves the establishment of what is sometimes referred to as the “big four” which include stature, age, ancestry and sex.[3,4]

In many populations, documented skeletal series, from which metric data could be obtained to serve as reference for predicting sex and reconstructing stature by forensic anthropologists, may be unavailable. Therefore, the technique suggested by Allbrook,[5] whereby percutaneous bone measurements of the living are taken and used to generate data from which formulae for sex and stature estimation can be derived using a population-specific approach can be adopted. In the absence of skeletal collections anthropometric dimensions of living subjects can be used to create sex and stature estimation models.[6] These models can be applied where body parts are located. Their use enables estimation of sex and stature to be obtained quickly and without the need to remove soft tissue to expose bone for analysis. The development of models to estimate sex and stature using anthropometric data are particularly important for populations where skeletal collections are unavailable such as Nigeria.[7,8]

For the fact that sex and stature demonstrate population-specific variation, it is accepted widely that it is not correct to apply equations generated for one population to another when identification of unknown human remains by metric analysis is demanded. For that reason, generating equations specific to all individual populations of the world for height and sex prediction is recommended.[9]

Recently, there is a greater thrust toward morphological and metrical analysis of other postcranial bones especially the long bones for the purpose of determining sex.[8,10] Sex determination is also supposed to be reliable when the remains are from long bones and up to 95% accuracy can be achieved.[11] This study was aimed at measuring anthropometric foot parameters of adult males and females from and within Cross River state, to investigate the possibility of using anthropometric foot dimensions to estimate Sex and Stature among adult Cross River State indigenes.

MATERIALS AND METHODS

Research Materials: Stadiometer: Alpha 220, (Germany) calibrated in centimeters, Harpenden anthropometer calibrated in centimeters, Vernier caliper: Mitutoyo™ (Japan) calibrated in centimeters, Spreading Calipers calibrated in centimeters, Anthropometric box Anthropometric pro-forma containing the participant's demographic data.

Study Design: The study was conducted among 249 people comprising 129 males and 120 female adult Cross River State indigenes. Aged 18–65 years. Random sampling method was employed in the study. All the measurements took place in the field under the auspices of the Department of Anatomy and forensic anthropology Cross River University of Technology (CRUTECH). Ethical clearance was sought and obtained from the faculty of Basic Medical Sciences Research and Ethics Committee of the Cross River University of technology (CRUTECH) with approval No. FBMS/REC/03/19/0048. Participants who have both paternal and maternal origin in Cross River state were included in this study. To ascertain their origin, they were asked verbally. Those with lower limb deformities, musculoskeletal or congenital anomalies, accident history as well as amputees were excluded from the study.

Direct Measurements: The measurements taken for this study were stature, foot length, foot width and bi-malleolar width. Owing to the diurnal variation of stature[12-16] all subjects were measured approximately at same time. The measurements were read to the nearest 0.1 cm.

Stature: Stature was measured in centimeters using an Alpha 220, stadiometer (Germany). The subjects were asked to stand barefoot on the platform of the stadiometer with the feet in close contact with each other, the trunk braced along the vertical board and the eyes looking forward. The face was adjusted on the Frankfurt plane, and then the projecting horizontal sliding bar was brought to the vertex.[12,13]

Foot length: Foot length was measured using a Harpenden anthropometer (figure 1A) as the straight distance between the most posterior and prominent part of the heel (the pternion) to the most distal part of the longest toe of the foot (the acropodian) as the subject stood upright with equal pressure on both feet.[11,14]

Foot width: Foot breadth was measured using digital vernier caliper (Mitutoyo Japan) as the straight distance between the metatarsal fibulare and the metatarsal tibiale, (figure 1B) with the foot in a fully 'loaded' position.[15]

Bimalleolar breadth: Bimalleolar breadth was measured as the distance between the most medial projection of the medial malleolus and the most lateral projection of the lateral malleolus (figure 1C) using a wide spreading caliper.[16]

Figure 1: Foot Length, Foot Width and Bimalleolar Breadth

Statistical Analysis: The statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 20.0. The means, standard deviations, (minimum and maximum) and differences were used to summarize the anthropometric measurements. A paired sample t-test was performed to determine if there is a significant bilateral asymmetry to warrant the creation of separate models for the left and right sides of the body for a given body part. An independent t-test was performed to test for sexual dimorphism. Pearson correlation coefficients were calculated in order to measure the strength of correlation between stature and each of the recorded measurements. Single-predictor models for stature estimation were generated for each potential predictor (foot dimension), left and right sides separately, and for males and females separately. The significance of the predictor variable was tested. The goodness of fit of the equations was assessed by the estimated residual variation which is represented by the Standard Error of the Estimate (SEE), also known as the square root of the mean square error of the model.

RESULTS

Descriptive Statistics: One sample Kolmogorov test was conducted to estimate the normalcy of the data sample according to each measured dimension. All the parameters were statistically significant at P<0.001*

Table 1: Kolmogorov-Smirnov Test For Normalcy Of Data

	Normal Parameters		Most Extreme Differences			Test	Significance
	Mean	S.D	Absolute	Positive	Negative	Statistic	
			RIGHT				
BMW	6.625	0.562	0.079	0.079	-0.045	0.079	0.001*
FL	23.967	3.189	0.051	0.030	-0.051	0.051	0.001*
FW	9.345	1.214	0.093	0.085	-0.093	0.093	0.001*
			LEFT				
BMW	6.624	0.559	0.093	0.093	-0.043	0.093	0.001*
FL	24.043	3.009	0.045	0.023	-0.045	0.045	0.001*
FW	9.323	1.154	0.096	0.096	-0.087	0.096	0.001*
Stature	157.4734	13.659	0.031	0.031	-0.029	0.031	0.001*

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*. *(BMW – Bi-malleolar width, FL - Foot length, FW – Foot width)*

Table 2: Descriptive statistics for data used in sex and stature estimation for right and left foot assessment

RIGHT FOOT		Mean±SD	Minimum	Maximum
Foot length	Male	24.50±2.9*	16.70	32.50
	Female	23.43±3.3*	14.10	30.10
	Combined	23.96±3.1*	15.10	32.50
Foot width	Male	9.53±0.9*	7.00	12.00
	Female	9.15±1.4*	5.00	26.60
	Combined	9.34±1.2*	5.00	26.60
Bimalleolar width	Male	6.87±0.5*	5.70	8.20
	Female	6.37±0.4*	4.90	8.30
	Combined	6.62±0.5*	4.90	8.3
LEFT FOOT		Mean±SD	Minimum	Maximum
Foot length	Male	24.56.6±2.9*	17.10	32.60
	Female	23.52±3.0*	9.00	30.50
	Combined	24.04±3.0*	9.00	32.60
Foot width	Male	9.48±0.9*	6.70	12.30
	Female	9.16±1.3*	6.00	25.90
	Combined	9.32±1.1*	6.00	25.90
Bimalleolar breadth	Male	6.87±0.5*	5.60	8.20
	Female	6.38±0.4*	4.90	8.00
	Combined	6.62±0.5*	4.90	8.20

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

Bilateral Asymmetry: A paired t-test as shown on table 3. found in most cases the mean differences between the left and right sides were less than 5mm in all cases, with bi-malleolar width showing the highest level of asymmetry. The t-test shows that there is bilateral asymmetry on bi-malleolar width, foot width and foot length which were all statistically significant at P<0.001*. Despite the bilateral asymmetry being very small, side-specific models for sex and stature estimation were created for each dimension. When using the model created in this study, one must first identify the side of the body part and then apply the appropriate formula developed for that side.

Table 3: Paired t-test for comparing left and right foot measurement

	Mean	S.D	S.E Mean	95% Confidence Interval		t	p-value
				Lower	Upper		
Bi-malleolar	0.001	0.250	0.011	-0.021	0.023	0.109	0.001*
Foot Width	0.021	0.414	0.018	-0.015	0.058	1.154	0.001*
Foot Length	-0.071	0.884	0.040	-0.150	0.008	-1.767	0.001*

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

Sexual Dimorphism: An independent two samples t-test was performed to test for the existence of sexual dimorphism. For all dimensions at (p<0.001) the results suggested that males have a statistically significantly larger mean than females for any given body dimension, thus supporting the existence of sexual dimorphism (Table 4). The foot dimension that displayed the greatest degree of sexual dimorphism was right bi-malleolar width, male mean 6.87cm and female mean 6.37cm (t =10.795). Stretched stature for the sample population was also showed a high level of sexual difference (fig 1. Boxplot), male mean 176.49cm female mean 166.36cm (t = 10.356)

Table 4: Result of test for sexual dimorphism for measured left and right foot dimensions

	t-value	P-value	Mean Difference	Std. Error Difference	95% Confidence Interval	
					Lower	Upper
			RIGHT			
Bi-malleolar Width	10.795	0.001*	0.496	0.046	0.406	0.586
Foot Width	3.446	0.001*	0.378	0.109	0.162	0.593
Foot Length	3.714	0.001*	1.065	0.286	0.501	1.628
			LEFT			
Bi-malleolar Width	10.710	0.001*	0.490	0.045	0.400	0.580
Foot Width	2.995	0.003	0.312	0.104	0.107	0.516
Foot Length	3.854	0.001*	1.040	0.270	0.510	1.571

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

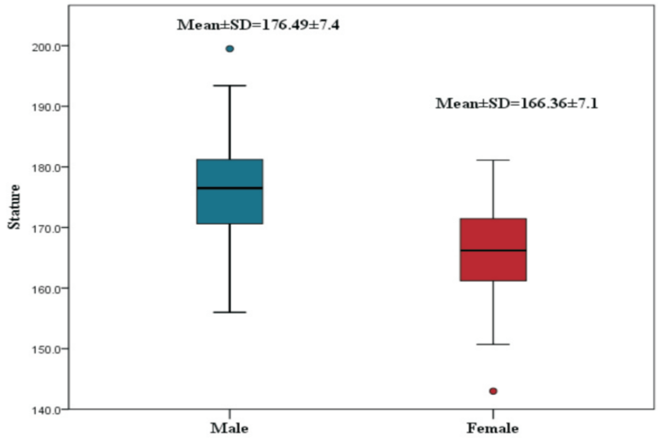

Figure 2: Box plot showing sexual difference in measured stature. t-value = 10.356, p<0.001*

Sex Estimation (Logistic Regression): In all six (6) tested logistic regression models, the single body dimensions were found to be statistically significant predictors (p<0.001) except for left foot length see Table 5. The sample data in this study suggested that females have a higher classification accuracy than males with 80.2% for right dimensions and 83.3% for left dimensions the classification accuracy for males showed 79.1% for right dimensions and 80.0-% for left dimensions. The combined classification accuracy for right measured dimensions was 79.7% while those of the left measured dimensions were 81.1%. the classification cut of used was 0.5 (0.0-0.5 males; 0.51-1.0 females) The formulae for gender estimation from right and left foot were: $L_n(P/1\text{-}p) = B_0 + B_1X_1 + B_2X_2 \ldots\ldots B_kX_k$

Table 5: Logistic regression for predicting sex using single left and right foot dimensions

	b0	b1	S.E.	t-value	95% C.I Lower	95% C.I Upper	Hosmer-Lemeshow p-value
			RIGHT				
Bi-malleolar Width	2.313	10.102	0.332	0.001*	5.270	19.362	0.540
Foot Width	-0.570	0.565	0.180	0.001*	0.397	0.805	0.989
Foot Length	0.010	1.010	0.037	0.001*	0.938	1.087	0.067
			LEFT				
Bi-malleolar Width	2.932	18.762	0.366	0.001*	9.149	18.474	64.020
Foot Width	-0.446	0.640	0.209	0.001*	0.426	0.964	4.567
Foot Length	-0.009	0.991	0.041	0.826	0.915	1.073	0.048

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

Table 6: Percentages of correctly classified for gender determination for multiple logistic regression

Groups	Right foot			Left foot		
	Correct	Incorrect	Correct %	Correct	Incorrect	Correct%
Male	103	26	79.1%	105	24	80.0%
Female	97	23	80.2%	100	20	83.3%
Combined	200	49	79.7%	205	44	81.1%

Classification cut off 0.5

Stature Estimation- *CORRELATION:* All body dimensions were positively correlated with stature. The strongest correlations with stature were ob served for left bi-malleolar width for all groups (combined r=0.576; males r=0.709; females r=0.438). The weakest correlations for all groups was for right foot length (combined r=0.371; males r=0.474; females r=0.242). see table 7 and 8.

Table 7: Correlation between stature and measured parameter in right and left foot

	Right		Left	
	Correlation coefficient (r)	p-value	Correlation coefficient (r)	p-value
Bi-malleolar Width	0.561	<0.001*	0.576	<0.001*
Foot Width	0.488	<0.001*	0.524	<0.001*
Foot Length	0.371	<0.001*	0.379	<0.001*
Correlation between stature and measured parameter according to gender in right and left foot dimensi ons				
	Right		Left	
	Male	Female	Male	Female
Bi-malleolar Width	0.698 (<0.001*)	0.419 (<0.001*)	0.709(<0.001*)	0.438(<0.001*)
Foot Width	0.708 (<0.001*)	0.324(<0.001*)	0.717(<0.001*)	0.372(<0.001*)
Foot Length	0.474 (<0.001*)	0.242(<0.001*)	0.490(<0.001*)	0.232(<0.001*)

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

Regression: Right bi-malleolar width had the lowest SEEs for all groups (combined ±6.32cm; males ±6.21cm; females ±6.46cm). This body dimension also explained the highest proportion of variation in stature, as indicated by the coefficient of determination (R^2) for the combined, males and female groups (81%, 75%, and 86% respectively). The formula for single linear regression models is given as:

Table 8: Simple linear regression model for Individual measurement in Right and left foot

	Equation	p-value	SEE	R	R^2
RIGHT					
Bi-malleolar width (BMW)					
Male	117.243+(2.33) BMW	0.001*	6.328	0.425	0.752
Female	133.26+(1.70) BMW	0.001*	6.214	0.162	0.869
Combined	99.309+(3.0)BMW	0.001*	6.463	0.148	0.813
Foot width (FW)					
Male	111.561+(4.22) FW	0.001*	7.087	0.305	0.577
Female	89.163+(7.76) FW	0.001*	11.624	0.234	0.286
Combined	97.477+(7.94)FW	0.001*	11.06	0.445	0.210
Foot length (FL)					
Male	140.36+ (4.29)BB	0.001*	7.170	0.269	0.372
Female	127.68+(5.6)0BB	0.139	16.29	0.244	0.111
Combined	112.22+(9.30)BB	0.001*	12.80	0.373	0.124
LEFT					

		Bi-malleolar width (BMW)			
Male	117.243+(2.33) BMW	0.001*	8.328	0.425	0.452
Female	123.26+(1.70) BMW	0.001*	6.224	0.162	0.069
Combined	89.309+(3.0)BMW	0.001*	7.433	0.148	0.213
		Foot width (FW)			
Male	121.561+(4.22) FW	0.001*	7.087	0.305	0.077
Female	89.163+(7.76) FW	0.001*	10.324	0.234	0.086
Combined	97.477+(7.94)FW	0.001*	12.06	0.445	0.210
		Foot length (FL)			
Male	134.36+ (4.29)BB	0.001*	7.170	0.269	0.072
Female	117.68+(5.6)0BB	0.201	15.29	0.244	0.111
Combined	102.22+(9.30)BB	0.001*	8.80	0.373	0.124

Values with similar superscripts (*) are statistically significant at P< 0.05. Male *n=129*, Female *n=120*, Combined *n=249*

Table 9: Multiple linear regression model using all measured

	Equation	p-value	Adjusted r^2
	Right		
Male	68.748 + (7.447) BMW + (4.685) FW + (1.029) FL	0.001*	0.039
Female	88.997 + (4.901) BMW + (1.043) FW + (00.362) FL	0.001*	0.065
Combined	98.795 (5.588) BMW + (2.513) FW + (0.758) FL	0.001*	0.217
	Left		
Male	95.477 + (7.002) BMW + (3.579) FW + (0.832)	0.001*	0.434
Female	50.447 + (1.721) BMW + (1.439) FW + (0.339)	0.130	0.069
Combined	73.983 + (.790) BMW + (2.469) FW + (.671) FL	0.001*	0.556

DISCUSSION

Human variation is what makes it possible to characterize and compare humans according to several characteristics or traits, as no two individuals are exactly alike in all their measurable traits or characteristics, despite the fact that all human beings belong to the same species of Homo sapiens.[7-19]

This study is focused on stature and gender estimation from foot anthropometry among people from Cross River state in Nigeria. The research work was concerned in documenting descriptive statistics, paired sample analysis to test for bilateral asymmetry and gender differences, to determine sex from foot dimensions, also to know the relationship that exist between stature and foot anthropometry by deriving regression equations that are population specific.

The results from the present study suggested the presence of statistically significant sexual dimorphism between the males and females in this sample with males being significantly larger for all measurements. When means of stature, foot length and foot width measurements were compared with other studies, differences were found among the communities.[20-22] Because of the significant sexual dimorphism observed in this study, there was need for the creation of models for sex estimation and sex specific models for stature estimation. The most sexually dimorphic of the dimensions tested for this study was right foot width. Across similar studies of different ancestries, it is evident that that males have statistically significantly larger means than females for any given body dimension,[15,23,24] this may be due to earlier skeletal maturity among females compared to males, which gives males an extra two years of growth.[15,25] Nutritional, geographic and climatic factors have been reported to have influence on stature.[14,26] Stretched stature for the sample population showed significant sexual differences (p<0.005) as shown on the boxplot(figure 2), with means 176.49cm for males and 166.36cm for females. For a given stature, foot dimensions have been found to be relatively smaller in females than in males.[8,27-30] Right foot width was consistently the most dimorphic foot dimension for Zeybeck *et al.*[8] Danborno & Elukpo[31] found that right foot length to be the most sexually dimorphic measurement in their analysis of foot measurements for sex estimation in a northern Nigerian population.

All measured dimensions were assessed for their ability to predict sex using logistic regression. To provide accurate and reliable models for the estimation of sex, classification accuracies of over 80%.[32-34] Logistic regression models have been used severally for sex estimation.[8,35,36] Although the methodology differs, the overall classification accuracies in the present study were comparable to the work of Zeybek *et al.*[8] and Bindurani *et al.*[30] Correct estimation rates were shown in Table 5. The limit value (classification cut-off) for logistic regression model evaluation was 0.50. The values less than 0.50 were evaluated as male and values more than 0.50 were evaluated as female. The developed model, estimates the gender in the combined group 79.7 % correctly with right foot measurements, and 80.2 % with left foot which suggest the left are more reliable in sided models. The measurements in this study is comparable to Zeybek *et al.*[8] where the logistic regression models developed estimated gender in the combined group at 89% for right and 83% for left measurements in the Turkish population used.

All dimensions were positively correlated with stature. Correlations between body dimensions and stature in the present research were similar to other studies[6,8,12,24] and in some cases were stronger. It is established that no two populations have the same average mean for stature.[29]

There was existence of significant ($P<0.005$) mean stature differences between males and females in the present study which was sexually dimorphic This suggested that male adults in this sample population are taller than the females. Ibeabuchi *et al.*[13] found similar values in a different population and different age range. These population differences in anthropometric dimensions are necessary for the establishment of population-specific algorithms for stature and sex prediction from foot dimensions.

All dimensions were assessed for their ability to predict stature using simple linear regression based upon SEEs and R^2 values. Right bi-malleolar width had the lowest SEEs for all groups (combined ±6.32cm; males ±6.21cm; females ±6.46cm). This body dimension also explained the highest proportion of variation in stature, as indicated by the coefficient of determination (R^2) for the combined, males and female groups (81%, 75%, and 86% respectively). Some studies have reported that lower extremity measurements are more defining than upper extremity measurements in stature estimation.[8,21,24]

Multiple linear regression models were generated for male, female and combined groups for both left and right sides the present study showed that the most efficient sex specific equation for predicting stature from foot dimensions is that of female left foot measurements which was statistically significant at $P<0.001$ with an adjusted R^2 of 0.469. for the combined parameters, female left measurements had a higher predictive value than females statistically significant at $p< 0.001$. The findings from the present study agrees with studies from other populations.[8,22,32,34] that single predictors are more efficient in estimating stature than multiple predictors that in cases where multiple dismembered fleshed body parts being recovered for analysis, the model with the lowest SEE should be chosen, as this will produce the most accurate stature estimate. Dependent on the body parts available, a simple or multiple regression model may provide the lowest SEE.

CONCLUSION

The purpose of this study was to create practical models for the determination of sex and stature using anthropometric data from the foot. There is an existing body of work which this study can support by supplying models that are specific to the present study population which had not been previously tested. Multiple regression models were also created which involved the combination of all foot measurements for stature and sex determination. Further exploration and testing with different ethnicities and a larger sample is required to confirm the value of these dimensions for sex and stature estimation.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

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