

Thickness and texture of the squamous temporal bone in a Nigerian tertiary hospital

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Abstract

Background: Thickness and texture of the squamous temporal bones (STBs) are the two main patient factors that determine the outcome of transtemporal transcranial Doppler ultrasound. The aim of this study was to determine the thickness and texture of the STB as well as their association with biodemographic characteristics in a tertiary hospital in Southwest Nigeria.

Material and Methods: Cranial computed tomography (CT) images of 142 adults acquired on a 64-slice multi-detector Toshiba Aquilion scanner were retrospectively evaluated for the thickness and texture of the bilateral STB at the expected location of the temporal acoustic window on a ClearCanvas® Workstation. Associations of thickness and texture of the STB with biodemographic data were determined by statistical analysis at $P < 0.05$.

Results: There were 79 male (55.6%) participants and the overall mean age was 51 ± 17.3 years (49 ± 16.1 years in males and 53.4 ± 18.5 years in females). Mean thickness of the 284 STB was 3.21 ± 1.11 mm (range 1.2–8.7 mm), which was thicker on the left (3.3 ± 1.2 mm) than the right (3.1 ± 1.0 mm, $P = 0.001$). Thickness of STB showed significant increase ($P < 0.05$) with age on the right ($\beta = 0.23$) and left ($\beta = 0.31$). Controlling for age, males tend to have thicker STB than females. Thicknesses of STB in 61.3% were favorable for transcranial insonation bilaterally. Homogenous texture was found in 64.8% of STB while the rest were heterogeneous. A combination of both thickness and texture appear favorable for transcranial insonation in 76.8% of STB evaluated.

Conclusion: Thickness of the squamous temporal bone varied significantly with age but not with gender, and the temporal squama were largely of a homogeneous texture. Overall, the important patient factors appear favorable for transtemporal cranial ultrasound in the majority of our participants.

Keywords: Acoustic window, computed tomography, skull thickness, transcranial Doppler, ultrasound

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INTRODUCTION

Adequacy of the acoustic window remains the most important determinant of successful ultrasound scan for many diagnostic and therapeutic purposes. The transtemporal

window is frequently exploited for a transcranial ultrasound for this reason. However, the thin plate of the squamous temporal bone (STB) is sometimes too thick to permit successful transcranial insonation.^[1-3] Likewise, the texture of STB, either homogeneous or heterogeneous, influences

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the transtemporal propagation of the ultrasound beam.^[1] Differences in skull thickness and texture at the squamous temporal bone between individuals, within individuals, and between racial groups may, therefore, modulate the outcomes of transcranial ultrasound procedures.^[4,5]

The thickness of the human skull was determined in the past for various reasons including forensic analysis and biomechanics of skull fracture.^[6-8] Skull thickness of alive and cadaveric human subjects have also been determined for some races by nonimaging and imaging techniques such as spreading calipers or plain radiography.^[9,10] Normative values derived from observations of cadavers may not always sufficiently apply to living subjects, hence the need for reliable observations in the latter. Advances in imaging technology have also made the determination of precise dimensions of human skull thickness possible in living individuals. Computed tomography (CT) is an excellent cross-sectional imaging modality for *in vivo* determination of skull thickness and texture because of its optimal sensitivity to bony structures when compared with plain radiography used in the past.

Reports in the literature of thicker squamous temporal bone among non-Caucasians, especially those of African and Asian descent may have discouraged the use of transcranial ultrasound in many indigenous black African populations, in addition to the dearth of expertise.^[11,11] However, ultrasound is often the only cross-sectional imaging modality accessible by the vast majority in these low-income populations; and measurement of temporal bone thickness may help determine the feasibility of transcranial insonation.^[3,12] Furthermore, there is a paucity of data on the thickness or texture of squamous temporal bone from living black African individuals in the literature. The aim of this study is to determine the thickness and texture of the squamous temporal bone on bone window CT images of living Nigerian adults for proper documentation and evaluation of relevant biodemographic associations, and a comparison with data from other races.

MATERIALS AND METHODS

This cross-sectional observational study was performed at a tertiary hospital in Southwest Nigeria between March 2016 and February 2017 in a large city of racially homogeneous black Africans with an estimated population of 3 million.

Inclusion criteria were adults who were between the ages of 18 and 90 years as at the time of the cranial CT scan for nontrauma indications, and whose scans were deemed suitable for analysis. Exclusion criteria were those adults

determined to be of non-African race as shown by their nationality obtained from the database of the CT unit in the radiology department of the hospital. Other exclusion criteria are CT images that revealed evidence of prior trauma including fractures, trepanations, other transcranial surgical procedures, evidence of bone lesions by tumoral or infectious processes, underlying meningiomas, and those whose CT scans were not suitable for analysis. These categories of patients were excluded from the study.

The cranial CT scans acquired according to standard practice and reconstructed with bone algorithms devoid of motion, or streak artifacts were identified as suitable for analysis. All CT examinations were done with a 64-slice scanner (Toshiba Aquilion, Japan) using the volumetric acquisition protocol with continuous slice thickness of 0.5 mm; maximum kilovoltage of 120 kV; 300 mA tube current; and field of view of 24 cm that covered the entire brain from the skull base to the vertex; and prospectively reconstructed with bone algorithm. The cranial CT data were processed and analyzed using the Vitrea[®] software Version 2 (Vital Images, Inc. Minnetonka, Minnesota). For consistency, the thickness of the STB on both sides was measured on bone window images (WW: 3000; WL: 500) 1 inch (2.5 cm) anterior and superior to the external auditory canal, the site frequently used for transcranial ultrasound scan [Figure 1]. The start point of the electronic caliper was placed at the outermost margin of the outer table while the endpoint was placed at the most medial margin of the inner table to obtain the total thickness of the STB. The thicknesses of the outer table, diploe, and inner table were similarly obtained when these layers were distinguishable. The mean of 3 sets of measurements taken on the axial sections was recorded for all participants by the same radiologist (RBO). A senior radiology resident (RCE) independently obtained measurements of the STB according to the previously described method in 20% of the study sample, and

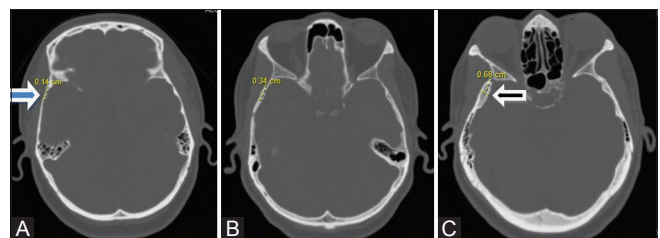


Figure 1: Bone window axial skull computed tomography images at the level of the temporal window 1 inch (2.5 cm) anterior and superior to the external auditory canal. Homogeneous texture of the squamous temporal bone is shown in A (arrow) while heterogeneous texture with trilaminar appearance is indicated by the arrow in C. The squamous temporal bone in A, B, and C are examples of potentially good, fair, and poor acoustic windows, respectively

the level of interrater agreement was determined for reproducibility. Interrater agreement determined by kappa statistics was excellent with kappa coefficient of 0.90 (95% confidence interval: 0.83,0.94; $P = 0.001$) The texture of the STB at the points of obtaining all aforementioned measurements was classified as homogeneous – when there was no perceptible difference in the opacity of the whole thickness of the temporal bone (making the layers indistinguishable) – or heterogeneous – with a trilaminar appearance when the intervening relatively hypodense diploic space was distinct from the hyperdense outer and inner tables [Figure 1]. The age and gender of the participants were also recorded. Data were analyzed using SPSS Version 20 (IBM, NY, USA) for descriptive statistics, appropriate parametric and nonparametric inferential statistical tests. The total thickness measured in all STB examined were stratified into normal or large using a cutoff value of 2.7 ± 0.9 mm determined in a previous study as conducive for transcranial insonation.^[5] Thus, total thickness above 3.6 mm (i.e., 2.7 ± 0.9 mm) was deemed large while thickness values $\leq 2.7 \pm 0.9$ mm were considered normal. Each STB was also further characterized as potentially good, fair, or poor acoustic window by the combination of thickness and texture categories. Potentially good (good) acoustic window was ascribed to the STB with normal thickness and homogeneous texture; potentially fair (fair) acoustic window means either normal thickness with heterogeneous texture or large thickness with homogeneous texture; and STB with large thickness and heterogeneous texture were designated as potentially poor (poor) acoustic window [Figure 1].

RESULTS

Cranial CT images of 142 patients were analyzed. The attributes of both STBs were obtained in each patient, thus a total of 284 STB were examined. Approximately 56% of the participants were male. The age of the study participants was between 20 and 90 years with a mean of 51 ± 17.3 years, and the mean age of 49 ± 16.1 years in males was lower than that of females (53.4 ± 18.5 years, $P = 0.13$). There was, however, no statistically significant difference in the composition of study sample according to gender on multiple linear regression analysis, having adjusted for age ($P > 0.05$).

The thickness of STB ranged between 1.2 and 8.7 mm with a mean of 3.21 ± 1.11 mm. The mean thickness of STB in females was 3.3 ± 0.99 mm (thickness range: 1.4–6.4 mm), more than that of males (3.1 ± 1.2 mm, thickness range: 1.2–8.7 mm; $P = 0.11$). The mean thicknesses of the STB were 3.1 ± 1.0 and 3.3 ± 1.2 mm on the right and

the left, respectively. There was a statistically significant difference between the mean thickness on the right and left sides ($P = 0.001$). However, a positive linear correlation was found between the thickness of STB on the right and the left sides ($r = 0.65$, $P < 0.001$) as presented in Figure 2.

Overall, the thickest STB was found in the ninth decade while the thinnest STB was found in the seventh decade. The distribution of the thickness of the STB according to age group is presented in Figure 3.

The thicknesses of STB in 81% of the patients were within the range of 2.7 ± 0.9 mm, favorable for transcranial insonation, on either or both sides. This favorable thickness (thin) was left sided in 69.7%, right-sided in 73.9%, and bilateral in 61.3% of the participants as shown in Table 1.

Homogenous texture was found in 64.8% of STB while the rest were heterogeneous. Among those with heterogeneous texture (trilaminar pattern), right-sided, left-sided, and bilateral trilaminar patterns were observed, respectively, in 34.5%, 35.9%, and 26.1% [Table 2].

Acoustic window was characterized as good, fair, and poor, respectively, in 170 (59.9%), 48 (16.9%), and 66 (23.2%) of all 284 STB evaluated. Among all 142 patients, 50.7%, 6.3%, and 14%, respectively, had bilateral good, fair, and poor acoustic windows while the remaining 29% had variable combinations of acoustic windows on the right and left sides as shown in Table 3. Poor acoustic window was found

Table 1: Squamous temporal bones thickness within/below (thin) and above (thick) the range of 2.7 ± 0.9 mm on both sides

Side	Right, n (%)			P
	Thick	Thin	Total	
Left, n (%)				
Thick	25 (17.6)	18 (12.7)	43 (30.3)	<0.001
Thin	12 (8.5)	87 (61.3)	99 (69.7)	
Total	37 (26.1)	105 (73.9)	142 (100)	

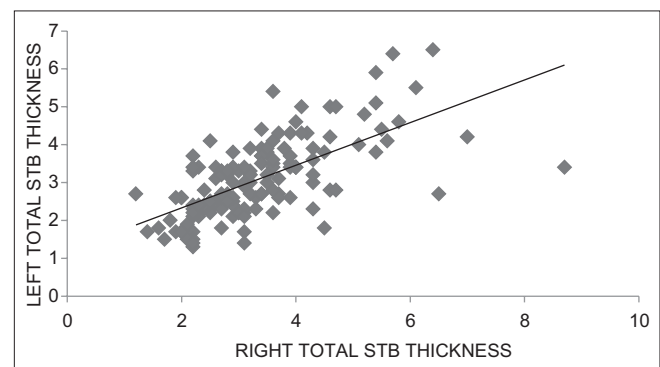


Figure 2: Scatter plot of total squamous temporal bone thickness on both side which shows linear correlation

more in the older age range (58.7 ± 19.0 years), compared with the fair and good windows which were observed in the younger individuals (58.7 ± 19.0 and 51.0 ± 17.2 years, respectively). This difference in the age ranges of the patients between the categories of acoustic window was statistically significant ($P < 0.001$) as shown in Table 4.

Multiple linear regression analysis was used to model the relationship between STB thickness and age as well as gender [Table 5]. The STB thickness showed significant increase ($P < 0.05$) with age on the right ($\beta = 0.23$) and left ($\beta = 0.31$). Controlling for age, males tend to have thicker STB than females. However, this difference is not statistically significant ($P > 0.05$).

The STBs with heterogeneous texture were significantly ($P < 0.001$) thicker (4.21 ± 1.1 mm) than those with homogenous texture (2.67 ± 0.7 mm). This difference in STB thickness between those with the distinct textures persisted on multiple linear regression even after controlling for confounders such as age and sex ($\beta = 0.64$; $P < 0.001$).

DISCUSSION

This study revealed the mean thickness of squamous temporal bone (STB) as 3.2 ± 1.1 mm in Nigerians at the expected site of the transtemporal acoustic window. The STB increased in thickness with age and was thicker in males than females after adjusting for age. At a discriminatory cutoff value of 2.7 ± 0.9 mm for normal and abnormal thickness, we found a high proportion of STB with normal thickness. Furthermore, there were more STB with homogeneous texture as there were with potentially good and fair acoustic windows, compared with heterogeneous STB or those with potentially poor acoustic window.

We evaluated only one, namely the patient factor, of the three determinant factors for successful transcranial insonation.^[1,5,13,14] The other two, equipment and operator

factors, are not presently feasible to evaluate locally in Nigeria for lack of proof of concept. The patient factor in Nigerians, or black Africans generally, is traditionally perceived as poor presumably due to negative bias from over-reliance on extrapolated data obtained from African Americans in the literature. This study as an attempt at elucidating the patient factors in our limited sample is, therefore, a significant first step toward establishing reliable proof of concept to justify further studies on the other two determinants.

Squamous temporal bone thickness and texture are the two constitutional patient factors with direct links to the outcomes of transcranial ultrasound examination in the literature.^[1,5] The density of the STB is, however, another constitutional patient factor but is not directly related to outcomes of transcranial insonation.^[1] Age and gender are also the two main demographic patient factors in addition to race-ethnicity which influences the outcome of transcranial insonation in each individual patient,^[1,3,4] therefore, the primary patient factor variables in this

Table 2: Distribution of squamous temporal bones texture on both sides

Left, n (%)	Right, n (%)			P
	Heterogeneous	Homogeneous	Total	
Heterogeneous	37 (26.06)	14 (9.86)	51 (35.92)	<0.001
Homogeneous	12 (8.45)	79 (55.63)	91 (64.08)	
Total	49 (34.51)	93 (65.49)	142 (100)	

Table 3: Distribution of potential temporal acoustic window on both sides

Side	Right, n (%)				P
	Poor	Fair	Good	Total	
Left, n (%)					
Poor	20 (14.08)	11 (7.75)	6 (4.23)	37 (26.06)	<0.001
Fair	4 (2.81)	9 (6.34)	7 (4.93)	20 (14.08)	
Good	5 (3.52)	8 (5.63)	72 (50.71)	85 (59.86)	
Total	29 (20.41)	28 (19.72)	85 (59.87)	142 (100)	

Table 4: Characteristics of participants with various potential temporal acoustic windows

Acoustic window (n=284)	Mean±SD		P
	Age	Thickness	
Poor (66)	58.74±16.7	4.70±0.98	<0.001
Fair (48)	56.63±18.56	3.51±0.52	
Good (170)	46.32±15.50	2.55±0.55	

SD – Standard deviation

Table 5: Linear regression model of the predictors of squamous temporal bones thickness

Side	Predictors	Regression coefficient (β)	P
Right	Sex	0.13	0.12
	Age	0.23	0.007
Left	Sex	0.01	0.930
	Age	0.31	<0.001

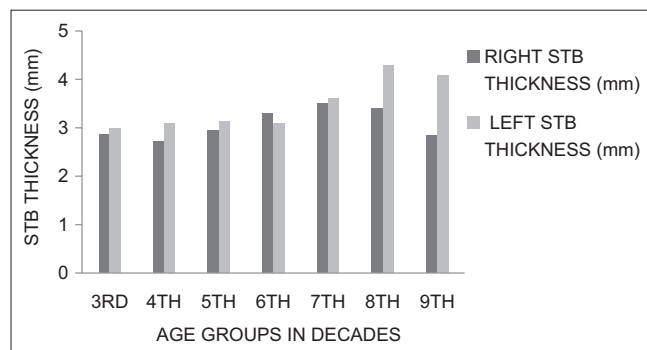


Figure 3: Distribution of squamous temporal bone thickness according to age groups

study were limited to the aforementioned demographic and constitutional factors. Suitability of each STB for transcranial insonation, termed potential acoustic window in this study, is a secondary patient factor derived from thickness and texture of STB.

There is a paucity of data for direct comparison of the thickness of STB obtained in this study due to differences in study objectives, methods, and population. A study on calvarial thinning with leakage of cerebrospinal fluid in Iowa, USA, reported a mean STB thickness of 4.25 ± 0.58 mm in 20 patients who served as controls for the study arm.^[15] Although the region of the STB sampled seem similar in both studies, the mean age of their participants (60.4 ± 16.5 years) was, however, higher than that of our participants (51 ± 17.3 years). Conversely, the mean STB thickness at the seventh decade in our participants was 3.5 and 3.6 mm on the right and left, respectively, still lower than the reported value in the Americans whose race-ethnicity affiliation was not specified. A similar trend of higher STB thickness in American participants than our participants were observed in the pioneering work of Jarquin-Valdivia *et al.* in San Francisco, USA, which did not stratify data based on race-ethnicity.^[3] Furthermore, the mean STB thickness in our participants is lower than that obtained in the control arm of a CT study on skull bone thickness of patients with chronic tension headache in Baghdad, Iraq.^[16] Using the same model of CT scanner as this present study, the Iraqi author reported a mean STB thickness of 5.37 ± 0.14 mm among 104 patients with mean age of 46.1 years. A study on 65 participants (mean age of 74.7 ± 6.7 years) in Ecuador reported a mean STB thickness of 3.6 ± 1.4 mm.^[5] However, the mean STB thickness in our participant was slightly higher in both males and females than those of 92 Korean participants who were also older.^[1] Whereas, it is difficult to conclude that the mean thickness of STB is definitely lower than those of Iraqis and some Americans due to the aforementioned differences among the studies, we can safely state that black Africans may not have the thickest STB in the world. A comparative study among black African, African American, and Caucasian populations in the future will be helpful to provide concrete data from which valid conclusions can be drawn.

Furthermore, our data suggest that STB is thicker among men compared to women. This evidence contradicts reports in the literature.^[1,5] At the initial analysis, our data aligned with the long-held notion that females have thicker STB than males. However, when adjustment was made for age, males were found with thicker STB than females, but the difference was not statistically significant in line with the autopsy findings of Lynnerup in Denmark.^[6] A

recent large autopsy study also revealed that neither sex nor ancestry correlated significantly with thickness of the skull vault, consistent with previous submissions that, in forensic analysis, it is difficult to assign gender to unidentified skulls based on thickness.^[6,7,17] Therefore, gender may not be an important determinant of skull thickness in our participants, but studies to address this observation will be necessary in the future.

About two-thirds of our participants had homogeneous texture on either side while bilaterally homogeneous STB texture was present in 55%. Likewise, about 57% of our participants had STB attributes compatible with good (50.7%) to fair (6.3%) acoustic window bilaterally. More than half of senior citizens were found with heterogeneous texture and higher window failure rates in a study from Ecuador.^[5] Texture of the STB was first identified as a major factor in transcranial insonation by Kwon *et al.*, in Korea.^[1] Patients with homogeneous texture suffer less window failure than those with heterogeneous texture of the STB as also recently confirmed by Del Brutto *et al.*, in Latin America.^[5] This is because ultrasound attenuation by scattering and absorption which occurs in cancellous bones, such as the skull diploe, is absent in STB with homogeneous texture, where diploe is virtually absent.^[18] With the use of image-guided transcranial insonation – in the form of transcranial color-coded sonography (TCCS) – and ultrasound contrast media, bilateral window failure rate in Nigerian adults is not expected to be more than 23% based on our data since TCCS is credited with more successful examinations than the nonimaging transcranial Doppler method.^[5,12] A subsequent study with TCCS in patients who had contemporaneous cranial CT will help validate or refute the foregoing hypothesis in our population.

The mean age of 51 ± 17.3 years in this study merit some comments as it provides further insights into the need for transcranial ultrasound in Nigerian adults. Reports from Africa indicates that stroke occurs at a mean age of 57 years and many such stroke victims lack access to timely neuroimaging.^[19,20] Intracranial atherosclerotic diseases, the most common stroke mechanism globally, is also on the increase among Nigerians.^[21,22] Since the majority of the STBs are of potentially favorable characteristics for successful transcranial insonation, it stands to reason therefore that point-of-care imaging with transcranial ultrasound may help expand neuroimaging access for stroke victims in Nigeria. Timely diagnosis and appropriate intervention, including sonothrombolysis, can then be hoped for if further studies encourage translation of our proof of concept into clinical practice.

Therefore, the findings from this study have profound implications in black Africans, particularly among Nigerians. Our results have kindled optimism about the potential roles that transcranial ultrasound can play in indigenous black Africans given the encouraging constitutional attributes in the majority of the STB evaluated. While the assertion that the black race has thicker STB with higher window failure rates than Caucasians may be true, it is also obvious that the case is not so bad as to totally preclude the use of ultrasound for neurovascular evaluation in native Africans.

The excellent interrater agreement with moderate sample size in a population whose temporal squama attributes were previously undocumented is a major strength of this study. There are also important limitations to this present study such as the retrospective design which made it impossible to correlate findings with TCCS. However, the facility for TCCS is presently unavailable at the study site. In addition, the cutoff value of 2.7 mm for determination of thick versus thin STB was based on data from other races derived from correlation with TCD studies, a less sensitive instrument than TCCS. It has been stated that TCCS may allow a higher cutoff value for the thickness of STB deemed conducive for successful transcranial insonation.^[1,5] Finally, bone mineral density (BMD) was not taken into account in our study participants. Although its effect on the success of transcranial insonation is negligible based on reports from other populations,^[1,5] it will be appropriate to determine the extent to which BMD should be considered in our population.

CONCLUSION

Thickness of the squamous temporal bone varied significantly with age but not with gender, and the temporal squama was largely of a homogeneous texture. Overall, the important patient factors were favorable for transtemporal cranial ultrasound in the majority of our black African subjects, but further studies are required for validation of the findings.

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Conflicts of interest

There are no conflicts of interest.

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