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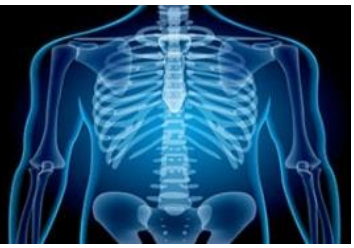

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Transcranial Doppler imaging of the middle and anterior cerebral arteries in pediatric patients with sickle cell anemia in Osun State, Nigeria

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Abstract
Background: The prevalence of stroke among sickle cell anemia (SCA) children in Nigeria, is between 4.3 - 5.2%. Transcranial Color Doppler (TCCD) could identify those at the highest risk for stroke. Demand for TCCD imaging technique is on the increase since non-imaging Transcranial Doppler (TCD) equipment are not available in many radiology departments.
Objectives: To evaluate the hemodynamic changes in the cerebral blood flow of children with SCA by measuring the Peak Systolic Velocity and Time Average Mean Maximum Velocity of the middle and anterior cerebral arteries
Methodology: One hundred subjects, consisting of 50 SCA patients and 50 controls were recruited from LAUTECH Teaching Hospital, Osogbo, Osun State, Nigeria. The PSV and TAMMX, of the MCA and ACA of these subjects, were assessed using the TCD imaging technique. Results were analyzed using SPSS (version 20)
Results: Increased TAMMX values of the SCA subjects were observed in all the vessels when compared with the control group with $p<0.001$ (except in the right ACA with $p>0.05$). PSV values in the MCA and ACA of SCA cases were also significantly higher than the control group $p<0.001$ (except in the right ACA with $p>0.05$). PSV also correlates well with TAMMX in all vessels. The average values of the assessed parameters are higher compared to values documented in developed countries.
Conclusion: TCCD imaging technique is equally a vital tool for the assessment of the hemodynamic changes in the MCA and ACA of SCA pediatric age group where non-imaging technique is not available in radiology departments.

Keywords: Pediatrics, sickle cell anemia, transcranial color Doppler, middle and anterior cerebral arteries

Introduction
Sickle cell disease is fast becoming a global hereditary disease largely due to increasing population migration from low and middle-income countries to high-income countries [1, 2]. While 75% of all patients with sickle cell disease (SCD) live in Sub-Saharan Africa, Nigeria alone accounts for more than 100,000 new births every year [3], largest worldwide [4]. A large retrospective study by Nwogoh *et al.* in Benin City, South-South Nigeria indicated the prevalence of SCD to be 2.3% [5]. As recently reported by Ogun *et al.*, mortality in SCD in Nigeria is mostly attributed to infections, acute chest syndrome, anemia, acute sequestration crisis and stroke [6]. Among patients with the common genotypes of SCD, stroke is most frequent in those with sickle cell anemia (SS) [7, 8].
About 15 million people were reported to have suffered from stroke annually worldwide [9]; about five million of this population was reported to have died and another 5 million were left with a permanent disability. A heavy burden is placed on the individuals, family and the community [10]. The required complex care for SCD patients are not readily available in the tropics, and this results in high morbidity and mortality [11].
Seventy percent of SCA deaths in Africa are preventable with simple, cost-effective interventions [12]. Early identification of risk factors has led to improved survival through targeted interventions [12]. The prevalence of overt stroke among SCA children in Nigeria is reported as between 4.3 - 5.2% [13, 14].

Approximately 11% of patients with SCA would have had a stroke before 20 years of age [6]. The incidence of stroke is higher in the 1 to 9 years of age group than in the 10 to 19 years of age group suggesting that a subset of patients may have additional risk factors for early stroke [7]. Stroke risk is noted to be higher in SCD patients with high systolic blood pressure, low baseline hemoglobin, low fetal hemoglobin and high white blood cell count [15]. Infantile stroke is a rare occurrence[16]. The incidence of stroke is higher in HbSS disease compared to other forms of hemoglobinopathies [17]. Complications and mortality among Nigerian SCD patients are significantly high in the face of suboptimal health care [18].

The STOP (Stroke Prevention Trial in Sickle Cell Anemia) study confirmed that non-imaging Transcranial Doppler (TCD) could reliably identify those at the highest risk for stroke [19, 20]. Doppler ultrasound-related techniques are beneficial in the assessment of cerebral hemodynamics. Doppler ultrasound is non-invasive and can be repeated often when clinically indicated at the patient's bedside for adults and children [21, 22].

TCD is increasingly recognized as an extension of the clinical examination similar to stethoscopes [23]. Transcranial Doppler ultrasonography commenced as a non-imaging study with the use of pulsed Doppler technology [24]; screening rates are low globally [25]. Non-imaging TCD is not available in most hospitals in Nigeria, however, most hospitals have facilities for Transcranial Color Doppler machine, which can serve as a reliable alternative in assessing the major intracranial vessels [26]. In addition, the transcranial Doppler imaging technique permits direct visualization of intracranial anatomy. Most of the currently utilized clinical applications have been best developed using the non-imaging TCD [26]. Data are limited and no studies have been done to evaluate the reliability of the imaging TCD technique in developing countries. This study aimed at evaluating the haemodynamic cerebral changes in Sickle Cell Anaemia and compared its findings with the already existing database in the developed world.

Materials and Methods

This was a cross-sectional comparative study carried out in the department of Radiology, Ladoke Akintola University Teaching Hospital (LAUTECH) (now UNIOSUN Teaching Hospital), Osogbo in Osun state, southwestern zone of Nigeria for a duration of one year. This research was conducted in accordance with the Ethical Principles for Medical Research involving human Subjects, as outlined in the Helsinki Declaration of 1975 (revised in 2013) [27]. Ethical approval was obtained from the Research Ethics Committee of the LAUTECH Teaching Hospital with ethical approval no; LTH/EC/2017/03/301.

Subject selection

Sickle Cell Anaemia subjects, between 2- 16 years of age were recruited mainly from Pediatric department, Sickle cell clinics of LAUTECH Teaching Hospital Osogbo, Osun State and were scanned consecutively after obtaining written informed consent from either of their parents. HbAA children meeting the set criteria were referred from the children outpatient department, National Health Insurance Authority (NHIA) clinic, and daily ultrasound clinic sessions of LAUTECH Teaching Hospital Osogbo after due written informed consent from their parents as control. The MCA and ACA of three SCA cases and three control subjects were assessed per ultrasound session on a designated day for Sickle cell Clinic. One hundred (100) pediatric patients, consisting of 50 controls and 50 SCA subjects were recruited and evaluated in the study. Inclusion criteria for SCA case group included children 2- 16 years age group, children with confirmed Homozygous SCD (HbSS) and absence of local abnormalities on neurological examination indicating previous vascular territory ischaemic injury

Inclusion criteria for the control group included; children 2-16 years age group and children with HbAA. Exclusion criteria for SCA case group included history of major head injury, history of seizure disorder and children already on active chronic transfusion or hydroxyurea therapy with no previously known baseline transcranial Doppler parameters. Exclusion criteria for control group included history of major head injury, history of seizure disorder, history of prenatal or perinatal hypoxic-ischemic brain injury and febrile children.

Ultrasound procedure

TCD ultrasound study was performed with Ultrasound machine unit - Landwind Mirror 5 Class 1 Digital Color Doppler Diagnostic Scanner (P.R China) using a transcranial transducer with a frequency of 2 -2.5MHz in compliance with the power Doppler imaging STOP technique.

Subjects were positioned supine, head facing up and supported on the unexamined side with a soft pillow. Following the application of acoustic gel on the skin of the temporal region, each side of the MCA and the ACA were assessed through the thin squamous part of the temporal bone via the anterior, posterior and preauricular windows as the acoustic window for examination. The transducer was oriented transversely on the plane with the transducer indicator pointing towards the face. The anatomical demonstration of the colour Doppler distribution of the vessels at the circle of Willis is highlighted as in Figure 1a. The cerebral peduncle was identified as the reference landmark (Figure 1b) for the circle of Willis on B-mode as a heart-shaped hypoechoic structure before Doppler imaging. The right and left MCA and ACA on each side were visualized and assessed separately through their separate acoustic window using the color Doppler (Figure 1a). The waveforms of the MCA and the ACA were also demonstrated. (Figure 1c and 1d). Power Doppler was also employed for better visualization and interrogation of difficult vessels. There was no angle correction in this study. The sample volume was adjusted to 5mm or varied as the case may be for each visualized cerebral vessel. This is similar to the ones used in the non-duplex imaging technique of the STOP study. Subjects were engaged in interactive communication to prevent them from sleeping during the transcranial ultrasound sessions. The active participation of the parents and guardians was implored especially in the under-aged subjects for adequate participation. The MCA was seen on color doppler interrogation coursing anterolateral in relation to the anterior aspect of the cerebral peduncle, as it continues from the ICA after the ICA has given off the ACA. The MCA usually demonstrates an elongated sigmoid course laterally. It was differentiated from the Posterior Cerebral arteries which wrapped around the cerebral peduncle and course

posteriorly. The ACA was seen extending to the midline toward the interhemispheric region after its bifurcation from the ICA anteromedially in relation to the cerebral peduncle. Doppler interrogation was commenced from the most peripheral portion of the MCA measuring the velocity with Doppler gate advancement in 2-3-mm increments. At the bifurcation, flow is bidirectional, with the flow within the MCA towards the transducer and flow within the ACA away from the transducer (Figure 1c and 1d). Measurements were made in both the ACA and the MCA portions of the bifurcation. The gate was advanced medially into the ACA to take its measurements. In all segments, the highest velocity was obtained. For a patient with more than one examination during the study period, due to follow-up on an abnormal risk category value, the highest value obtained on various examinations was used for classification. We manually measured the TAMMX (Time Average Mean Maximum Velocity), as in the STOP study, to eliminate any changes that might be introduced electronically. Examination results were interpreted as normal if all TAMMX values were less than 170 cm/sec in any artery. Examination results were interpreted as conditional if the TAMMX was greater than or equal to170 cm/sec but less than 200 cm/sec in any vessel. Examination results were interpreted as abnormal if the TAMMX in the MCA and the ACA was greater than or equal to 200cm/sec. Children with abnormal risk results (TAMMX > 200cm/s) were referred for a repeat examination after three weeks. The abnormal risk groups were also sent to National Sickle Cell Centre Lagos for non-imaging TCD assessment and their results were compared with the duplex imaging TCCD.

RIGHT MCA- Right Middle Cerebral Artery
RIGHT ACA- Right Anterior Cerebral Artery
RIGHT PCA- RIGHT Posterior Cerebral Artery
LEFT MCA- Left Middle Cerebral Artery
LEFT ACA - Left Anterior Cerebral Artery
LEFT PCA - Left Posterior Cerebral Artery

Fig 1a: Duplex Transcranial imaging showing cerebral arteries at the Circle of Willis in a control case

Fig 1b: Duplex Transcranial imaging at the level of the cerebral peduncle (curved arrow) in a control case

Fig 1c: Triplex Transcranial imaging of M1 segment of the left Middle Cerebral artery (white arrow) and its biphasic low resistance high velocity waveform in control case

Fig 1d: Triplex Transcranial imaging of A1 segment of the right anterior cerebral artery (white arrow) and its biphasic low resistance high velocity waveform as it flows away from the transducer in a control case

Data Analysis and Statistics

Data analysis was performed using a statistical package for social science 22 (SPSS, Inc., USA). Quantitative data were presented as means and standard deviations. Chi-Square was used to compare the impedance of the vessels. The values from the MCA and ACA were compared using a paired 2-sided *t*-test. Pearson correlation coefficient (*r*) was used to quantify bilateral relationships between Doppler parameters, and a 2-sided *t*-test to compare Doppler values between genders.

Results

Sociodemographic characteristics

One hundred pediatric subjects in the age range 2-16yrs were recruited for this study, with 50 SCA cases and 50 controls comprising 51% male and 49% female subjects. Twenty-seven SCA case subjects were males while 23 SCA case subjects were females. The control group consisted of 24 male subjects and 26 female subjects (Table 1).

The mean age of male subjects in the SCA group was 7.98 ±3.86 while the mean age in female subjects was 8.38 ± 4.12. The age range for both male and female subjects were 2 - 15 yrs. and 2 – 16 yrs. respectively (Figure 1d).

Table 1: Age and sex distribution pattern of SCA subjects and controls

	SCA Subjects		Control Subjects	
Age	**Male**	**Female**	**Male**	**Female**
< 5 years	7	6	4	6
5 – 10 years	10	9	16	14
11 – 15 years	10	6	4	4
>15y ears	0	2	0	2

Tammx in Control and SCA Cases

Table 2 shows the mean values of TAMMX of the control group and SCA subjects in the MCA and ACA.

There was a significant difference in the TAMMX mean values in the control and SCA cases in all the demonstrated cerebral arteries. The TAMMX mean values were significantly higher in the SCA groups when compared with the control group with $p<0.001$ (except Right ACA with $p>0.05$).

Table 2: The mean values of TAMMX of the control group and SCA subjects in the MCA and ACA

	Mean TAMMX values in SCA (cm/s)	Mean TAMMX values in Control (cm/s)	*p* Value
RMCA	102.48±29.63	79.21±13.57	0.000
RACA	64.92±32.36	62.05±14.26	0.568
LMCA	102.55±34.13	73.26±19.62	0.000
LACA	71.37±30.87	55.64±14.98	0.002

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
TAMMX - Time Average Mean Maximum Velocity
SCA- Sickle Cell Anaemia

Table 3 shows the mean values of PSV of MCA and ACA in the Control and SCA.
Mean PSV values in the MCA and ACA of SCA cases were significantly higher than the control group $p<0.001$ (except right ACA with $p>0.05$) (Table 3).

Table 3: The mean values of PSV of MCA and ACA in the Control and SCA

	Mean PSV values in SCA (cm/s)	Mean PSV values in Control (cm/s)	*p* Value
RMCA	148.94±39.58	113.31±15.31	0.000
RACA	99.38±45.50	89.02±15.54	0.130
LMCA	148.90±47.30	105.80±23.18	0.000
LACA	106.71±44.81	82.01±19.00	0.001

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
PSV - Peak Systolic Velocity
SCA- Sickle Cell Anaemia

TAMMX correlation with PSV in SCA
Table 4 shows the correlation of the TAMMX with PSV in the MCA and ACA in SCA group on both cerebral hemispheres.
TAMMX correlates strongly with PSV in all the insonated vessels with $p< 0.05$.

Table 4: Correlation of the TAMMX with PSV in the MCA and ACA in SCA group on both cerebral hemispheres.

TAMMX	PSV	
	r value	*p* Value
RMCA. 966		0.000
RACA	.949	0.000
LMCA	.952	0.000
LACA	.977	0.000

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
TAMMX- Time Average Mean Maximum Velocity
PSV - Peak Systolic Velocity
SCA- Sickle Cell Anaemia

Ipsilateral and contralateral paired sample test of TAMMX and PSV
Table 5 Paired Samples Tests Comparing Ipsilateral TAMMX with PSV in the MCA and ACA of SCA Subjects
The paired difference in the ipsilateral cerebral vessel of PSV and TAMMX was significant in all the demonstrated vessels. However, no significant difference was noted comparing the contralateral hemispheric values of TAMMX and PSV (Table 6). The mean MCA TAMMX and PSV were significantly higher than the corresponding hemispheric values in the ACA. (Figure 1).

Table 5: Paired Samples Tests Comparing Ipsilateral TAMMX with PSV in the MCA and ACA of SCA Subjects

Side to side hemispheric variables	Paired Difference ± SD(cm/s)	*T* values	*P* values
RMCA TAMMX - RMCA PSV	46.45±13.33	24.64	.001
RACA TAMMX - RACA PSV	34.46±17.94	13.58	.001
LMCA TAMMX - LMCA PSV	46.35±18.08	18.13	.001
LACA TAMMX - LACA PSV	35.34±16.09	15.53	.001

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
TAMMX - Time Average Mean Maximum Velocity
PSV - Peak Systolic Velocity
SCA- Sickle Cell Anaemia

Table 6: Paired Samples Tests Comparing Contralateral Hemispheric Velocities in the MCA and ACA of SCA Subjects

Side to side hemispheric variables	*t* values	*p* values
RMCA PSV - LMCA PSV	.006	.996
RACA PSV - LACA PSV	-1.113	.271
RMCA TAMMX - LMCA TAMMX	-.013	.989
RACA TAMMX - LACA TAMMX	-1.404	.167

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
TAMMX - Time Average Mean Maximum Velocity
PSV - Peak Systolic Velocity
SCA- Sickle Cell Anaemia

Table 7 shows PSV variation in different age groups in the SCA group A significant difference in age group mean velocity variation in the SCA was noted. The PSV mean values were significantly higher in the younger group (2-9yrs) when compared with the older group (10-16yrs) in SCA groups. (Table 7).

The highest velocities were seen between the age group 2 -5 yrs. The mean PSV values observed at this age group are as follows: Right MCA PSV (161.16cm/s), Right ACA PSV (123.37cm/s), Left MCA PSV (165.25cm/s), and Left ACA PSV (131.91cm /s). (Table 7).

Table 7: PSV variation in different age groups in the SCA group

Age group (SCA)	RMCA PSV Mean ± SD (cm/sec)	RACA PSV Mean ± SD (cm/sec)	LMCA PSV Mean ± SD (cm/sec)	LACA PSV Mean ± SD (cm/sec)
2-5 YRS (N=15)	161.16±37.59	123.37±36.40	165.25±27.70	131.91±36.99
6-9 YRS (N =13)	153.52±40.85	102.78±52.14	150.01±63.23	97.02±53.89
10-13 YRS (N = 17)	142.86±35.89	98.45±48.96	141.83±47.71	90.76±36.21
14-16 YRS (N =5)	121.02±48.27	90.74± 30.82	121.00±37.85	110.54±45.41

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
PSV - Peak Systolic Velocity
SCA- Sickle Cell Anaemia

Table 8: Gender Comparison of Stroke Risk Categorises in SCA Case Group Using the PSV.

		Standard Risk	Conditional Risk	Abnormal Risk	Chi-square value	*P* value	
RMCA PSV	Male	40	8	6	.125	.939	
	Female	32	8	6			
RACA PSV	Male	54	0	0	5.104	.078	
	Female	38	6	2			
LMCA PSV	Male	38	14	2	3.830	.147	
	Female	26	10	10			
LACA PSV	Male	54	0	0	3.747	.154	
	Female	40	2	4			

RMCA- Right Middle Cerebral Artery
RACA- Right Anterior Cerebral Artery
LMCA- Left Middle Cerebral Artery
LACA - Left Anterior Cerebral Artery
PSV - Peak Systolic Velocity

Discussion

This study showed a significant increase in hemodynamic changes in the SCA paediatric age group as evidenced by an increase in the PSV and TAMMX when compared to their non-SCA peers. Similar hemodynamic changes were noted by Adams *et al.* [28] and were attributed to the anaemic status in the SCA group [28, 29]. A baseline anaemic status was also noticed in this study with a Stable PCV mode of 24%. This anaemic status was noted to have no relationship with age at diagnosis and management duration in this study. A similar study done by Soyebi *et al.* [30] also corroborates changes in the TCD patterns in SCA in Africa similar to previously reported works on TCD [25, 30]. Other studies also noted that stenotic changes in the vascular wall in SCA patients contribute to further increase in the measured cerebral arterial parameters for assessing the hemodynamic changes (PSV, TAMMX, PI, RI) [24, 28, 29]. The similarities in these hemodynamic changes and baseline anaemic status may probably be due to the non-geographic and universal effect of the Sickle cell disease process on the Paediatric age group.

TAMMX increased significantly in the SCA subjects as compared to the control across different age groups in this study. Studies have shown that this increase in TAMMX in the SCA group correlates significantly with the increase in the risk of stroke in SCA. This was identified in the work of

Adams *et al.* [28] and Aaslid *et al.* [24] which serve as the basis for the STOP criteria [28]. The TAMMX of children with SCA was higher than the control in this study, corroborating what was also indicated in the STOP study [18, 31].

TAMMX was well correlated with the PSV in this study. Studies done by Jones *et al.* [27] and Naffaa *et al.* [32], showed that PSV was also well correlated with TAMMX; and a viable hemodynamic parameter in the determination of stroke risk in the SCA pediatric age group [32, 33]. This study is in consonance with other studies' findings of higher velocities (TAMMX and PSV) in the MCA than the ACA [19, 33]. The reference values for MCA and ACA as stated by Babikian were MCA 100-130 cm/s and ACA 85-110 cm/s respectively [34]. The mean velocity of 130cm/sec in the MCA was also indicated by Adams [29]. This study however showed higher values (MCA 148.94±39.58, ACA 106.71±44.81). The higher incidence of SCD in this region and late presentation of SCD patients due to misinformation of the disease and high poverty level could have accounted for the higher velocities noted in the MCA and ACA in this study.

There was no significant difference in the side-to-side velocities in the MCA and ACA in this study. This was similar to a previous study done by Krejza *et al.* [31]. However, slightly higher values were noted on the right hemisphere as against higher values reported previously on the left hemisphere by Krejza *et al.* [31].

The age group variations in the MCA and the ACA velocities (PSV and TAMMX) in this study between 2-5yrs and 6-9yrs demonstrated higher mean velocity than their peers above 9yrs. The incidence of stroke and risk of stroke have been noted to be higher in the 1 to 9 years of age than in the 10 to 19 years of age groups suggesting additional risk factors for stroke in the younger age groups [7]. Soyebi *et al.*, [30] also indicated that children with a high risk of stroke were between 2-8years of age group. The age group with the highest velocity in this study was noted to be 2-5yrs which also corresponds to the age with the highest incidence of mortality in SCD, as indicated by Adams [28]. This finding further confirms the vulnerability of the younger age group (< 10 years) to stroke when compared to the older age group.

The risk of stroke is not gender-dependent in the SCD group as seen in this study. This also agrees with the findings of Ohene-Frempong *et al.*, [7].

Conclusion

Sickle cell disease is fast becoming a global occurrence due to inter-marriage. Hence, Sickle cell anemia has no gender or geographical coloration. This study revealed a significant increase in the hemodynamic parameters (TAMMX and PSV) of the cerebral vessels in SCA cases when compared with the control group using the Transcranial Color Doppler imaging technique. It also demonstrates higher values of these parameters and increases possibilities of stroke risk in a child with Sickle Cell Anaemia in a developing country. The Transcranial Color Doppler imaging technique is equally a vital tool in developing countries when non-imaging TCD techniques are not available.

Limitations

The acoustic window in some of the older age groups were thickened, limiting proper assessment of the vessels. Limited cooperation from some children below 3yrs of age despite parental support is worth mentioning as a limitation in this age group.

Intra observer errors could also not be ruled out in this study.

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Conflict of Interest

The authors declare that there is no conflicts of interests.

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