Original Article

Poor Acoustic Window Limits the Diagnostic Utility of Transcranial Colour Doppler Ultrasonography for Acute Stroke in an African Population

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Abstract

Background: Stroke is a major cause of death and disability. Brain computed tomography (CT) scan is used for evaluating such patients with stroke followed by prompt interventions to reduce associated complications. Transcranial colour Doppler (TCCD) offers relatively affordable, nonionising, noninvasive analysis of cerebral hemodynamics. **Aim:** The aim of this study was to provide preliminary data on the utility of TCCD in adult acute stroke in sub-Saharan Africa, specifically to correlate Doppler assessed vascular flow dynamics with morphological CT variables observed in patients with stroke. **Patients, Materials and Methods:** A prospective study on fifty adult patients with acute stroke (25 ischemic and 25 hemorrhagic) who had computed tomography scans and duplex ultrasonography performed within 24 h of the onset of acute stroke. The Doppler variables from TCCD were correlated with the brain CT data. **Results:** For ischemic stroke, the middle cerebral artery (MCA) and anterior cerebral artery (ACA) were visualised bilaterally in 8 (32%) of patients, while the posterior cerebral artery (PCA) was seen bilaterally in only 1 (4%) case. For the hemorrhagic stroke category, the MCA and ACA were visualised bilaterally in 16 (64%) of patients, while the PCA was seen bilaterally in only 6 (24%) cases. The ACA asymmetry index showed a strong negative correlation ($r = -0.938$, $P = 0.046$) with the total stroke volume and a strong correlation with the amount of midline shift ($r = 0.993$, $P = 0.0006$). There was no correlation between the other indices of asymmetry and the CT scan quantitative data. **Conclusion:** This study shows that evaluating adult patients with acute stroke using TCCD with the currently available two-dimensional ultrasound transducers may be limited by poor acoustic window in a sub-Saharan African population. In future, the application of three-dimensional transducers with lower frequencies and the introduction contrast enhanced TCCD might bring about a positive outcome.

Keywords: Acoustic window, stroke, transcranial Doppler

Introduction

Stroke remains a major cause of death and disability globally.[1] In Nigeria, the current age-adjusted incidence rate is 54.08 per 100,000 per year,[1] while the estimated annual mortality rate of 153/100,000 population.[2] Prompt intervention following emergency room presentation relies on clinical suspicion and confirmation through radiological assessment. This enables the application of life-saving therapies and institution of measures aimed at rapidly addressing physiological parameters to reduce associated complications.

Brain computed tomography (CT) scan is used for evaluating such patients with stroke. The stroke volume, degree of midline shift, ventricular ratio, etc., are some morphological criteria used to assess the severity of stroke on CT scans.[3]

Nonimaging transcranial Doppler (TCD) also offers relatively affordable, nonionising, noninvasive analysis of cerebral hemodynamics in those with acute stroke.[4,5] Nonimaging TCD

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involves blind sampling of an intracerebral artery at a given depth within the cranium. The morphology of the interrogated artery may be predicted from the analysis of the displayed spectral Doppler waveform of the arterial blood flow.[5] TCD can detect cerebral artery stenosis or other abnormalities from cerebral arterial hemodynamics.[6]

Nonimaging TCD has been standardised for monitoring stroke risk in children with sickle cell anemia.[5] In adults, nonimaging TCD has been used to demonstrate middle cerebral artery (MCA) occlusion in patients with ischemic stroke within 5 h. Suitable patients may be commenced on thrombolytics. TCD can also be used to assess for posttherapy recanalisation.[7]

TCD may also demonstrate vasospasm that occurs in the MCA a few days after subarachnoid hemorrhage. Vasospasm may cause cerebral ischemia in patients with hemorrhagic stroke and should be promptly controlled.[7] It may be used to monitor cerebral edema in those with ischemic stroke.[8] Brain swelling increases the intracranial pressure resulting in increased peripheral resistance of the terminal arterioles with concomitant decrease in end diastolic velocity of the intracerebral arteries and increased pulsatility index (PI).[8]

Increased PI may be correlated with the midline shift in patients with stroke-induced cerebral edema and it is helpful in deciding when to proceed from medical decompression to decompressive hemicraniectomy.[9]

In patients with stroke, asymmetry in the distribution of cerebral blood flow parameters may be observed on bilateral TCD studies and this has been associated with the infarct size or asymmetrical location in the brain.[6] MCA asymmetry index has been used to assess the functional outcome in these patients with a higher value associated with poorer outcomes.[6] The asymmetry index provides a value that does not depend on the absolute velocities measured.[10]

Transcranial colour Doppler (TCCD) has advantage over nonimaging TCD as it involves placement of the sampling cursors within a directly visualised artery on a two-dimensional (2D) ultrasound image.[11] In addition, the ultrasound machine used for TCCD is multipurpose and readily available. It is routinely used for echocardiography and found in many diagnostic facilities.[10]

The aim of this study was to provide preliminary data on the utility of TCCD in adult acute stroke in a sub-Saharan African population, specifically to correlate Doppler assessed vascular flow dynamics with morphological CT variables observed in patients with acute stroke.

Patients, Materials and Methods

Fifty consecutive patients who presented with CT evidence of acute stroke (25 ischemic and 25 hemorrhagic) and were admitted to the Acute Stroke Unit of the University Teaching Hospital were enrolled in the study.

Written informed consent was obtained from all patients. An interpreter was present to translate the consent form for those unable to read English. Consent was also obtained from the next of kin of unconscious patients. Ethical approval was obtained from the Health Research Ethics Committee of the institution. Participants for inclusion in the study were patients with a clinical diagnosis of stroke made by a neurologist, who had a CT scan preformed within 24 h of the onset of acute stroke.[12] Those who did not undergo CT scan as part of their normal diagnostic work-up or whose CT scan was performed 24 h after the onset of the stroke were excluded from the study. All enrolled patients had bilateral TCCD performed within 48 h after the onset of the stroke. The Doppler based variables were correlated with the brain CT quantitative data.

Transcranial colour Doppler

A portable ultrasound scanner (SonoScape S2 Portable Colour Doppler Ultrasound System) was employed with 7a low frequency phased array transducer (1.5–4.5 MHz). The patient was placed in the supine position and the intracranial arteries were interrogated via the temporal acoustic window as follows: The transducer was positioned above the zygomatic arch, just anterior to the ear. The cerebral peduncle, a hypoechoic butterfly shaped structure was used as a landmark for the circle of Willis on the B-mode image. Then colour Doppler was applied to visualise the nearly intracerebral arteries.[11]

Colour and spectral Doppler of the MCA, anterior cerebral artery (ACA) and posterior cerebral artery (PCA) were performed bilaterally at a sample volume of 10–15 mm and an insonation angle of 30–45°C. The mean velocity (Vm) and PI of the arteries were calculated automatically by the scanner from the spectral Doppler waveforms.[13]

The MCA index (%) was obtained using the formula:[6] 100 × (MCA Vm + MCA PI × 10)/(MCA Vm–MCA PI × 10). Then the MCA asymmetry index (%) was calculated as[6] 100 × (|Rt MCA index – Lt MCA index|)/(Rt MCA index + Lt MCA index)/2. The values for the ACA and PCA were calculated similarly.

Computed tomography scan

Nonenhanced brain CT scan was performed using a 128-slice spiral CT scanner (Aquilion, Toshiba). Axial images were obtained which were reformatted for other planes (Coronal and sagittal).

The total stroke volume was estimated using the formula for an ellipsoid (4/3 π abc, where a, b, and c represent the respective radii in three dimensions.[3,14] The degree of midline shift, was quantified by measuring the lateral displacement (in centimeters) from the midline of the septum pellucidum, the third ventricle, or the pineal gland.[3] The ventricular size was quantified using the Evans ventricular ratio which is the ratio between the maximum spread of ventricular horns to the breadth of cranial cavity.[3] The presence of intraventricular and/or subarachnoid hemorrhage was noted.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were presented as percentages. The Pearson correlation coefficient[15] was used to test for correlation of the Doppler variables (TCCD and CT) and CT data. The TCCD variables included the MCA, ACA, and PCA asymmetry indices. CT data included total stroke volume, midline shift, and ventricular ratio.

The R project for statistical computing[16] was used to analyse the data. Results were considered statistically significant when $P < 0.05$.

Results

The mean age of patients with ischemic stroke was significantly higher ($P = 0.0003$) than those with hemorrhagic stroke [Table 1]. More male participants were enrolled in the study [Table 1]. Out of the 25 patients with hemorrhagic stroke, 8 (32%) had intraventricular hemorrhage while 3 (12%) had subarachnoid hemorrhage on CT scan.

The cerebral peduncle [Figure 1] was not visualised bilaterally on TCCD in 17 (68%) ischemic and 9 (36%) hemorrhagic cases despite efforts to optimise the image. TCCD was unsuccessful in those in which the cerebral peduncle was not visualised.

For ischemic stroke, the MCA and ACA were visualised bilaterally during TCCD studies in 8 (32%) of patients, while the PCA was seen in only 1 (4%) case [Table 2]. For the hemorrhagic stroke category, the MCA and ACA were visualised bilaterally during TCCD studies in 16 (64%) of patients, while the PCA was seen in only 6 (24%) cases [Table 2]. The asymmetry index could not be calculated in patients in which bilateral values for the Doppler indices were unobtainable.

Table 3 shows the averages values for the CT scan data that were correlated with the Doppler variables. In Table 4, the ACA asymmetry index had a strong correlation ($r = 0.938$, $P = 0.046$) with the total stroke volume and a strong correlation with the amount of midline shift ($r = 0.993$, $P = 0.0006$). Correlation of PCA asymmetry index with the CT scan variables could not be calculated in patients with ischemic stroke [Table 4] because it was only seen bilaterally in one patient [Table 2]. There was no correlation between the other indices of asymmetry and the CT scan quantitative data.

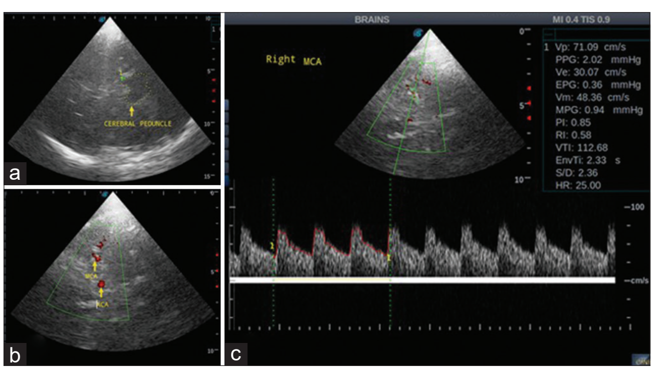

Figure 1: Transcranial colour Doppler B mode, colour and spectral Doppler images. The hypoechoic butterfly shaped cerebral peduncle is outlined on the B mode image (a). On colour Doppler, the MCA and ACA are demonstrated (b). The Vm and PI were obtained from the spectral Doppler waveform (c). MCA: Middle cerebral artery, ACA: Anterior cerebral artery, Vm: Mean velocity, PI: Pulsatility index

Discussion

CT scan plays an important role in managing patients with stroke in our sub-Saharan African location. However, in cases where CT scan is not available possibly due to cost, radiation hazards or affordability, we sought to explore if TCCD is a viable option for monitoring progress.

In this study, we observed that stroke was more common among men which may be explained by the protective effect that the female hormone, estrogen, has on vascular health.[13] We also noted that the sex-based difference was more in those with ischemic stroke. This may be because ischemic stroke is often due to atherosclerosis, a degenerative disease that occurs less in premenopausal women[17] while hemorrhagic stroke could be due to vascular anomalies such as aneurysms.[18]

Table 1: Patients' demography and blood pressure at presentation

	Type of stroke	
	Ischemic (n=25)	**Hemorrhagic (n=25)**
Age (years)*	60.48±12.47	48.24±9.06
Sex, n (%)		
Male	13 (52)	21 (84)
Female	12 (48)	4 (16)
Blood pressure at presentation (mmHg)		
Systolic	158.11±33.40	171.70±32.79
Diastolic	100.89±23.97	111.52±21.85

*Statistically significant difference at P<0.005

Table 2: Distribution of cases in which the intracerebral arteries were visualised bilaterally using Transcranial Colour Doppler

	Type of stroke	
	Ischemic (n=25), n (%)	**Hemorrhagic (n=25), n (%)**
MCA	8 (32)	16 (64)
ACA	8 (32)	16 (64)
PCA	1 (4)	6 (24)

MCA: Middle cerebral artery, ACA: Anterior cerebral artery, PCA: Posterior cerebral artery

Table 3: CT parameters in patients with ischemic and hemorrhagic stroke, respectively

Parameter	Mean±SD	
	Ischemic	**Hemorrhagic**
Total stroke volume (mL)	22.33±64.63	18.91±15.56
Midline shift (cm)	0.60±2.00	1.26±2.61
Ventricular ratio	0.30±0.04	0.27±0.03

SD: Standard deviation

Table 4: Correlation of Transcranial Colour Doppler with CT scan data

Ischemic stroke	Total stroke volume		Midline shift		Ventricular ratio	
	r	*P*	*r*	*P*	*r*	*P*
MCA asymmetry index (%)	0.217	0.639	−0.085	0.857	0.516	0.236
ACA asymmetry index (%)	−0.938	0.046	0.993	0.0006	−0.005	0.992
PCA asymmetry index (%)	ISD	ISD	ISD	ISD	ISD	ISD
Hemorrhagic stroke	**Total stroke volume**		**Midline shift**		**Ventricular ratio**	
	r	*P*	*r*	*P*	*r*	*P*
MCA asymmetry index (%)	0.156	0.646	−0.112	0.691	0.095	0.736
ACA asymmetry index (%)	−0.100	0.770	0.081	0.773	−0.473	0.008
PCA asymmetry index (%)	0.251	0.839	−0.302	0.622	0.290	0.636

MCA: Middle cerebral artery, ACA: Anterior cerebral artery, PCA: Posterior cerebral artery, ISD: Insufficient data

TCD is used in western countries to monitor vasospasm in hemorrhagic stroke[5] and TCCD may be used as part of ultrasound-enhanced thrombolytic therapy for ischemic stroke.[19]

TCCD requires an adequate temporal acoustic window as evidenced by visualisation of the butterfly-shaped mesencephalic brain stem or cerebral peduncle.[20]

When the cerebral peduncle is not visualised due to poor temporal acoustic window, TCCD is often unsuccessful.[21] In our study, the cerebral peduncle was not visualised bilaterally in 17 (68%) ischemic and 9 (36%) hemorrhagic cases despite efforts to optimise the image. This is much higher than the range of 10%–15% found in previous studies for the percentage of inadequate acoustic windows.[22]

The difficulty we experienced with TCCD may be explained by other studies which highlight challenges with TCD in noncaucasian patients. For example, in a Taiwanese study population, 20.3% were found to have insufficient temporal acoustic windows bilaterally.[18] Similarly, in a Brazilian study, poor temporal acoustic window was observed amongst those of African or Asian descent.[23] Noncaucasians such as African − Americans in the USA who have been observed to have temporal acoustic window insufficiency are a population at risk for stroke.[24]

The asymmetry index has been proposed as a useful tool for predicting short-term functional outcomes in patients with cryptogenic stroke.[6] It is suggested to be a reflection of the hemodynamics and collateral status in both cerebral hemispheres.[6] To compute this value, data from the intracranial arteries are required bilaterally. Therefore, in patients with unilateral or bilateral inadequate temporal acoustic windows, the asymmetry index cannot be calculated.

Some authors have proposed the use of three-dimensional (3D) diagnostic transcranial ultrasound at lower frequencies, near 1 MHz[24] for populations with poor acoustic windows. In our study, we performed 2D ultrasound with a low-frequency-phased array transducer (1.5–4.5 MHz) and used frequencies as low as 1.5MHz in challenging cases. However, this did not result in any improvement in detecting Doppler signals in some patients. Perhaps, newer 3D transducers with frequencies at 1 MHz or below might make a difference. Application of echo contrast agents during the TCCD has been suggested as a means of increasing visibility of the intracranial arteries.[21] However, we did not explore this option in our study.

Conclusion

This work demonstrates that acute stroke patients may not currently be adequately evaluated with TCCD using the widely accessible 2D low frequency phased array transducers in our African context. Future improvements could result from the use of 3D transducers with lower frequencies and the introduction of contrast-enhanced TCCD.

Statement of ethics approval/consent

We obtained ethics approval from the institution and informed consent from patients for the research study.

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Conflicts of interest

There are no conflicts of interest.

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