Anatomical validation of middle cerebral artery position as identified by transcranial pulsed Doppler ultrasound

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SUMMARY The basal cerebral arteries were insonated using transcranial pulsed Doppler ultrasound (TPDU) at 2 MHz. The Doppler sample volume (SV) depths at which signals were obtained which could be attributed to the middle, anterior and posterior cerebral arteries (MCA, ACA and PCA) were compared with measurements in adult cadavers and with B-scan ultrasound studies in infants. The depth of the internal carotid artery (ICA) terminal division into ACA and MCA was closely correlated for both groups. In adults, it was found at 5.6 ± 1.0 cm using TPDU while in cadavers it was found at 5.3 ± 0.5 cm from the temporal bone. In infants, it was found at 3.2 ± 0.3 cm for the right side, and 3.2 ± 0.2 cm for the left side using TPDU, and at 3.4 ± 0.4 cm and 3.4 ± 0.5 cm for right and left sides respectively using B-scan ultrasound. The mean depth of the MCA mid-point in infants as defined by TPDU and B-scan was also closely correlated, with values of 2.8 ± 0.3 cm and 2.7 ± 0.3 cm for right and left sides respectively using TPDU and of 2.8 ± 0.4 cm and 2.7 ± 0.4 cm for right and left sides respectively using B-scan ultrasound. Values for the most lateral part of the MCA did not correlate. In adults, signals from the ACA and PCA were obtained at greater SV depth than the MCA, thus preventing confusion.

There is a need for continual measurement of changes in cerebral blood flow (CBF) at times when cerebral perfusion may be compromised. Isotope methods are not suitable because the dosage of radioactivity precludes very frequent studies. Investigation has therefore continued into other non-invasive methods of which transcranial pulsed Doppler ultrasound is one of the most promising. The technique was described by Aaslid in 1982.¹ Despite signal attenuation by the temporal bone,² if low incident frequencies (2MHz) are used, it is possible to obtain Doppler signals which have been attributed to the intracerebral arteries.^{1,3} The method has been shown to be reproducible and to follow changes in cerebral blood flow produced by changing carbon dioxide in normals.^{4,5}

It has previously been shown that B-scan ultrasound imaging of intracerebral structures might be difficult because of refraction and differential attenuation of the incident beam by the diploe of the skull.²

However, if the transducer is held still, the differential attenuation should remain constant throughout the examination⁶ so that confusion over the insonation and collection of Doppler signals from individual arteries should not occur. No clinical study has yet confirmed this hypothesis. It has been demonstrated that the technique may be used to detect localised spasm⁷ and stenosis in the intracranial arteries as well as to test the collateral potential in patients with transient ischaemic attacks.^{1,3} Anatomical validation studies are therefore important.

The purpose of this study was to test the hypothesis that these signals are from the vessels to which they are attributed. The SV depth and transducer position findings were correlated with anatomical studies in normal adults and B-scan ultrasound appearances in infants.

Methods

(1) Infants

Twenty-four healthy babies were studied. The mean age was 48 days (range 1–162 days). Parental consent for the study was obtained in each case. B-scan coronal section ultrasound and transcranial pulsed Doppler ultrasound exam-

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Fig 1 Sonograms from the basal cerebral arteries from (a) an infant and (b) an adult with the sample volume set progressively deeper. (i) Signal just seen towards the transducer, Point B_d , presumed middle cerebral artery; (ii) Presumed main trunk of the middle cerebral artery; (iii) Signal away from the transducer just seen, presumed anterior cerebral artery, together with middle cerebral artery; terminal division of internal carotid, Point A_d ; (iv) Anterior and middle cerebral arteries clearly seen together; (v) Sample volume set deeper and angled posteriorly, signal towards the transducer, presumed ipsilateral posterior cerebral artery and signal away from the transducer, presumed contralateral posterior cerebral artery.

inations and measurements were carried out independently by different observers.

(a) *Pulsed Doppler ultrasound* A 2 MHz directional pulsed Doppler velocimeter (Alfred, Vingmed, Norway) was used to obtain blood velocity signals from the basal cerebral arteries by transcranial insonation. The axial length of the Doppler sample volume (SV) was ~ 9 mm (6 μ s pulse). SV depths quoted refer to the proximal end of the SV. The signals were displayed on a 2 channel spectral analyser (Dop-tek, Chichester, Sussex) and were simultaneously recorded

Fig 2 B-scan ultrasound coronal section of an infant's brain demonstrating middle cerebral arteries. Point A_s is the origin of the MCA and Point B_s is the horizontal MCA termination.

using a stereo cassette tape recorder (Sony). The 2 MHz transducer was placed on the squamous temporal bone just above the zygomatic arch. The SV was set at 3 cm. The position of the transducer was then adjusted until a signal towards the transducer was obtained (fig 1a (ii)). The SV was then set progressively deeper until a signal away from the transducer could be seen together with the signal towards the transducer (fig 1a (iii) & (iv)). The depth at which these two signals could first be seen together was noted (Point A_d) (fig 1a (iii)). The depth of the SV was then progressively reduced until the signal towards the transducer was no longer seen clearly. This depth was noted (Point B_d) (fig 1a (i)).

(b) *B-scan ultrasound* Coronal section images (fig 2) were obtained through the open anterior fontanelle using a Dasonics DRF-1 sector scanner with 6 MHz neonatal transducer (focal zone 3–8 cm, lateral resolution 1 mm). The sylvian fissure was easily seen, bordered by the temporal lobe inferiorly and the parietal lobe superiorly. The MCA was seen pulsating in the sylvian fissure, with its branches on the surface of the insula. Usually the ICA was seen pulsating on the medial aspect of the temporal lobe. Two depths were measured: (1) From the surface of the temporal bone to the origin of the MCA or the point it crossed the medial border of the temporal lobe (Point A_s) (2) From the surface of the temporal bone to a point where the MCA was no longer horizontal in the plane of the scanning sector, or to the origin of the insular branches. (Point B_s). To avoid the inaccuracy caused by not scanning exactly in a coronal plane, an attempt was made to visualise both MCAs simultaneously when measurements were made.

Fig 3 Lateral view of the skull to show the cantho meatal line and the MCA surface projection. The superior height is measured from the MCA surface projection perpendicularly to the cantho meatal line.

(2) Adults

(a) *Clinical study* Fifty-eight healthy volunteers were studied. Their median age was 21 years with a range of 20–32 years. Signals from the MCA were obtained using a 2 MHz pulsed ultrasound velocimeter set at 6 μ s pulse length (fig 1b (i)–(iv)), as described for the infant study, the only differences being that the SV depth was set at 4.5 cm and the transducer position on the squamous temporal bone was recorded with reference to the cantho-meatal line (fig 3). The posterior cerebral arteries (PCA) were insonated by setting the SV depth deeper and angling posteriorly (fig 1b(v)).

(b) *Cadaver study* A detailed examination was made of 15 cadavers. The cranial vault was removed 2–3 cm above the external auditory meatus. The brain was then carefully sectioned so as to expose the basal cerebral arteries and the circle of Willis without disturbing the branches of the MCA. The frontal lobes were removed completely and the temporal and occipital lobes were removed to the level of the circle of Willis. The projection of the straight portion of the proximal trunk of the MCA was extrapolated to the external surface of the temporal bone, the theoretical transducer site position. The position of this projection was then recorded with reference to the cantho-meatal line (fig 3), and depths of the various vessel sites were measured from that theoretical position. The angle θ_{μ} , of the MCA proximal trunk to the sagittal plane was measured as was the angle θ_A , in the axial plane, between the proximal ACA and the proximal MCA (fig 4).

The distance of the theoretical transducer position, posteriorly from the lateral canthus along the cantho-meatal line and the perpendicular height above this line were noted (fig 3). From this position on the temporal bone, projected distances were measured to the following points (fig 5): (i) the

Fig 4 Schematic diagram of the internal carotid terminal division, taken from a photograph of a cadaver specimen. The angle θ_A between middle cerebral and anterior cerebral arteries is shown as is the angle θ_{μ} between the middle cerebral artery projection and the temporal bone.

ICA terminal division into MCA and ACA (Point A_2), (ii) the first branch of MCA (Point B_1), (iii) the genu of the ipsilateral PCA.

The theoretical transducer site in cadavers as defined above was also compared with those sites found when insonating normals.

Results

(1) Infants

The mean depths of the MCA mid-point from the temporal bone, measured using the B-scan and the pulsed Doppler ultrasound, are shown in table 1. A paired Student's *t* test comparing values from right and left sides demonstrated no significant difference between the two sets of measurements ($p = 0.77$ and 0.79 for right and left sides respectively).

The depths at which the ICA terminal division (Point A_4 for the Doppler, A_5 for the B-scan) were demonstrated by each method were compared using a paired *t* test. For both right and left sides there was no significant difference ($p = 0.16$ and 0.06 respectively) (table 1).

The least depth at which the MCA could be demonstrated (Point B_4 for the Doppler, Point B_5 for the B-scan) was compared for each method using a paired *t* test. For both right and left sides there was a significant difference in the depth of the lateral end of the MCA main trunk as defined using the B-scan (Point B_4) and the depth of the distal end of the MCA found using Doppler ultrasound (Point B_5) (table 1).

(2) Adults

The results are shown in table 2. The depth of the ICA terminal division, in cadavers (Point A_4) was compared with the point at which it was *first* possible to obtain both ACA and MCA signals simultaneously (Point A_4 , fig 1b (iii)). The comparison, using an inde-

Fig 5 Basal cerebral arteries in a cadaver. Point A_c is the terminal division of the internal carotid artery and B1 is the position of the first branch of the middle cerebral artery. The main trunk of the middle cerebral artery is clearly seen between these two points.

pendent t test, showed no significant difference between the ICA terminal division depths in cadavers and in normals ($p = 0.13$). The shallowest depth at which MCA signals could still be obtained was always less than the depth of the first branch (B1) of the MCA found in cadavers. These depths could not be treated statistically as they were not strictly comparable.

In the clinical study it was not possible to obtain signals attributable to the ipsilateral ACA at a depth of less than 5.1 cm from the transducer site. The closest depth at which it was possible to obtain PCA signals was 5.5 cm. The comparable figure in cadavers was 5.0 cm.

The range of angle, θ_μ , (fig 4) between the MCA projection and the sagittal plane in cadavers, was 30° to 115° with a mean of 79° . The range of angle, θ_A , (fig 4) between the MCA and ACA was 70° to 180° with a mean of 138° . The posterior distance of the theoretical optimal transducer site along the cantho-

Table 1 Depths from the temporal bone of the MCA in 24 infants: comparison of Doppler ultrasound pulse volume depth with B-scan ultrasound measurements (cm)

	Right			Left		
	Doppler pulse volume mean depth	B-scan mean depth	p value*	Doppler pulse volume mean depth	B-scan mean depth	p value*
Presumed ICA bifurcation depth	3.2 $\pm$ 0.3†	3.4 $\pm$ 0.4‡	0.16	3.2 $\pm$ 0.2†	3.4 $\pm$ 0.5‡	0.06
Most lateral defined MCA depth	2.4 $\pm$ 0.4§	2.1 $\pm$ 0.4	0.005	2.3 $\pm$ 0.4§	2.1 $\pm$ 0.4	0.05
Mean depth of main trunk of MCA	2.8 $\pm$ 0.3	2.8 $\pm$ 0.4	0.77	2.7 $\pm$ 0.3	2.7 $\pm$ 0.4	0.79

* From Students' paired t test.

† Point A_d ; ‡ Point A_c ; § Point B_d ; || Point B_c .

Table 2 T-test comparison between cadaver and normal depths (cm)

	Mean	Standard deviation	Number of sides	Range	p value*
ICA bifurcation depth					
Clinical (Point A_d)	5.60	1.00	77	5.10–6.50	0.13
Cadaver (Point A_c)	5.30	0.50	28	4.10–6.15	
Shallowest MCA signal					
Clinical (Point B_d)	3.20	0.80	93	2.50–5.90	0.005
Cadaver—First branch (B1)	3.70	0.60	28	2.80–5.00	
PCA depth					
Clinical	6.30	0.30	63	5.50–6.90	0.005
Cadaver	5.90	0.90	27	5.00–8.90	

*From Students' t test.

Table 3 T-test comparison between cadaver and normal transducer sites

	Mean	Standard deviation	Number of sides	Range	p value*
Posterior site					
Cadaver	4.70	1.40	29	0.6–7.3	0.28
Clinical	4.30	1.40	115	1.6–7.2	
Superior height					
Cadaver	2.20	0.90	29	0.3–3.6	0.01
Clinical	1.80	0.70	115	–0.9–4.5	

*From Students' t test.

meatal line in cadavers (4.7 ± 1.4 cm) was compared with that found in normals (4.3 ± 1.4 cm) using an independent *t* test. There was no significant difference between them ($p = 0.28$) (table 3). The superior height, above the cantho-meatal line, of the theoretical transducer site in cadavers (2.2 ± 0.9 cm) and that found in normal volunteers (1.8 ± 0.7 cm) were compared using an independent *t* test. There was a significant difference between them ($p = 0.01$) (table 3).

Discussion

This study has demonstrated that backscattered Doppler signals, obtained transcranially from infants and adults, can be attributed to specific basal cerebral arteries. In infants, the depth of the origin of the MCA as defined with pulsed Doppler ultrasound agreed with that from the B-scan, both measured from the temporal bone site. In addition the mean depth of the MCA mid-point as defined by both methods agreed closely.

In adults there was close agreement between the depths of the ICA terminal division as found in the cadaver studies and that of the Doppler SV found in normals. There was good agreement between the predicted transducer sites on the side of the head and the actual sites found in normals despite the wide range of orientations of the MCA found in the cadavers. Whilst the posterior distances along the cantho meatal line are not significantly different between cadavers and normals ($p = 0.28$), the superior heights above this line are significantly different. This difference may be due to the difficulty found in positioning bone calipers accurately.

From this study it would appear that, provided the ICA terminal division is found first (Point A_d), and the Doppler SV depth is then brought slightly towards the surface, the signals obtained will be due to the MCA. In adults, the measurements show that if the Doppler SV depth is set to less than 5.0 cm it is unlikely signals due to the PCA will be obtained with a SV axial length of ~ 9 mm. This methodology excludes signals due to the contralateral ACA and ipsilateral PCA. The range of angles between the ACA and MCA, found in the cadavers, indicates that the ipsilateral ACA signal obtained in normals would always be in the opposite direction to that of the MCA.

In the infant study, the most shallow Doppler signals were always deeper than the most lateral part of

the artery as visualised on the B-scan. This was probably because the angle between the proximal artery and the insonating beam increased so that the artery was not insonated at a point where it was still visualised on B-scan. When the closest depth at which MCA signals were obtained in normal adults were compared with the first branch of the MCA in the cadavers, the cadaver depths were deeper. This may have been due to the finite length of the SV.

In conclusion, the cadaver and B-scan ultrasound measurements support the hypothesis that transcranial pulsed Doppler signals, assumed to be from the MCA, originate from this vessel. The good correlation with anatomical studies in both infants and adults suggests that the method may be used with confidence in all age groups.

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