Continuous wave Doppler ultrasound in evaluation of cerebral blood flow in neonates

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SUMMARY The cerebral circulation of 25 normal term infants was investigated using continuous wave Doppler ultrasound. Serial blood flow velocity signals were obtained from the common carotid and anterior cerebral arteries during the first week of life. The records were processed using a frequency spectrum analyser to provide cerebral blood velocity waveforms. The pulsatility index (PI), A/B ratio, and rise and fall slope of the waveforms were calculated. The results indicated that cerebrovascular resistance was raised appreciably on day 1 of life compared with later in the first week. In 18 of 25 infants (72%) there was no continuous carotid blood flow in the first hours of life. We suggest that the human cerebral circulation adapts to the process of birth in a similar fashion to that of animal models.

Intracranial haemorrhage and ischaemic hypoxic encephalopathy are major causes of mortality and morbidity in the newborn infant. The pathogenesis of these disorders is not, however, clearly understood and there is little information concerning cerebral blood flow.¹ Much of the data on cerebral circulation has been inferred from animal experiments,² ³ or has been obtained by venous occlusion plethysmography⁴ or by the use of isotopes.⁵ More recently Bada et al.⁶ used Doppler ultrasound to study the pulsatile flow in the anterior cerebral arteries of the newborn infant and this technique has since been employed to assess infants with hydrocephalus⁷ and patent ductus arteriosus.⁸ The pattern of cerebral blood flow in normal or distressed newborn infants has yet, however, to be fully elucidated. We used continuous wave Doppler ultrasound with frequency spectrum analysis to evaluate red blood cell velocity in the cerebral circulation of healthy newborn infants during the first week of life.

Patients and methods

Twenty five normal term infants with a mean birthweight of 3380 g (range 2750–4420 g) and a mean gestational age of 40·0 weeks (range 37·6–41·9 weeks) were examined. In all these babies, who presented vertex and were delivered without assistance, labour started spontaneously and was not accelerated. The infants were studied twice on the first day of life and the first examination was within 6 hours of birth. Further assessments took place on days 2, 3, and 5. The examinations were carried out by the same person (P G) at least 1 hour after a feed apart from those performed on day 1. The following technique was used: the tip of a pencil probe of a bidirectional Doppler instrument (Medasonics Versatone D–9) operating at a frequency of 5 MHz was placed on the skin over each common carotid artery at the base of the neck using a water based gel as a coupling medium. The Doppler signals were monitored through headphones and the probe was manipulated to obtain the best quality signals which were then recorded on magnetic tape. The probe was then placed in a similar fashion over the anterior cerebral arteries as they course along the longitudinal fissure.

Audiofrequency analysis of the Doppler signals was performed with a frequency spectrum analyser (Medishields, Spectrascribe Mk II) that can provide sonagrams on light sensitive paper (Kodak-Linagraph, direct print paper). Chart recorder speed used in all recordings was 100 mm/s, and by measuring the distance between the waveforms the heart rate was calculated.

Sonagram

The velocities of red blood cells in an artery vary across its lumen and hence a wide spread of Doppler shifted frequencies is back scattered from these cells. The Doppler signals received thus contain a spectrum
of frequencies corresponding to the different velocities of blood cells within an artery. The sonagram displays this spectrum of frequencies on the Y axis with time on the X axis. The blackness of different parts on the sonagram reflects the number of cells at that particular velocity at that time. The outline of the sonagram represents the maximum velocity throughout the cardiac cycle and the shape of the waveform reflects the pulsatile nature of blood flow.

In adults the shape of the sonagram is characteristic of the arterial site. Thus sonagrams of the peripheral arteries in the lower limbs where resistance to flow is high manifest a triphasic pattern with reverse flow in early diastole, whereas those of the carotid arteries that supply low resistance circulations exhibit forward flow throughout the cardiac cycle.10

In newborn infants sonagrams of the common carotid artery (Fig. 1) are similar to those in adults and show 2 systolic peaks with continuous blood flow during diastole. The peaks in systole have been signified as A and B by Baskett et al.11 Planiol and Pourcelot12 referred to the systolic amplitude of the waveform as S and the end diastolic amplitude D. The systolic amplitude S is thus equivalent to the peak height A of Baskett et al. In contrast, the sonagram of the anterior cerebral artery (Fig. 2) has a waveform with just 1 systolic peak.

In this study the waveforms were analysed by measuring the following parameters.

1) The pulsatility index (PI) defined as the difference between the systolic and diastolic amplitudes divided by the systolic amplitude (S-D)/S.12 This is an index of resistance to blood flow with a high value representing a high cerebrovascular resistance.

Fig. 1 Sonagram recorded from the common carotid artery displaying frequency (velocity) on the Y axis and time on the X axis. The maximum blood velocity waveform shows the parameters that were measured; AS, B, and D were measured as the height above the baseline. The tan of angles $\alpha$ and $\beta$ were calculated to estimate the rise and fall slopes.

Fig. 2 Typical sonagram recorded from the anterior cerebral artery with the maximum blood velocity waveform.

Fig. 3 Pulsatility index (PI) (mean (SD)) of the common carotid arteries on days 1, 2, 3, and 5.

PI day 1 (examinations (a) and (b)) v days 2, 3, and 5, $P<0.001$

PI day 1 examination (a) v day 1 examination (b), $P<0.001$. 
Continuous wave Doppler ultrasound in evaluation of cerebral blood flow in neonates

(2) The A/B ratio, namely the ratio of the primary peak in systole (A) to the secondary peak (B) in the waveform of the common carotid artery. This has been found to correlate with health and disease in adults.

(3) The rise and fall slopes estimated by calculating the tan of the angle of the rise (α) and the fall (β) of the waveform. The rise slope depends on cardiac contractility, the density of the blood, and the elasticity of the vessel wall whereas the fall slope reflects the cerebrovascular resistance.

Results

The 25 infants were examined on a total of 112 occasions. Eleven infants had only 1 study performed on day 1 while 1 baby left hospital before the day 5 examination. Two hundred and twenty six common carotid arteries and a similar number of anterior cerebral arteries were insonated. Satisfactory Doppler signals were obtained from all but 12 observations when excessive movements prevented adequate recordings. Waveforms of the left and right sides did not differ appreciably so the data obtained each day from the 2 sides were analysed together.

Fig. 3 shows the PI (mean (SD)) from the common carotid arteries on each day they were studied. The PI of both examinations on day 1 was significantly higher (P<0.001) than on day 2 and subsequent days. Furthermore the PI of the first examination on day 1(a) was significantly higher (P<0.001) than that of the second examination 1(b). In 18 of the 25 babies the cerebrovascular resistance was so high on the first examination on day 1 that continuous blood flow did not occur throughout diastole (Fig. 4). On the second examination, however, 2 infants only showed this type of waveform.

The PI (mean (SD)) from the anterior cerebral arteries (Fig. 5) was also significantly higher in both examinations on day 1 compared with subsequent days (day 1(a) v days 2, 3, and 5 P<0.001; day 1(b) v days 2, 3, and 5 P<0.05). The PI of day 1(a) was significantly higher (P<0.01) than that of day 1(b).

Calculation of the A/B ratio of the common carotid artery showed a progressive fall in the value from day 1 to day 5 (Fig. 6) but there was only a significant difference (P<0.01) between the values on day 1 and day 5.

The rise slope of the common carotid arteries varied widely (Table). The mean on the day 1(a) examination was significantly higher (P<0.01) than

![Fig. 4 Typical sonagram from the common carotid artery on day 1. There is absence of continuous blood flow during diastole.](http://adc.bmj.com/)

![Fig. 5 Pulsatility index (mean (SD)) of the anterior cerebral arteries on days 1, 2, 3, and 5.](http://adc.bmj.com/)

Day 1(a) v days 2, 3, and 5, P<0.001.
Day 1(b) v days 2, 3, and 5, P<0.05.
Day 1(a) v day 1(b), P<0.01.

![Fig. 6 Ratio of the primary peak in systole (A) to the secondary peak (B) in the waveform of the common carotid artery (mean (SD)) on days 1, 2, 3, and 5.](http://adc.bmj.com/)

Day 1(a) and (b) v day 5, P<0.01.
that on days 2 and 3. There was no significant day
to day variation in the rise slope of the anterior
cerebral artery or the fall slope of either the common
carotid or anterior cerebral arteries. The mean heart rate calculated from the sonagrams of the
common carotid arteries was 130/m on the day 1(a)
examination, 113/m on day 1(b), 116/m on day 2,
and 112/m on day 3. On day 5 some babies were
more active during the examinations and the mean
heart rate was 124/m.

Discussion

Doppler ultrasound has been used extensively in
adults in the investigation of cerebrovascular dis-
orders. In neonates the Doppler technique has been
recently used to evaluate cerebral blood flow but
there is controversy over its value in the determina-
tion of cerebral haemodynamics.15 16

To date, neonatal studies using Doppler ultra-
sound in the determination of cerebral blood flow
velocity have used zero cross detection in the
processing of the Doppler shift signals. This simple
system gives a trace of the average Doppler fre-
quency but has several limitations that may produce
unreliable results. Waveforms produced by zero
cross detection may contain important errors or
artefacts in up to 85% of instances.17 This problem
may be overcome by the use of frequency spectral
analysis to process the Doppler signals, as this
 technique meets all the requirements necessary for
the analysis of peak velocity waveforms.18 In this
study blood velocity waveforms from the common
carotid and anterior cerebral arteries were in-
vestigated using continuous wave Doppler ultra-
sound with spectrum analysis, thus eliminating the
inherent disadvantages of the zero cross frequency
meter used by previous investigators.

Using continuous wave Doppler ultrasound it is
not possible to calculate absolute values of red cell
velocities without knowing the angle of the trans-
ducer to the insonated vessel. The values obtained
from the PI, A/B ratio, and the rise and fall slopes
of the waveform are independent of the incident
angle, however, so these methods of evaluating red
cell velocity may be used for serial determinations.

Hence information on cerebrovascular haemo-
dynamics that cannot be calculated from volume
flow determinations may be obtained.

The shape of the blood velocity waveform is a
function of the forward compression wave caused by
cardiac systole and the reflected waves from peri-
pheral arterioles. After cardiac contraction a pressure
gradient is created and forward blood flow occurs.
This is opposed by the peripheral resistance with the
result that blood velocity decreases. In the femoral
artery where resistance is high, forward blood flow
briefly ceases so that a period of reverse flow occurs
during the cardiac cycle. The cerebral, renal, and
fetoplacental circulations are of low resistance and
forward flow continues throughout the cardiac cycle
with the waveform remaining raised above the
baseline. Examination of the blood velocity wave-
form can therefore be used to assess arterial haemo-
dynamics. In the present investigation both the PI
and the fall slope of the waveforms of the common
carotid and anterior cerebral arteries were used to
evaluate cerebrovascular resistance. The A/B ratio
was used, in addition, to assess the resistance in the
common carotid arteries.

The results of our investigation showed that the
cerebrovascular resistance as reflected by the PI of
both the common carotid and anterior cerebral
arteries was appreciably higher on day 1 compared
with subsequent days. Lucas et al.9 showed that,
in lambs, clamping of the umbilical cord after birth
resulted in a 30% decrease in carotid blood flow
related to a marked increase in carotid vascular
resistance. This alteration in vascular resistance has
been ascribed to the sudden changes in blood gas
tensions (principally the fall in P<sub>CO<sub>2</sub></sub>) that follow the
initiation of respiration and subsequent lung ex-
ension.2 8 Our study suggests that the human
cerebral circulation adapts to the process of birth in
a similar fashion to animal models.

Doppler ultrasound studies on preterm babies
have noted a sharp decrease in diastolic flow velocity
in those with patent ductus arteriosus.8 9 It could be
postulated that the high PI noted in our infants on
day 1 was not caused by a raised cerebrovascular
resistance but by a patent ductus arteriosus leading
to abnormal haemodynamics. Gentile et al.19, how-
ever, using pulsed Doppler echocardiography,
found the ductus arteriosus to be closed in 8% of
newborn infants on day 1, in 50% on day 2, and in
100% by day 5. While we noted an appreciable drop
in PI between days 1 and 2, the fact that no further
change occurred by day 5 suggests that this alteration
was not related to closure of the ductus arteriosus.

The cerebral circulation has been considered to be
one of low resistance with blood flow present
throughout diastole except in severe pathological

### Table Rise slope common carotid arteries

<table>
<thead>
<tr>
<th>Day</th>
<th>No</th>
<th>Mean</th>
<th>(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(a)</td>
<td>50</td>
<td>25.5</td>
<td>(11.7)</td>
</tr>
<tr>
<td>1(b)</td>
<td>26</td>
<td>21.6</td>
<td>(7.5)</td>
</tr>
<tr>
<td>2</td>
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<td>49</td>
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<tr>
<td>5</td>
<td>42</td>
<td>23.0</td>
<td>(12.0)</td>
</tr>
</tbody>
</table>

Day 1(a) v days 2 and 3, P<0.01.
Continuous wave Doppler ultrasound in evaluation of cerebral blood flow in neonates

states. The striking feature of the present study, however, was the absence of continuous diastolic flow in the common carotid arteries in most infants studied during the first few hours of life. The importance of this finding will become evident when neonates in whom raised cerebrovascular resistance is expected are investigated. If these infants do not have continuous carotid blood flow on day 1, we will know that this is not a pathological feature.

Values of the A/B ratio of the common carotid artery showed a progressive decline from day 1 to day 5 but no abrupt change from day 1 to day 2 occurred as was seen for the PI. The fall slope of the waveform showed no notable day to day variation. These findings suggest that these methods of analysis are less sensitive indicators of cerebrovascular resistance in the neonate than the PI.

The rise slope of the waveform of the anterior cerebral arteries showed no appreciable change from day to day, whereas that of the common carotid artery was higher on day 1 compared with days 2 and 3. The rise slope is primarily a function of cardiac contractility, though it is also influenced by the density of the blood and the elasticity of the vessel wall. Because of important structural and functional differences between the fetal and adult myocardium, the fetus has a very limited ability to increase stroke volume, and cardiac output is almost completely dependent on heart rate. Despite the lack of experimentation on the human neonate it is assumed that the infant myocardium behaves like that of the fetus and thus the considerable variability in the heart rate of the newborn infant will be reflected in the waveform. In the case of the carotid arteries the rise angle of the waveform was in general above 85°. Accordingly even a small variation in the angle will result in large change in the slope (the tan of the angle). Thus the change encountered in the rise slope of the waveform was likely to be caused by variation in the neonatal heart rate, as was seen when this was calculated from the sonagrams.

We have shown that Doppler ultrasound with spectrum analysis is a non-invasive and safe technique that may be used successfully in the evaluation of cerebral blood flow in the neonate. Its application may be useful in assessment of neonatal, pathological cerebral states. For term infants with birth asphyxia it is hoped that monitoring changes in cerebrovascular resistance will prove useful in the evaluation of the efficacy of ventilation and drugs. Studies of cerebral blood flow in preterm infants may contribute to our knowledge of the pathogenesis of intraventricular haemorrhage.

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References

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