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Role of Transcranial Doppler and Pressure Provocation in Evaluation of Cerebral Compliance in Children with Hydrocephalus

I ***Ahmad***, S ***Wahab***, RS ***Chana***, RA ***Khan***, A ***Wahab***

Abstract ***Aim:*** To evaluate the role of transcranial Doppler sonography and Resistive Index (RI) of Anterior Cerebral artery without and with pressure provocation as a marker of altered cerebral compliance in hydrocephalic children. ***Materials and Methods:*** Transcranial doppler study of 30 hydrocephalic children with elevated intracranial pressure and 30 controls with normal brain scan was done and resistive index of anterior cerebral artery was measured both with pressure provocation (applied by uniform pressure with transducer on anterior fontanelle for less than 5 seconds) and without pressure provocation. ***Results:*** The difference of resistive index and pressure provocation test values between the study and control group was found to be statistically significant ($p<0.001$). The application of Pressure Provocation Test markedly improved the specificity of RI by eliminating the false positives. ***Conclusion:*** Resistive index using transcranial Doppler sonography particularly with pressure provocation can serve as a useful and specific marker of altered cerebral compliance thus evaluating the necessity and effectiveness of CSF drainage procedures.

Key words Hydrocephalus; Pressure Provocation Test; Resistive Index; Transcranial Doppler Sonography

Introduction

Normal intracranial hydrodynamics rely on harmony between production, resorption and storage of CSF. In hydrocephalic processes one, two or even all of them are disturbed. The cause can be congenital or acquired or obstructive (intraventricular or extraventricular) or non-obstructive.[1] Ultrasonography is a non invasive, easy to perform and reliable procedure in assessing the ventricular size.[2] It is being increasingly used as an initial screening procedure in many pediatric neurological centres.[3] Transcranial Doppler Sonography (TCD) is an accepted non invasive method to quantify intracranial blood flow in adults and children.[4] The mere presence of ventriculomegaly on CT scan, Ultrasound or MRI cannot be used as an indication for CSF drainage in hydrocephalus. When Intracranial Pressure (ICP) values are normal or minimally elevated the risks of drainage outweigh the benefits and drainage is therefore contraindicated. On the other hand early obstruction to the CSF flow initially may not lead to ventricular dilatation yet may distort the brain architecture and compromise the cerebral circulation to the extent that brain damage ensues.[5]

TCD Ultrasonography has helped to describe the relationship between raised ICP and Doppler waveform of major intracranial arteries expressed by several indices as Resistive Index (RI) and Pulsatality Index (PI). This relation

Department of Radiodiagnosis, J N Medical College Hospital, Aligarh Muslim University, Aligarh, India

I **Ahmad** *MD*
S **Wahab** *MD*

Department of Surgery, J N Medical College Hospital, Aligarh Muslim University, Aligarh, India

RS **Chana** *MS, MCh*

Department of Paediatric Surgery, PGI Chandigarh, India

RA **Khan** *MS, MCh*

Centre of Cardiology, J N Medical College Hospital, Aligarh Muslim University, Aligarh, India

A **Wahab** *MD*

Correspondence to: Dr RA **Khan**

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is predominantly due to reduction in End Diastolic Velocity (EDV). Compression of the anterior fontanelle (pressure provocation) during Doppler ultrasound examination of Anterior Cerebral Artery (ACA) results in little, if any, change in RI of a healthy child.[5] In infants with hydrocephalus, however with fontanelle compression, there is a transient increase in ICP and an acute increase in arterial pulsatality occurs so that the RI of ACA progressively increases. The cerebral blood flow parameters change significantly following CSF drainage – RI falls and EDV increases. The measurement of ICP and cerebral blood flow velocity are currently one of the best ways of assessing the need for CSF diversion and monitoring subsequent shunt function.[6]

The aim of this study was to evaluate the role of Transcranial Doppler (TCD) sonography in children with hydrocephalus and to study the role of Resistive Index of Anterior Cerebral Artery without and with Pressure Provocation as a marker of altered cerebral compliance in hydrocephalic children by:

1. Comparing the Resistive Index (RI) of Anterior Cerebral Artery (ACA) in hydrocephalic children (study group) and controls.
2. Comparing the change in RI of ACA following Pressure Provocation Test (PPT) in study and control group.
3. Studying the change in RI of ACA in study group before and after drainage of CSF.
4. Comparing the sensitivity, specificity, positive and negative predictive value of RI without and with PPT as a marker of altered cerebral compliance.

Materials and Methods

The study was carried out from January 2005 to August 2006 at J N Medical College Hospital, Aligarh Muslim University, Aligarh, India. Patients up to 2 years of age were included in the study. A total of 30 patients diagnosed with hydrocephalus on USG were evaluated. Preterm babies and patients with intracranial tumours as the cause of hydrocephalus were excluded from the study because of possibility of altered vascularity. Another group of 30 children were selected as controls based on the USG finding of normal ventriculohemispheric ratio (<30%) and normal brain scan. Ventriculohemispheric Ratio (VHR) is a standard method of grading hydrocephalus. It is ideally taken at level of foramen of Monro/third ventricle in coronal section and is the ratio of distance of the lateral wall of lateral ventricle from midline to the hemispheric width. Values above 30% are classified as hydrocephalus.[7] Other factors known to affect the RI of cerebral vessels such as congenital heart disease, bradycardia/tachycardia, vasoactive drugs were ruled out clinically. The study and control group were evaluated through a strict protocol of history taking, clinical examination especially neurological examination and investigations.

The presence of hydrocephalus was confirmed by ultrasound and ventriculohemispheric ratio. Elevated intracranial pressure was defined by the presence of hydrocephalus and at least two of the following signs i.e. increasing head circumference, bulging anterior fontanelle, projectile vomiting, lethargy/irritability, prominent scalp veins, forced downward gaze (Sunset sign).

Transcranial Doppler Sonography for ACA is to be performed through the anterior fontanelle in all patients in whom the acoustic window exists. For accurate measurements the angle of insonation was kept under 60 degrees. Resistive index (RI) was computed after determining the Peak Systolic Velocity (PSV) and End Diastolic Velocity (EDV) of ACA.

$$RI = PSV - EDV / PSV$$

Measurements were taken at pericallosal or callosomarginal branches of ACA. Measurements were repeated during application of uniform continuous pressure with transducer on anterior fontanelle over a period of less than 5 seconds. A rise of more than 20% was considered significant.[8] The whole procedure was repeated on hydrocephalic children 7-8 days after CSF drainage. Similar procedure was repeated in the control group.

Statistical Analysis

Ventriculohemispheric ratio more than 30% is diagnosed as hydrocephalus. The cut off value for normal resistive index was taken as 0.65 without pressure and 0.78 with pressure provocation. After data collection the findings were tabulated and subjected to statistical analysis:

1. Change in RI on application of PPT in study and control group.
2. Mean RI without PPT and mean RI with PPT in the study and control group was calculated and the statistical significance of the difference between the values of two groups determined using unpaired t-test.
3. Mean preoperative and postoperative RI without PPT and RI with PPT in hydrocephalic children undergoing CSF drainage and the statistical significance of the difference between the preoperative and postoperative

values using paired t-test.

4. Sensitivity, specificity, positive and negative predictive value of RI without and with pressure provocation in the detection of raised intracranial pressure.

Results

Children included in the study ranged from neonate to 2-year-old child primarily because of the limitation of open anterior fontanelle which acts as a suitable acoustic window for anterior cerebral artery and its pericallosal and callosomarginal branches. There was an obvious male preponderance in the study with 19 out of 30 patients being males and the rest females. The ratio of male to female was 1.73:1. Congenital hydrocephalus was found to be the most common cause accounting for 23 (76.67%) cases with acquired causes accounting for 7 (23.33%) cases. Progressive enlargement of head was the most common clinical presentation followed by bulging fontanelle, sunset sign and prominent scalp veins. The parameters compared in study and control group are summarized in Table 1. In the comparison of the mean head circumference, VHR, RI of ACA without and with PPT between the study and control group, the difference was statistically significant ($p< 0.001$). The lowest RI without PPT recorded was 0.405 and highest 1.000. The lowest RI with PPT was 0.528 and highest 1.278 (Figures 1 and 2).

Out of 30 patients included in the study, 25 were operated with ventriculoperitoneal shunt placement. In the operated group mean head circumference decreased from 51.08 cm preoperatively to 50.58 cm postoperatively while ventriculohemispheric ratio also showed a significant decrease of 0.0634. The difference between the preoperative and postoperative values of RI without and with PPT was also statistically significant with preoperative values of RI decreasing from 0.772 and 1.0537 to 0.543 and 0.588 respectively. Figure 3 illustrates the graphical depiction of preoperative and postoperative values of RI without and with PPT. Only one patient in the study showed persistently elevated RI (both without and with PPT) even after CSF drainage procedure (postoperative values being 0.701 and

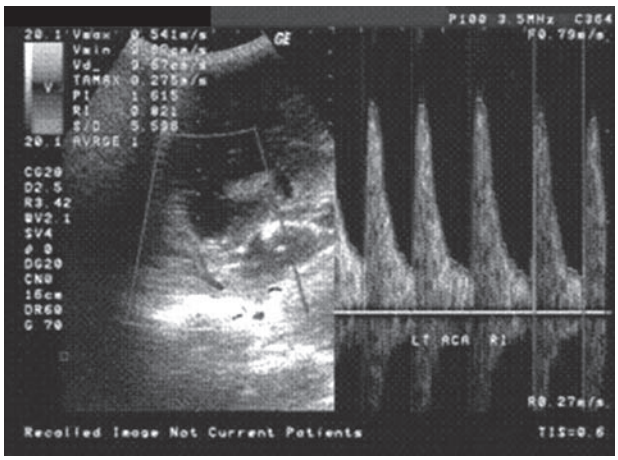

Figure 1 TCD of ACA in hydrocephalus showing raised resistive index (RI=0.821).

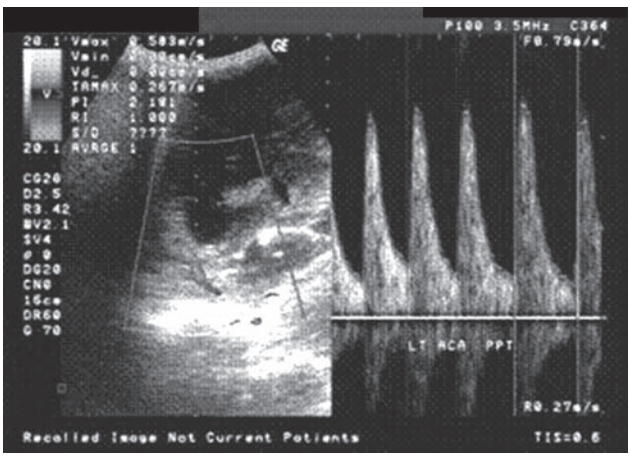

Figure 2 TCD of ACA showing increase in resistive index following pressure provocation.

Table 1 Comparison of various parameters between the two groups

Parameters	Study group	Control group
Mean Head Circumference	49.92 cm	38.83 cm
Mean VHR	0.572	0.149
Mean RI of ACA (without pressure provocation)	0.733	0.558
Mean RI of ACA after application of PPT	0.973	0.595
Increase in RI of ACA on application of PPT	32.74%	6.63%

VHR: Ventriculohemispheric Ratio; RI: Resistive Index; ACA: Anterior Cerebral Artery; PPT: Pressure Provocation Test

0.831 respectively). Unfortunately, the patient expired during the course of the study.

In the study group RI was almost equally effective in the detection of elevated intracranial pressure with RI being positive in 22 patients without PPT and in 23 patients with PPT. In the control group 5 false positives values of RI were obtained without PPT while only 2 false positives values of RI were detected with PPT. Tables 2 and 3 show the analysis of the results of the study.

The sensitivity of RI without pressure was 73.33% while with pressure provocation it was 76.69%; the specificity was 83.33% and 93.33% respectively. The false positive percentage was 16.67% for RI without PPT and 6.67% for RI with PPT with false negative percentage being 26.67% and 23.33% respectively. Positive predictive value of altered cerebral compliance as a direct consequence was higher for RI with PPT at 92% as compared to RI without PPT (81.48%).

Discussion

The introduction of Transcranial Doppler Ultrasonography by Aaslid et al in 1982[9] offered a portable, noninvasive means for measuring cerebral blood flow velocity in the major intracranial vessels. Transcranial

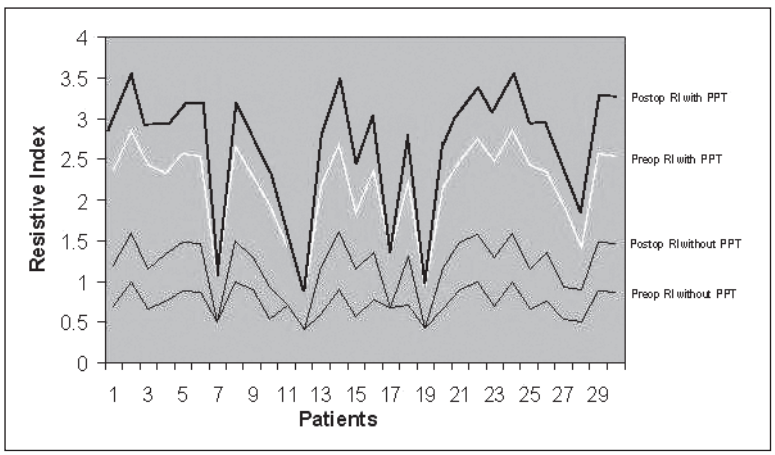

Figure 3 Comparison between pre-op and post-op RI without and with PPT.

Table 2 Comparison between RI without and with PPT as a marker of altered cerebral compliance

	RI without PPT (%)	RI with PPT (%)
Sensitivity	73.33	76.69
Specificity	83.33	93.33
Positive predictive value	81.48	92
Negative predictive value	75.75	80
Percentage of false positive	16.67	6.67
Percentage of false negative	26.67	23.33

RI: Resistive Index; PPT: Pressure Provocation Test

Table 3 Mean RI in the two groups before and after pressure provocation

Variable	Control Group (n=30)		Study Group (operated) (n=25)			
			Preoperatively		Postoperatively	
	Without PPT	With PPT	Without PPT	With PPT	Without PPT	With PPT
Mean RI	0.558	0.595	0.772	1.0537	0.543	0.588
%age increase	6.63%		32.74%		8.28%	

RI: Resistive Index; PPT: Pressure Provocation Test

pulsed doppler imaging of cranial blood flow is useful in evaluation of cerebral vasculature particularly when decreased blood flow is a cause of concern for infarction or rising intracranial pressure causes decrease in velocity of blood flow. It provides an easily repeatable means of monitoring ventricular size and consequent cerebrohaemodynamic changes which would be helpful in determining the need for ventricular shunting.[10] Arterial haemodynamics in the cerebral circulation are affected by normal maturational events in the healthy newborn.[11] RI shows a gradual fall from a range of 0.65-0.85 in the neonate, 0.60-0.70 in the child before fontanelle closure to 0.50-0.60 in older children and adults through temporal window after fontanelle closure.[12] In addition many factors like cardiac output, heart rate, presence of patent ductus arteriosus, use of vasoactive drugs and scanning pressure can affect the measured value for RI.[8] The range of normal values is broad and there is considerable overlap between normal and abnormal values, therefore there can be high false positive results when only resistive index is considered as an indicator of increased intracranial pressure. To increase the accuracy and specificity of resistive index as a marker of altered cerebral compliance, Taylor et al reported the use of fontanelle compression during transcranial doppler sonography of anterior cerebral artery.[8] This application of fontanelle pressure during measurement of resistive index is referred to as Pressure Provocation Test and is based on the Monroe-Kellie hypothesis, that the volume of the brain, cerebrospinal fluid, blood and all the intracranial components is constant. During fontanelle compression in normal infants CSF or blood can be easily displaced to compensate for small increase in volume, which results in no increase in intracranial pressure (ICP). In infants with abnormal intracranial compliance, however the increase in intracranial volume during fontanelle compression is translated into transient increase in intracranial pressure and concomitant decrease in cerebral perfusion. Hence RI of anterior cerebral artery progressively increases on application of pressure over the anterior fontanelle. Taylor et al in 1990[13] have suggested a change of more than 20% on pressure provocation as significant for elevated resistive index.

In the present study transcranial Doppler ultrasound of ACA was performed in 30 patients of hydrocephalus in the age group ranging from 2-day-old neonate to 2 years. The small age range was selected because of the open anterior fontanelle as a suitable acoustic window. Besides measuring the head circumference and ventriculohemispheric ratio, resistive index of anterior cerebral artery was measured and pressure provocation test was performed by compressing over the anterior fontanelle with transducer for less than 5 seconds and observing the change in RI of ACA. The analyses of the observations are discussed as follows:

Analysis of Mean RI Without PPT and Mean RI With PPT in Cases and Controls

In our study the Mean Resistive Index (RI) in Anterior Cerebral Artery (ACA) in study and control group was 0.733 and 0.558 respectively while after pressure provocation the values increased to 0.973 and 0.595 respectively. In the comparison of values of RI without PPT and RI with PPT between the study and control group, the differences were statistically significant between the two groups with the p value <0.001. These findings were similar to the earlier study by Westra et al in 1998; where the corresponding values were 0.82 ± 0.15, 0.63 ± 0.17 and 0.93 ± 0.13, 0.70 ± 0.10 respectively.[14] There was not much difference in the mean RI (without and with PPT) in different age groups or between male and female children. Gera et al in 2002 also showed similar findings.[5]

In our study, the average increase in Resistive Index of ACA on application of pressure provocation was 32.74% in the study group which was higher than the earlier study by Taylor who recorded an average increase of 17.4%.[8] However the increase in control group on application of pressure provocation test was comparable at the values of 6.63% versus 5.2%.

Analysis of Mean Preoperative and Postoperative RI (Without and With PPT) Values in the Study Group

Out of 30 patients in the study group, 25 were operated with ventriculoperitoneal shunt placement, mean RI without PPT and with PPT decreased from 0.772 and 1.0537 to 0.543 and 0.588 respectively. The difference between the preoperative and postoperative values for each of these groups was statistically significant ($p<0.001$).

Similar results were obtained by Goh et al in 1992.[15] They concluded that this fall in RI was due to increase in end diastolic velocity with the decrease in intracranial pressure after ventricular shunt placement. Postoperatively on application of pressure provocation, the average increase in RI of ACA was only 8.28% compared to 36.48% preoperatively. Only one patient in our study showed persistent elevated RI (both without and with) even after ventriculoperitoneal shunt placement. Shunt blockage was detected; however the patient expired before shunt revision could be performed.

Analysis of Sensitivity, Specificity, Positive and Negative Predictive Value for RI Without and With PPT in the Detection of Raised Intracranial Pressure

With a cut-off value of 0.65 for RI without PPT and 0.78 for RI with PPT, the sensitivity, specificity, positive and negative predictive value of RI without PPT in our study was found to be 73.33%, 83.33%, 81.48%, 75.75% and that of RI with PPT was 76.69%, 93.33%, 92% and 80% respectively. Thus the application of PPT mainly improved the specificity of the RI by eliminating the false positives. Similar findings were obtained in the earlier studies by Gera et al in 2002[5] and Westra et al in 1998.[14] However there were few drawbacks in our study as in earlier studies as the actual scanning pressure could not be directly quantified as a result it is impossible to assure that scanning pressure was equivalent in both the groups. But all examinations were performed by single radiologist using almost similar scanning pressure in every infant. Also we did not take into account the individual age group variation of normal RI values separately but as our study comprised of only small age group (up to 2 years) patients there was no significant variation in RI values and lastly infants with Arnold Chiari II Malformation whose meningomyelocele defect has been repaired but who have persistent CSF leak may be a source of false negative results of RI on PPT.

Conclusion

To conclude Transcranial Doppler sonography is a non invasive, safe and cost effective modality of investigation in hydrocephalic children and the RI of anterior cerebral artery can be used to evaluate the effect of elevated intracranial pressure on cerebral circulation in these children. With the modification of fontanelle compression (pressure provocation) the specificity of RI of ACA as a marker of altered cerebral compliance is considerably increased mainly by elimination of false positives, thus Pressure Provocation Test can serve as a better, more accurate and specific parameter in evaluation of the necessity and effectiveness of CSF drainage procedures.

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