9

Transcranial Doppler Ultrasonography in the Management of Neonatal Hydrocephalus

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1. Introduction

Neonatal hydrocephalus is characterised by an excessive accumulation of cerebrospinal fluid with enlargement of cerebral ventricles, that occurs as a result of disturbance of production, flow or resorption of cerebrospinal fluid.

The pathophysiological changes of progressive neonatal hydrocephalus include: increased intracranial volume of cerebrospinal fluid, progressive dilatation of cerebral ventricles, decreased intracranial compliance, raised intracranial pressure, alteration of cerebral circulation and subsequent secondary brain tissue damage (decreased cerebral blood flow, hypoperfusion, ischaemia), alteration of energy metabolism (tissue acidosis, higher lactate concentration), changes in neurotransmiter systems, damage of white matter, associative tracts and cerebral cortex. The primary target of injury are periventricular axons and myelin. Secondary changes in neurons reflect the compensation to the stress or ultimately the disconnection (De Riggo et al., 2007).

Transcranial color coded Doppler sonography provides a bedside noninvasive and repeatable method of monitoring of the cerebral circulation with good clinical applications. Progressive hydrocephalus leads to the stretching, displacement and compression of cerebral vessels with increased vascular resistance. Doppler parameters reflect good the changes of cerebral circulation. In generall, there is a good corelation between the increase of intracranial pressure and changes in Doppler curve parameters, mainly decreased end-diastolic blood flow velocity and increased resistive index and pulsatility index. The mean cerebral blood flow velocity is mainly determined by diastolic blood flow. In the cases of intracranial hypertension, the arterial blood flow is more affected during diastole than during systole, resulting in an increase of resistive index and pulsatility index. Transcranial Doppler ultrasonography can be used as a noninvasive method for the indirect monitoring of intracranial pressure and dynamics in newborns with hydrocephalus.

2. Transcranial Doppler ultrasonography

The introduction of transcranial Doppler ultrasonography by Aaslid et al., in 1982 offered a noninvasive method for the assessment of cerebral blood flow velocity in the major intracranial arteries (Aaslid et al., 1982). This new method was used also in the examination of children with hydrocephalus. Neonatal Doppler studies date from 1979 (Bada et al., 1979).

2.1 Transcranial color coded Doppler ultrasonography

Transcranial color coded Doppler ultrasonography, first performed by Schoning et al. in 1989, allows direct visualization at basal cerebral arteries and demostrates cerebral blood flow easily because of the color coding (Schoning et al., 1989).

During the examination of newborn by transcranial Doppler ultrasonography is important to comply with precise method of examination. The examiner should not to upset the child. The newborn has to lie calm, the vessel cross-sectional area and the position of sample volume in the vessel should be constant. Also an inadequate rotation of head could decrease the venous outflow and change the real Doppler parameters of cerebral vessels. Color coding enables visualization of the selected segment of cerebral vessels and detection of blood flow direction. The measurement of the blood flow velocity depends upon the angle between the Doppler beam and the longitudinal axis of the vessel. The angle of insonation should be kept as close to zero as posssible. The measurement of Doppler curve parameters is made by the software equipment.

In neonatal transcranial Doppler studies are used following acoustic windows:

-    transfontanellar – through the anterior fontanelle, mainly for the visualization of anterior cerebral artery, internal carotid artery and basilar artery (Fig. 1)
-    transtemporal – through the temporal bone, for the visualization of middle cerebral artery and posterior cerebral artery (Fig. 2)
-    suboccipital – through the foramen magnum, visualization of distal segments of vertebral arteries and basilar artery
-    transorbital and submandibular – are used only occasionally

Fig. 1. Transcranial Doppler ultrasonography – examination of the newborn, transfontanellar acoustic window (photo – authors)

Fig. 2. Transcranial Doppler ultrasonography – examination of the infant, transtemporal acoustic window (photo – authors)

2.2 Doppler curve and parameters

The cerebral circulation is a low-resistive vascular system, which is typicall for organs with the need of constant high minute blood flow. Therefore Doppler curve of cerebral vessels has the positive blood flow during systole and also during diastole (Fig. 3).

Several factors influence the shape and parameters of Doppler curve. The pressure gradient in arteries is produced by myocardial contractility. The systolic peak of Doppler curve is related to the pressure gradient, arterial elasticity and blood viscosity. The shape of diastole is determined mainly by distal vessels resistance, but can be influenced also by systematic arterial, venous and intrathoracic pressure. In the cases of increased peripheral vessels resistance, the diastolic blood flow velocity is decreased. The zero or reverse end-diastolic blood flow is always pathological.

The mainly used Doppler curve parameters are:

- peak systolic blood flow velocity (Vsyst) – the maximal velocity during systole (m/s, cm/s)
- end-diastolic blood flow velocity (Ved) – the blood flow velocity at the end of diastole (m/s, cm/s)
- mean flow velocity (Vmean) – the mean value of blood flow velocity between the begining of systole and the end of diastole.

Analysis of Doppler curve enables the calculation of qualitative Doppler parameters, which are less influenced by the angle of insonation and local turbulent flow in arterial lumen. The mainly used qualitative Doppler curve indices are:
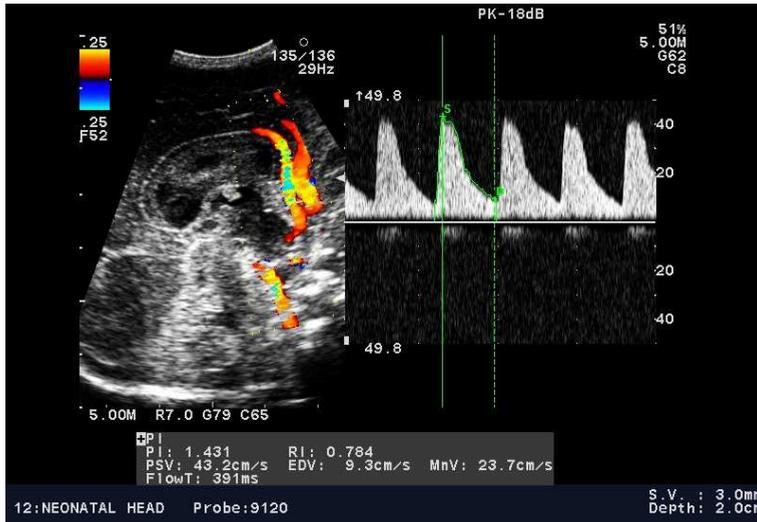
Fig. 3. Doppler curve of pericallosal artery: PI – pulsatility index, RI – resistive index, PSV – peak systolic blood flow velocity, EDV – end-diastolic blod flow velocity, MnV – mean blood flow velocity, FlowT – flow time (figure – authors)

- resistive index (RI, Pourcelot, 1975) – reflects the blood vessel resistance. Is defined as:

$$RI = Vsyst – Ved\ /\ Vsyst$$

- pulsatility index (PI, Gösling et al., 1974) – the value of pulsatility index is higher than resistive index. The assessment of pulsatility index is helpfull in the situation of zero or reverse diastolic blood flow, when the calculation of resistive index or S/D ratio is impossible. Pulsatility index is defined as:

$$PI = Vsyst – Ved\ /\ Vmean$$

- S/D ratio (S/D index, Stuart et al., 1980) – is defined as:

$$S/D = Vsyst\ /\ Ved$$

- trans-systolic time – reflects the time-related changes of the cerebral blood flow velocities (Hanlo et al., 1995a)

The basal Doppler parameters are measured at first. There is only a light contact between sonographic probe and the surface of anterior fontanelle through the layer of gel. Than anterior fontanelle compressive test is performed – the Doppler parameters are measured during the compression of anterior fontanelle using sonographic probe. The compression of anterior fontanelle by means of ophtalmodynamometer allows exact determination of applied pressure (g/cm2). The Doppler parameters could be measured through transtemporal acoustic window (Taylor et al., 1994; Taylor et al., 1996; Westra et al., 1998). If the value of basal resistive index increased more than 25% or the value of compressive resistive index is more than 0,90, the compressive test is considered to be positive (Westra et al., 1998).

2.3 Reference values of Doppler parameters

There were published several studies with the analysis of reference values of Doppler parameters of cerebral vessels in newborns and children (Babikian & Wechsler, 1993; Bode, 1988; Bode & Wais, 1988; Brouwers, 1990; Deeg & Rupprecht, 1989; Hayashi et al., 1992; Horgan et al., 1989; Ozek et al., 1995; Schöning et al.,1996).

The determination of generally accepted normal Doppler parameters of the cerebral circulation have some limitations:

- use of different sonographic technique
- the changes in the quality of sonographic equipment
- sometimes unclear method of examination
- ununiformity of documentation and results presentation.

Therefore the presented data can not be generally used for each institution. In our institution, the reference values of Doppler parameters of selected cerebral vessels were determined by Minarik (2000) using transcranial color coded Doppler ultrasonography: ultrasonographic equipment Aloka Color Doppler SSD-830, probes 3,5 and 5 MHz for B-picture, 2 MHz for CW (continuous wave Doppler) and PW (pulsed wave Doppler). The analysis of Doppler signal was performed using Fourier transformation with the spectrum visualization. The sample volume was 1 mm3 and low frequency filter 100 kHz was used. The adjustment of alliasing and the angle of insonation was performed. The reference values of Doppler parameters of selected cerebral vessels in the first year of life determined by Minarik (2000) are presented in the Table 1, Table 2 and Table 3.

There is a linear corelation between the gestational age and the blood flow velocity of all cerebral arteries during the first 21 days of life. The cerebral blood flow velocity is increased by increasing gestational age. In generally, the preterm newborns have decreased cerebral blood flow velocity and increased value of resistive index (Table 4). The main changes of cerebral blood flow velocity occur during first hours and days after delivery, when the increase of blood flow velocity and decrease of resistive index is most rapid. The prematurity and low birth weight is associated with the changes of end-diastolic blood flow velocity (Minarik, 2000).

	1. month	1. month	3. month	3. month	6. month	6. month	12. month	12. month
	A1	A3	A1	A3	A1	A3	A1	A3
Vsyst (cm/s)	67-82	56-69	74-87	64-77	81-90	68-85	95-104	87-96
Ved (cm/s)	19-28	18-27	21-34	20-31	26-34	25-33	25-44	33-40
Vmean (cm/s)	36-46	29-42	36-54	30-50	46-58	38-54	57-67	51-63
RI	0,65-0,73	0,60-0,69	0,59-0,71	0,59-0,69	0,62-0,68	0,58-0,65	0,57-0,63	0,58-0,62

Table 1. The reference values of Doppler parameters of A1 and A3 segment of anterior cerebral artery during the first year of life (Minarik, 2000). Published with author´s permission.

	1. month	1. month	3. month	3. month	6. month	6. month	12. month	12. month
	M1	M3	M1	M3	M1	M3	M1	M3
Vsyst (cm/s)	75-86	65-80	80-90	70-79	91-100	83-92	104-115	95-106
Ved (cm/s)	20-30	19-28	24-35	22-32	32-40	28-36	41-49	36-45
Vmean (cm/s)	39-51	35-49	46-60	41-55	56-68	51-65	64-80	61-74
RI	0,65-0,74	0,63-0,73	0,61-0,70	0,60-0,70	0,60-0,65	0,59-0,66	0,55-0,61	0,56-0,62

Table 2. The reference values of Doppler parameters of M1 and M3 segment of right middle cerebral artery during the first year of life (Minarik, 2000). Published with author´s permission.

	1. month	1. month	3. month	3. month	6. month	6. month	12. month	12. month
	M1	M3	M1	M3	M1	M3	M1	M3
Vsyst (cm/s)	75-85	64-79	80-90	70-82	91-99	81-90	103-112	96-106
Ved (cm/s)	20-29	19-28	23-34	22-30	32-40	29-37	41-48	38-45
Vmean (cm/s)	39-51	35-49	48-62	40-56	57-68	50-66	64-80	57-72
RI	0,65-0,73	0,62-0,71	0,63-0,68	0,60-0,68	0,59-0,65	0,56-0,68	0,56-0,61	0,57-0,64

Table 3. The reference values of Doppler parameters of M1 and M3 segment of left middle cerebral artery during the first year of life (Minarik, 2000). Published with author´s permission.

< 33. gestational week	0,77 ± 0,09
> 34. gestational week	0,70 ± 0,07

Table 4. The reference values of resistive index of Doppler curve in the vertical segment of pericallosal artery before the genu corporis callosi in preterm newborns (Bode, 1988; Chadduck & Seibert, 1989; Westra et al., 1998) (table – authors)

2.4 Factors that influence Doppler parameters of cerebral circulation

The values of Doppler parameters are influenced by several factors that change mainly diastolic, but also systolic part of Doppler curve. The significant fluctuation of qualitative indices during the examination is the sign of alteration of cerebral autoregulation.

The crying and restlessness of newborn, unequale and unadequate compression of anterior fontanelle by the sonographic probe, influence the Doppler parameters of cerebral circulation (Hadač, 2000).

Interindividual changes – the method of examination and technical parameters of sonographic equipment have to be taken in the consideration. When the conclusion of

sonographic examination is not unambiguous, it is better to assess the dynamic intraindividual trends (Myers et al., 1987).

The studies of several authors showed the influence of physical and mental activity on the cerebral blood flow (Diehl et al., 1998; Roberts & McKinney, 1998; Owega et al., 1998). There is a significant increase of systolic, diastolic and mean blood flow velocity in proximal and distal segments of cerebral vessels during the period of increased mental activity of child. The value od resistive index is not significantly changed (Minarik, 2000).

The manipulation and suction from orotracheal tube can influence the cerebral blood flow velocity (Perlman & Vople, 1983). The cerebral circulation is affected also by bradycardia and apnoic pauses (Perlman & Volpe, 1985).

The review of extracranial and intracranial factors that influence Doppler parameters of the cerebral circulation is presented in Table 5.

2.4.1 Pathologic conditions with increased resistive index

- hypocapnia – decreased value of $paCO_2$ leads to the vasoconstriction of cerebral arteries with subsequently decreased cerebral blood flow. The loss of CO_2 vasoreactivity corelates with the severity and prognosis of clinical status of infant (Klingelheofer & Sander, 1992; Miller et al., 1992). The decrease of $paCO_2$ leads to the decrease of end-diastolic blood flow velocity and increase of resistive index. Sometimes the end-diastolic blood flow velocity can be zero. During the extreme decrease of $paCO_2$, also the decrease of systolic blood flow velocity occurs (Macko et al., 1993; Menke et al., 1993; Vergesslich et al., 1989; Wyatt et al., 1991).

- hyperoxia – increased value of paO_2 leads to mild cerebral vasoconstriction and decreased cerebral blood flow. The paO_2 cerebral vasoreactivity is more uniform than $paCO_2$ vasoreactivity.

- acute intracranial hypertension – in brain injury, cerebral oedema or active hydrocephalus negatively affects the cerebral blood flow. End-diastolic blood flow velocity is decreased and resistive index increased. The systolic blood flow velocity is changed in relationship to the systemic arterial blood pressure adaptation response. Blood flow during the diastole is affected first. When the value of intracranial pressure is the same than diastolic blood pressure, the end-diastolic block occurs (Barzo et al., 1991; Czernicki, 1992; Hanlo et al., 1995b; Kopniczky et al., 1995).

- intraventricular haemorrhage – in the brain tissue near intracerebral or intraventricular haemorrhage is resistive index increased because of cerebral vasoconstriction. In the cases of severe intraventricular haemorrhage, the vasoconstriction could occur also in all main cerebral arteries (Bada et al., 1979).

- brain infarction – typically there is no detectable blood flow in the occluded segment of cerebral artery, in proximal part of the artery is detected decreased end-diastolic blood flow velocity and increased resistive index (Babikian & Wechsler, 1993).

- congenital heart disease with left-right shunt – for example persistent arterial duct or truncus arteriosus, affects cerebral blood flow. Typically, the persistent arterial duct leads to

the decrease or reverse diastolic blood flow with increased resistive index. The extent of the cerebrovascular changes is related to the hemodynamic severity of left-right cardiac shunt (Bissonnette & Benson, 1998; Wright, 1988). When the compensation mechanisms are sufficient, there is no decrease of cerebral blood flow under the ischaemic border. In the case of the combination with another pathological findings, the status of achieved hemodynamic equilibrium could be lost with the potential ischaemic damage of brain tissue (Shortland et al., 1990).

- blood hyperviscosity – polyglobulia is associated with the decrease of absolute values of cerebral blood flow velocity, the value of resistive index is increased only slightly. The vascular changes are seen in proximal and distal segments of cerebral arteries. The changes of haematocrit, blood viscosity and rheological properties of blood lead to the alteration of Doppler parameters.

- indomethacin – the administration of indomethacin leads to the cerebral vasoconstriction with the increase of resistive index. Inadequate use of indomethacin can cause ischaemic damage of brain tissue (Lundel et al., 1986).

- critically ill newborns – in severe arterial hypotension with decreased cardiac output the diastolic blood flow is more affected than systolic blood flow and therefore resistive index of cerebral vessels is increased.

- brain death – the Doppler curve demonstrates diastolic block or reverse diastolic blood flow at cerebral arteries.

2.4.2 Pathologic conditions with decreased resistive index

- hypercapnia – leads to the vasodilatation of cerebral vessels and increased cerebral blood flow. End-diastolic blood flow velocity is increased and resistive index is decreased. When the value of $paCO_2$ is more increased, also the systolic blood flow velocity increases (Fisher & Truemper, 1993; Menke et al., 1993).

- hypoxemia, hypoxia – decrease of paO_2 causes the cerebral vasodilatation (Ausina et al., 1998; Curz et al., 1998; Dings et al., 1996).

- seizures – increased brain metabolism leads to the cerebral vasodilatation

- inflammation – inflammatory brain congestion and the cerebral vasodilatation cause decrease of resistive index.

- asphyxia – hypercapnia, hypoxia, tissue hypoperfusion and acidosis have negative influence on the cerebral circulation. The alteration of cerebral autoregulation is presented. The Doppler curve parameters changes include decrease of resistive index and increase of end-diastolic blood flow velocity.

- idiopathic respiratory distress syndrom – the combination of hypoxia, hypercapnia and arterial hypotension decreases the resistance of cerebral arteries, resistive index is decreased

- increased cardiac output, hypervolemia

- increased central venous pressure – for example pnemothorax and right sided cardiac failure can decrease resistive index of cerebral arteries

- cerebral arteriovenous malformation – the cerebral blood flow is ussualy bidirected with increased end-diastolic blood flow velocity and decreased resistive index.

	EXTRACRANIAL FACTORS	INTRACRANIAL FACTORS
INCREASED RESISTIVE INDEX	hypocapnia, hyperoxia, congenital heart disease with left-right shunt (persistent arterial duct, truncus arteriosus), blood hyperviscosity, increased hematocrit, polyglobulia, indomethacin, severe arterial hypotension, decreased cardiac output, brain death	acute intracranial hypertension (brain injury, cerebral oedema, active hydrocephalus), brain infarction, intraventricular and intracerebral haemorrhage
DECREASED RESISTIVE INDEX	hypercapnia, hypoxemia, hypoxia, seizures, asphyxia, idiopathic respiratory distress syndrom, increased cardiac output, hypervolemia, increased central venous pressure (pnemothorax , right sided cardiac failure)	inflammatory brain tissue congestion, cerebral arteriovenous malformation, seizures

Table 5. Extracranial and intracranial factors that influence Doppler parameters of the cerebral circulation (table – authors)

3. The assessment of cerebral circulation by means of transcranial Doppler ultrasonography in neonatal hydrocephalus

The analysis of Doppler parameters of the cerebral circulation in neonatal and pediatric hydrocephalus remains still disputable. In recent years, the main interest is focused on the monitoring of intracranial biomechanics, analysis of pressure-volume relationship, intracranial compliance, intracranial pressure and changes of cerebral circulation in hydrocephalus. The knowledge and clinical application of pathophysiological mechanisms of hydrocephalus is the base for the improvement of treatment of newborns and children with hydrocephalus.

In generally, there is a good corelation between resistive index, pulsatility index of cerebral vessels and intracranial pressure. The population of newborns is heterogenous. Because of different gestational age and biomechanical properties of head the analysis of relationship between resistive index and intracranial pressure in different subgroups is needed. Imporant is the fact, that during the progression of hydrocephalus occur not only the enlargement of cerebral ventricles and increase of intracranial pressure, but also the main cerebral arteries are stretched, compressed or distorsed (Finn et al., 1990).

The relationship between intracranial pressure and Doppler parameters of cerebral arteries is of a complex nature. Many extracranial and intracranial factors may influence the cerebral blood flow.

The relationship between increased resistive index and increased intracranial pressure in preterm infants with posthaemorrhagic hydrocephalus was first described by Bada et al. (Bada et al., 1982).

The changes of resistive index of anterior cerebral artery in newborns with hydrocephalus was assessed by Hill & Volpe (1982). In 9 from 11 cases with raised intracranial pressure, the dilatation of cerebral ventricles was presented. In all cases the resistive index was increased. The significant decrease of resistive index after the successful drainage procedure was detected.

The study of Fisher & Livingstone (1989) showed increased pulsatility index, significantly decreased end-diastolic blood flow velocity and slight decrease of peak systolic blood flow velocity in anterior cerebral circulation (anterior cerebral artery, middle cerebral artery, internal carotid artery) in pediatric hydrocephalus. The values of Doppler parameters after the drainage procedure with functional internal drainage system were normal. The dilatation of cerebral ventricles (except the width of third ventricle) persisted also after the drainage procedure. There was found no corelation between the size of cerebral ventricles and peak systolic blood flow velocity. The relationship between end-diastolic blood flow velocity and the size of cerebral ventricles was intraindividual. Pulsatility index showed the highest level of corelation with the size of cerebral ventricles. The width of third ventricle seems to be the most sensitive morphological parameter of intracranial volume changes. Anterior cerebral artery and middle cerebral artery are the most sensitive cerebral vessels to the intracranial dynamics (Aaslid, 1984; Fisher & Livingstone, 1989). Also the studies of another authors confirmed the significant increase of pulsatility index of cerebral vessels before the drainage operation and significant decrease of pulsatility index after the drainage procedure (Jindal & Mahapatra, 1998; Nadvi et al., 1994).

Nishimaki et al. (1990) were interested in the changes of resistive index of anterior cerebral artery and basilar artery in children with hydrocephalus. There was increased resistive index of both arteries before the drainage procedure. The successful drainage operation led to the significant decrease of resistive index of anterior cerebral artery and basilar artery. The decrease of resistive index of anterior cerebral artery was significantly higher than decrease of resistive index of basilar artery. Normal values of resistive index of anterior cerebral artery in children are lower than the values of resistive index of basilar artery. The difference between the haemodynamic changes of anterior cerebral artery and basilar artery can be caused by the anatomical localisation of vessels. The anterior cerebral artery has close relationship to the lateral cerebral ventricles and third ventricle, basilar artery is localised in pontine cistern. In most cases of pediatric hydrocephalus, the progressive dilatation of lateral cerebral ventricles and third ventricle is greater than the dilatation of fourth ventricle. Therefore authors suggest, that the enlargement of cerebral ventricles in hydrocephalus affects more haemodynamic parameters of the anterior cerebral artery than basilar artery.

Quinn & Pople (1992) in their study confirmed increased pulsatility index in the cases of malfunction of ventriculoperitoneal shunt in children with hydrocephalus. After revision surgery the pulsatility index decreased. The change of the dilatation of cerebral ventricles

was detected only in 10 from 32 patients with malfunction of ventriculoperitoneal shunt. In spite of stable dilatation of cerebral ventricles, there were presented clinical signs of intracranial hypertension and an increase of pulsatility index before the revision surgery.

Goh et al. (1991) studied the corelation between resistive index of cerebral arteries and intracranial pressure in newborns and children with hydrocephalus. There was found good intraindividual corelation between the resistive index and intracranial pressure in newborns, whereas in older children the corelation between resistive index and intracranial pressure was good in generally. The differences between age groups are probably caused by highly individual volume-pressure compensation mechanisms in newborns in different stages of hydrocephalus and different compliance of neonatal head (biomechanical and fibroelastic properties of bones, sutures and soft tissue of head). The intracranial dynamics in older children is more uniform, therefore the corelation of resistive index of cerebral arteries and intracranial pressure is generally good. There was found significant decrease of resistive index and increase of end-diastolic blood flow velocity after the drainage procedure in all age groups, but only in newborns was detected moderate increase of peak systolic blood flow velocity and mean blood flow velocity. The same haemodynamic Doppler changes of cerebral vessels were found in the cases of shunt malfunction and after the successful revision surgery.

Goh et al. (1995) in their study confirmed, that there was no increase of resistive index of cerebral vessels in newborns with hydrocephalus in the cases of stable dilatation of cerebral ventricles. The results of the study suggest, that the increase of resistive index of cerebral arteries is caused by raised intracranial pressure and not by enlargement of cerebral ventricles alone.

In spite of detection of increased values of resistive index of cerebral vessels there was found also altered CO_2 cerebral vasoreactivity in children with hydrocephalus with the need of drainage procedure. After the insertion of shunt or revision surgery for shunt malfunction, the improvement of CO_2 cerebral vasoreactivity was confirmed (De Oliveira & Machado, 2003).

Vajda et al. (1999) found the significant decrease of pulsatility index of middle cerebral artery in children with obstructive hydrocephalus after successful endoscopic third ventriculostomy in relationship to the preoperative value. The function of ventriculostomy was confirmed by the detection of cerebrospinal fluid flow by means of magnetic resonance imaging. The clinical symptomatology improved in 17 from 22 patients. There was found no corelation between the pulsatility index and the age and sex of children. The results of this study show the role of transcranial Doppler sonography in the indirect assessment of the function of endoscopic third ventriculostomy in the early postoperative period.

Cosan et al. (2000) analysed the haemodynamic changes of cerebral circulation in neonatal rats with progressive communicating hydrocephalus by means of transcranial Doppler ultrasonography. There was confirmed, than in the acute phase of hydrocephalus, the dilatation of cerebral ventricles was not accompanied by the alteration of Doppler parameters of cerebral vessels (the value of pulsatility index was normal). During the progression of communicating hydrocephalus an increase of the size of cerebral ventricles and an increase of pulsatility index occured. The enlargement of cerebral ventricles alone in the initial phase of communicating neonatal hydrocephalus did not lead to the changes of

pulsatility index of cerebral vessels. The alteration of Doppler parameters of cerebral vessels (increased pulsatility index, decreased end-diastolic blood flow velocity) occured in the phase of progression with increased intracranial pressure. In this phase, the cerebral circulation is more affected by increased intracranial pressure than by the dilatation of cerebral ventricles. The raised intracranial pressure leads to the compression of brain capillaries and increase of vascular resistance of cerebral arteries with increased pulsatility index (Cosan et al., 2000; Seibert et al., 1989). In the chronic phase of hydrocephalus, the enlargement of cerebral ventricles and haemodynamic changes of cerebral circulation are accompanied by several pathologic changes (Del Bigio, 1993).

Taylor et al. (1994) analysed the anterior fontanelle compressive test as a part of the examination of newborns with altered intracranial compliance by means of transcranial Doppler sonography. Basal and compressive values of resistive index of middle cerebral artery were measured. The basal resistive index in the preterm newborns and term newborns with altered intracranial compliance was significantly higher than in healthy term newborns. There was only a minimal change of basal resistive index during the anterior compressive test in healthy preterm and term newborns. In newborns with altered intracranial compliance, the value of resistive index during the compressive test was increased. In newborns with hydrocephalus with increased intracranial pressure, increased values of basal resistive index were detected. After the drainage procedure, the haemodynamic response on anterior fontanelle compression was improved.

In another study Taylor et al. (1996) assessed the haemodynamic response of anterior cerebral artery on anterior fontanelle compression in newborns with hydrocephalus. The results suggest, that the significant increase of resistive index was found in newborns with increased intracranial pressure with the need of drainage procedure.

Also the study of another authors confirmed increased basal and compressive values of resistive index of anterior cerebral artery in children with hydrocephalus in the cases of increased intracranial pressure. After the successful drainage procedure, the significant decrease of basal and compressive values of resistive index was found. The borderline value of basal resistive index of anterior cerebral artery was defined as 0,70, for positive anterior compressive test as 0,90 or increase of basal resistive index more than 25% (Westra et al., 1998).

Gera et al. (2002) were interested in the assessment of Doppler parameters of anterior cerebral artery in newborns and children with hydrocephalus in relationship to the need of drainage procedure. There was found a significant increase of basal and compressive resistive index in patients with the need of drainage operation. After the drainage procedure, the significant decrease of basal and compressive resistive index was detected. The results of the study suggest significant increase of intracranial compliance after the drainage procedure. There was no significant change of head circumference after surgery. The importance of the assessment of resistive index of anterior cerebral artery in newborns and children with hydrocephalus in relationship to the need of drainage procedure was defined: basal resistive index – sensitivity 72,5%, specificity 80%, diagnostic accuracy 75%, false negativity 25%, compressive resistive index – sensitivity 75%, specificity 100%, diagnostic accuracy 83,3%, false negativity 25%.

The asessment of Doppler parameters of cerebral vessels in premature newborns with hydrocephalus is still disputable. The results of published studies are sometimes different

and incoherent. The reason for this discrepancy can be the use of different type of sonographic equipment, method of sonographic examination, heterogenity of the group of premature newborns (gestational age, weight, extracranial factors, medication, number of patients) and different indication for drainage procedure.

Perlman & Volpe (1982) analysed the Doppler parameters of anterior cerebral artery in 32 premature newborns with intraventricular haemorrhage. The gestational age of premature newborns was in the range from 26 to 34 weeks. There was found no corelation between intraventricular haemorrhage and resistive index of anterior cerebral artery. In 29 cases, the intraventricular haemorrhage was not accompanied by the decrease of cerebral blood flow velocity. There was no corelation betwen the time of the onset of intraventricular haemorrhage and the value of resistive index. In 9 cases with pneumothorax, the significant decrease of resistive index was detected. Another authors described increased value of resistive index (more than 0,90) of cerebral arteries in premature newborns with intraventricular haemorrhage.

Van Bel et al. (1988) analysed the Doppler parameters of anterior cerebral artery in 10 premature newborns with posthaemorrhagic hydrocephalus. There was found a significantly increased pulsatility index and peak systolic blood flow velocity before the drainage procedure. After the drainage procedure, a significant decrease of pulsatility index and peak systolic blood flow velocity was detected. The values of postoperative pulsatility index were normal. There were found no significant changes of end-diastolic blood flow velocity and mean blood flow velocity before and after the drainage procedure. The increase of pulsatility index before the surgery was caused by an increase of peak systolic blood flow velocity. The reason for the earliest indication of drainage procedure was the reduction of the damage of cerebral circulation. The indication criterion included the progressive dilatation of cerebral ventricles with increased size more than 97th percentil. The same results were published by Alvisi et al. (1985). Authors suggest, that the increase of peak systolic blood flow velocity before the drainage procedure is caused by the dislocation and compression of anterior cerebral artery by enlarged cerebral ventricles. The transport of cerebrospinal fluid into the white matter also causes the loss of transmural pressure gradient (Alvisi et al., 1985; Weller & Shulman, 1972; Wozniak et al., 1975).

The frequency and timing of intermitent drainage of cerebrospinal fluid in newborns with posthaemorrhagic hydrocephalus is still the topic of discussion. One of the aims of intermitent drainage of cerebrospinal fluid is the prevention of negative influence of raised intracranial pressure on cerebral circulation.

Kempley & Gamsu (1993) assessed the changes of intracranial pressure and Doppler parameters of anterior cerebral artery in the group of 6 newborns with posthaemorrhagic hydrocephalus before and after the drainage of cerebrospinal fluid (23 drainage procedures). There was found significant decrease of intracranial pressure after the derivation of cerebrospinal fluid. The decrease of intracranial pressure was accompanied by an increase of mean blood flow velocity and decrease of pulsatility index. The results of the study suggest, that the derivation of cerebrospinal fluid in newborns with posthaemorrhagic hydrocephalus leads to the significant improvement of haemodynamic parameters of cerebral circulation. Authors recommend, that the alteration of Doppler parameters of cerebral vessels should be taken in the consideration in the indication and timing of drainage procedure in newborns with posthaemorrhagic hydrocephalus.

Also the results of the study by Nishimaki et al. (2004) confirmed an increase of resistive index of anterior cerebral artery before the drainage procedure in newborns with posthaemorrhagic hydrocephalus. The drainage procedure, lumbar punction or punction of subcutaneous reservoir, with the aspiration of cerebrospinal fluid (5-10 ml/kg) led to the significant decrease of resistive index.

Maertzdorf et al. (2002) analysed the Doppler parameters of anterior cerebral artery and middle cerebral artery in premature newborns with posthaemorrhagic hydrocephalus. The authors performed repeated aspiration of cerebrospinal fluid from the subcutaneous reservoir. The increased resistive index and decreased end-diastolic blood flow velocity was confirmed in the cases of increased intracranial pressure (≥ 6cm H2O) before the aspiration of cerebrospinal fluid. After the derivation of cerebrospinal fluid with a decrease of intracranial pressure (≤ 6cm H2O), a significant increase of end-diastolic blood flow velocity and decrease of resistive index was found. There was no significant change of peak systolic blood flow velocity after the drainage procedure. The results of the study suggest a good intraindividual corelation between the resistive index of anterior cerebral artery and middle cerebral artery and intracranial pressure in premature newborns with posthaemorrhagic hydrocephalus.

The qualitative indices of Doppler waveform (resistive index, pulsatility index) have certain disadvantages. Both indices are influenced by the heart rate and have a broad range of reference values, especially in children. Hanlo et al. (1995a) presented a hydrodynamic model, which showed the effects of raised intracranial pressure on the cerebral circulation. The authors defined a new Doppler index, the trans-systolic time, reflecting specific changes in the Doppler waveform induced by changes in the intracranial pressure.

Leliefeld et al. (2009) analysed the relationship between the trans-systolic time of Doppler waveform of middle cerebral artery and intracranial pressure in infants with hydrocephalus.

There was found significant decrease of the intracranial pressure after the drainage procedure (p<0.005), accompanied by the significant increase of trans-systolic time (p<0.005), significant decrease of pulsatility index (p<0.05) and significant decrease of resistive index (p<0.05). Trans-systolic time has a strong correlation with the intracranial pressure (p<0.005). Trans-systolic time reflects the relative changes in the cerebral blood flow velocity caused by intracranial dynamics changes. The results of the study suggest, that the trans-systolic time has a closer relation to intracranial pressure than the pulsatility index and the resistive index.

The changes of Doppler parameters of pericallosal artery before and after the drainage procedure in preterm newborn with posthaemorrhagic hydrocephalus are shown in Figures 4-7.

Transcranial Doppler ultrasonography plays an important role in the management of newborn with hydrocephalus. Is widely used because of it´s noninvasivity, repeatability and the possibility of bedside examination. The clinical applications of transcranial Doppler ultrasonography in the management of neonatal hydrocephalus include:

-    the indication and timing of drainage procedure
-    monitoring of the efficacy of the drainage procedure – shunts, external ventricular drainage, derivation of cerebrospinal fluid from subcutaneous reservoir in
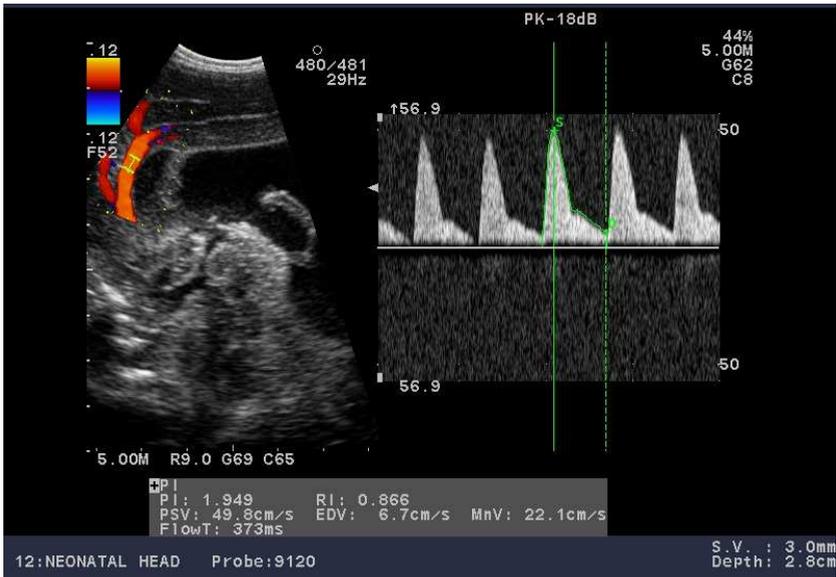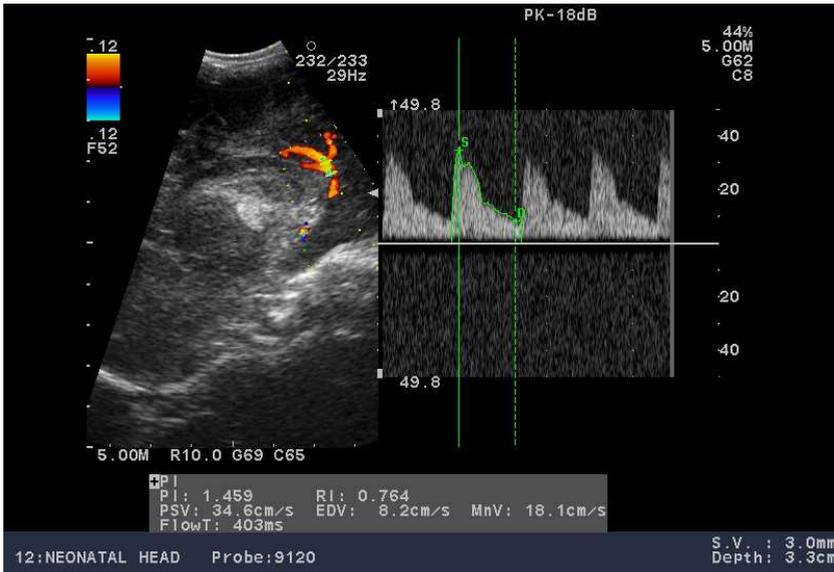
Fig. 4. Basal Doppler parameters of pericallosal artery in preterm newborn with posthaemorrhagic hydrocephalus before the drainage procedure: decreased end-diastolic blood flow velocity, increased resistive index, increased pulsatility index (figure – authors)
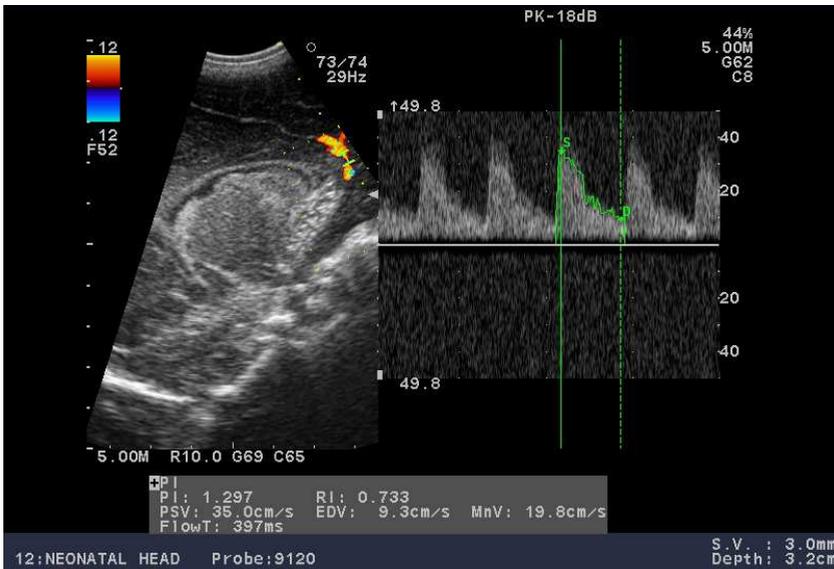

Fig. 5. Positive anterior fontanelle compressive test, compressive Doppler parameters of pericallosal artery in preterm newborn with posthaemorrhagic hydrocephalus before the drainage procedure -reverse end-diastolic blood flow (figure – authors)

Fig. 6. Basal Doppler parameters of pericallosal artery in preterm newborn with posthaemorrhagic hydrocephalus after the drainage procedure: increased end-diastolic blood flow velocity, decreased resistive index, decreased pulsatility index (figure – authors)

Fig. 7. Negative anterior fontanelle compressive test, compressive Doppler parameters of pericallosal artery in preterm newborn with posthaemorrhagic hydrocephalus after the drainage procedure (figure – authors)

posthaemorrhagic hydrocephalus (frequency and the volume of derivated cerebrospinal fluid), endoscopic third ventriculostomy
- monitoring of the function and the detection of malfunction of internal (shunts) and external drainage systems (external ventricular drainage) and endoscopic third ventriculostomy
- detection of shunt-dependency of newborn with hydrocephalus – the change of external ventricular drainage or subcutaneous reservoir to the shunt, the need of revision surgery of the shunt with malfunction

4. Conclusion

Increased intracranial pressure in progressive neonatal hydrocephalus leads to the alteration of cerebral circulation (decreased cerebral blood flow, hypoperfusion and ischaemia). Transcranial color coded Doppler sonography provides a noninvasive method of monitoring of the blood flow velocities in cerebral vessels. In generall, there is a good corelation between the increase of intracranial pressure and changes in Doppler curve parameters. Before the drainage procedure there was confirmed increased basal and compressive values of resistive index and pulsatility index of cerebral arteries. After the successful drainage procedure, the significant decrease of basal and compressive values of resistive index and pulsatility index was found.

The published studies and clinical experiences confirm, that transcranial Doppler ultrasonography can be routinely used as a noninvasive method for the monitoring of cerebral circulation, indirect monitoring of intracranial pressure and compliance with good clinical applications in the indication of drainage procedure or the monitoring of the function of drainage systems and endoscopic third ventriculostomy in newborns with hydrocephalus.

5. Acknowledgment

6. References

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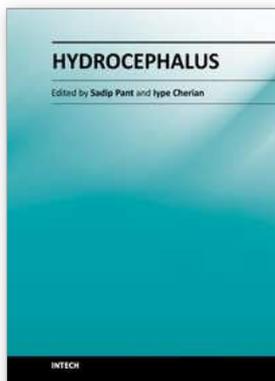
Hydrocephalus

Edited by Dr Sadip Pant

Description of hydrocephalus can be found in ancient medical literature from Egypt as old as 500 AD. Hydrocephalus is characterized by abnormal accumulation of cerebrospinal fluid (CSF) in the ventricles of the brain. This results in the rise of intracranial pressure inside the skull causing progressive increase in the size of the head, seizure, tunneling of vision, and mental disability. The clinical presentation of hydrocephalus varies with age of onset and chronicity of the underlying disease process. Acute dilatation of the ventricular system manifests with features of raised intracranial pressure while chronic dilatation has a more insidious onset presenting as Adams triad. Treatment is generally surgical by creating various types of cerebral shunts. Role of endoscopic has emerged lately in the management of hydrocephalus.

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