Acta Paediatrica Hungarica, 26 (1), pp. 15—29 (1985)

Intracranial sonography in infancy

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Neonates and older infants were subjected to sonography through the anterior fontanelle with grey-scale compound scanner. The patients were referred to us from neurosurgery or showed clinical symptoms of perinatal CNS damage (ventricular or intracerebral haemorrhage, subdural effusion, etc.) or malformations (meningomyelocele, encephalocele, cystic brain, cerebral dysgenesis, etc.).

Sonography is the simplest non-invasive diagnostic method to exclude suspected hydrocephalus in cases of macrocephalus, or when the head of premature infants grows more rapidly than the rest of the body. When screening showed alterations, sonography was performed weekly or fortnightly according to the extent of deviation from the normal. In cases of progressive hydrocephalus, when shunt surgery was indicated, ultrasound was used to monitor the operation of the shunt. In early age, ultrasound is a tool equal in value to CT, but is far less expensive and the examination can safely be repeated at any time.

During the 24 years of its existence, ulrasound examination has developed into one of the most important tools of preventive medicine. Before that the intracranial cavity could only be examined by invasive procedures such as pneumo-encephalography or iodine ventriculography. CT scanning is a method with comparatively low radiation dosage but the exposure to radiation limits its serial repetition.

The ultrasound technique is a non-invasive diagnostic procedure which is completely harmless, painless and which can be repeated at will. In neonates and infants it gives reliable information on the cerebral ventricles until the anterior fontanelle remains large enough i.e. until the 8—10 postnatal month.

Initially, ultrasound as an examination technique was applied principally for echo-encephalography. This was based on the A-echo technique but this required extensive experience and there was a large margin of error [18].

Two-dimensional ultrasound examinations were first used extensively in obstetrics to visualize the fetal skull. This then gave rise to the idea of trying to examine the intracranial region. The possibility of examining the cerebral ventricles and brain structures of neonates and young infants through the anterior fontanelle seemed self-evident [2, 3, 4, 13, 16].

Through this acoustic window it was generally possible to get a look into the intracranial cavity until the fontanelle was open. At the beginning, the size of the transducers limited accurate depiction. Depending on the angle of penetration (60—120°) the mechanical real-time heads generally gave a suitable picture in the plane in question.

Of the two ways used for visualizing the intracranial structures, the one which spread more rapidly in the beginning was the real-time technique and this was then followed by the advanced grey scale method. The latter gave structural distinctions using the black and white colour scale, thus creating two-dimensional pictures. A cross-sectional picture with far more detail is obtained from the multifocal compound scanning method which also gives gross morphological cross-sectional depiction [3, 4, 8, 16].

There is no real difference in quality between real-time and compound scanning installations with up-to-date digital ancilliaries but the linear arrays depict only part of the important regions [10]. The breakdown of detail on modern digital real-time scanners coincides with that of compound scanning. With computer-aided link-up of several transducer heads it is possible to examine the intracranial cavity of children older than two years but since the skull bone refracts the majority of acoustic energy, the pictures contain less detail even with use of a water bag [5, 6].

Intraoperative real-time ultrasonic sector scanning was performed through the unincised dura mater of the intact brain surface during craniotomy, to define the location, configuration and consistency of the tumour mass [12, 15, 16].

As far as the cerebral ventricles and cerebral structures are concerned, the accuracy of echotomographic examination shows a good coincidence with the results of CT examination [3, 6, 7, 8].

Method

A Brüel—Kjaer type 3402 real-time sector scanner was used for screening and a Brüel—Kjaer type 3401 one for compound scanning. The nominal frequency of the transducer heads was 4 and 5 MHz and the transducer diameters were 12 and 5 mm, respectively. (These are short-focussed transducers). The sole requirement of the examination is the presence of an open anterior fontanelle of at least 1 cm^2 area. No sedation was required. A restless infant could always be placated by feeding during the examination. Satisfactory temperature conditions were provided for premature and small-for-dates infants. Average examination time was ten to fifteen minutes, the maximum was twenty minutes. For documentation a video-recorder or photography was used.

Planes of Section and Normal Anatomy

Ready given specific planes of section should be used to standardize documentation and facilitate repetition. We used serial frontal and sagittal planes (Figs 1 and 2).

Clinical indications for intracranial examination

Premature Babies

Low birth weight premature infants require special attention since intracranial haemorrhage is more frequent among them than in full-term infants.

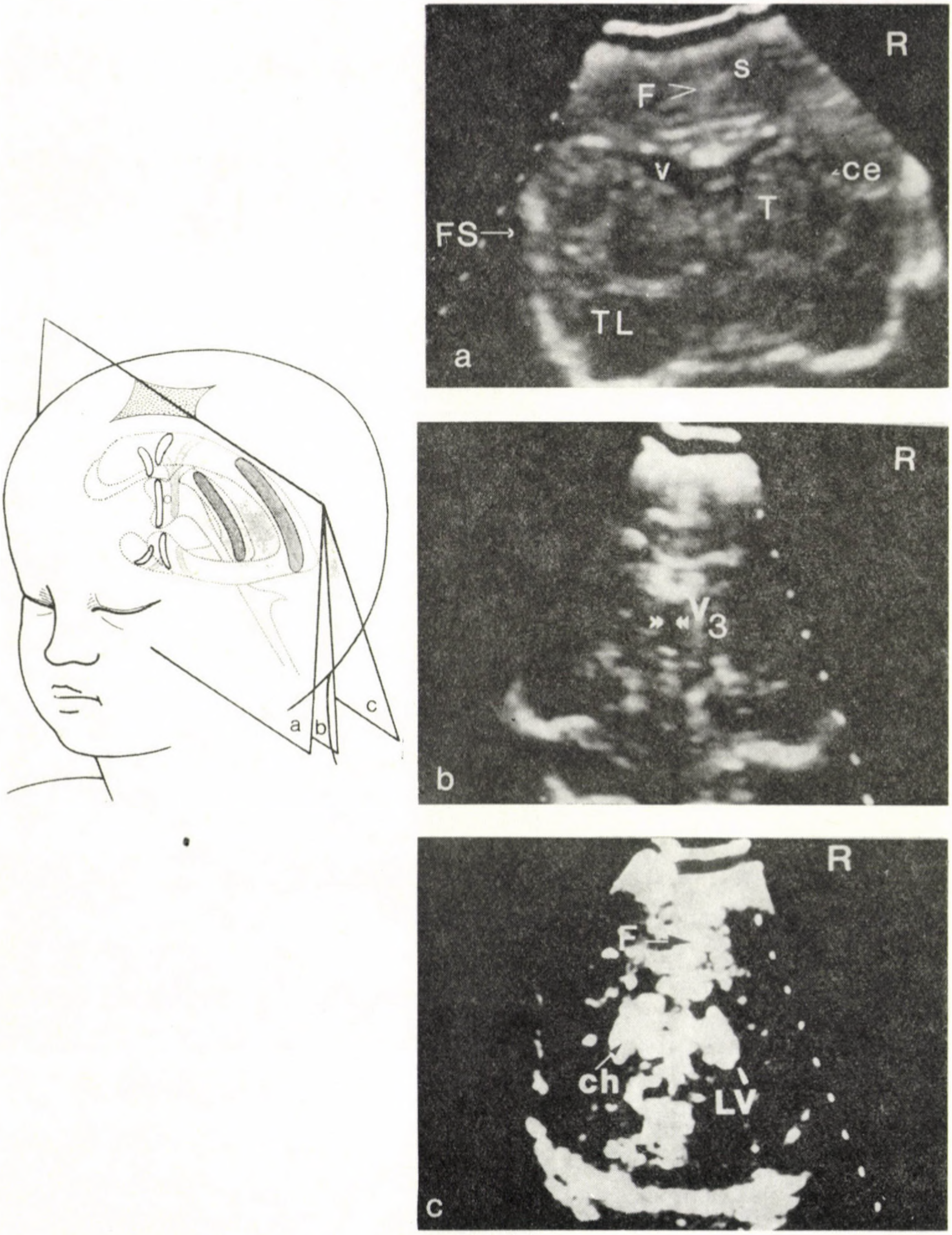

FIG 1. A: Standard frontal planes. — Scheme and pictures: a) The frontal section is the plane of the coronal suture (the plane of the sutura coronaria toward the base following the line of the external auditory canal) showing normal lateral ventricles (V) of echo-free, butterfly-shaped form; the anterior longitudinal cerebral fissure with the echogenic dura; the falx cerebri (F); the cingulate sulcus (s), the thalamic area (T), the Silvian fissure (FS), the external capsule (ce), and the temporal lobe (TL). R: right side. b) The second frontal plane aimed backwards and downwards from the coronary suture. The third ventricle usually gives a narrow echo-free zone (V3). c) The third frontal section where the plane is even further backwards and downwards, behind the foramen occipitale magnum. It shows the posterior areas of the lateral ventricles, the transition of the temporal horns and the choroid plexus in homogeneous, echogenic symmetric form (ch), surrounding a narrow echo-free space, i.e. the lateral ventricle (LV)

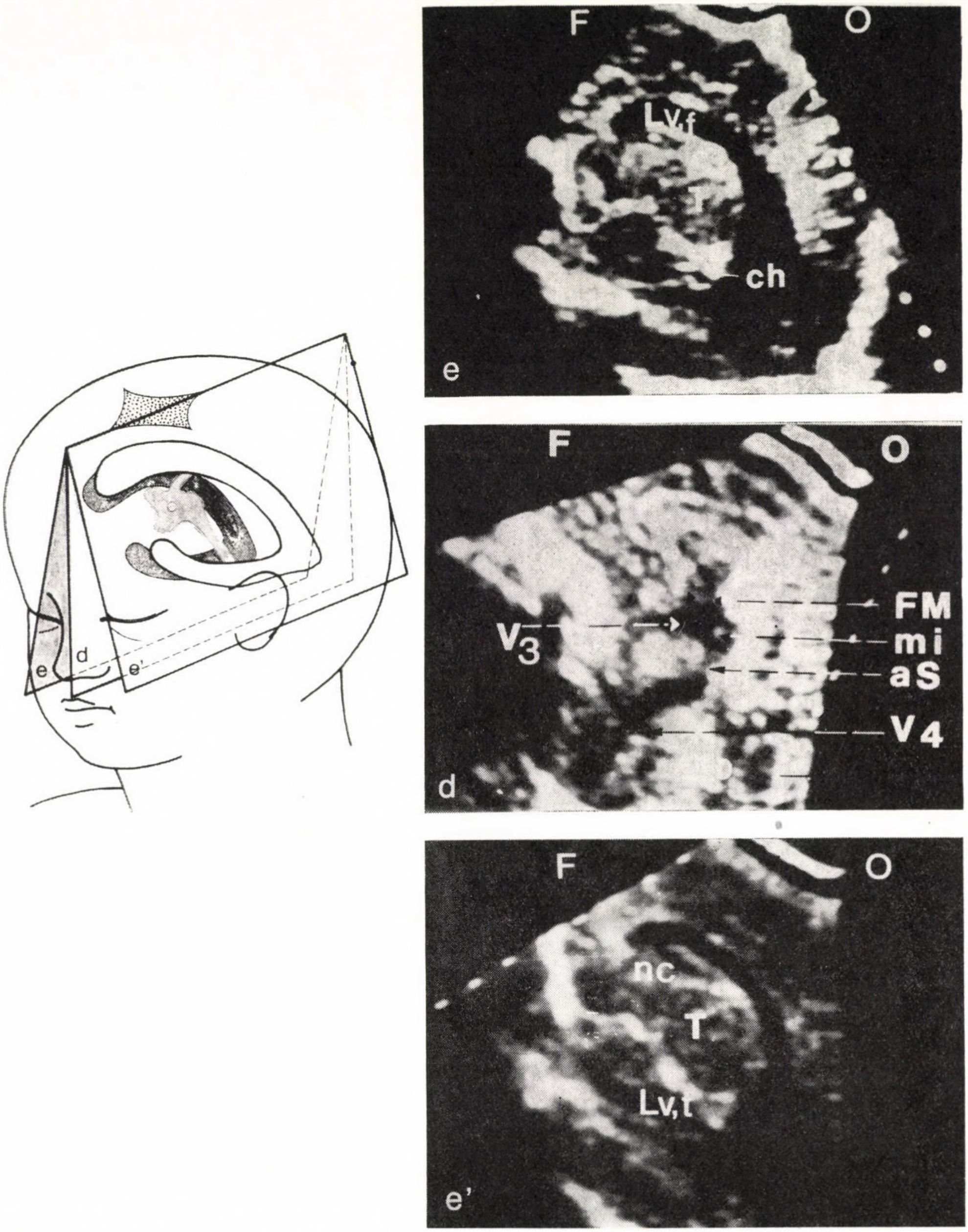

FIG 2. B: Standard median and parasagittal sections. Scheme and pictures: d) The median sagittal section shows the echo-free third ventricle (V3) with the echogenic massa intermedia (mi), above this the foramen of Monro (FM) and the connected Sylvian aqueduct (aS), the fourth ventricle (V4) and the mixed echogenic cerebellum (Cb). F: frontal, O: occipital direction. e-e') In the parasagittal sections the planes are shifted on both sides, displaying the full echo-free arc of the lateral ventricle, its frontal (Lv, f) and temporal (Lv, t) parts, the thalamic area (T), the caudate nucleus (nc), and the periventricular germinal matrix which is a common site of intracranial haemorrhage in preterm infants. The most echogenic structure is the choroid plexus (ch)

TABLE I

Clinical Indications for intracranial sonography

I Pre-term, full term and small-for-dates babies under 1500 g in all cases.

II Over 1500 g birth weight
Complications (asphyxia or other) during delivery
Respiratory distress, hypoxia and post-hypoxic conditions, artificial respiration, CPAP, PEEP
Any type of bleeding
Small for-dates
High-risk neonates
Monosymptomatic or multiple developmental anomalies (myelo-meningocele, congenital hydrocephalus, etc.)
Macrocephalus (suspect cerebral malformation)
Perinatal infection

III Older infants
Rapidly increasing head circumference
Inflammatory conditions of CNS
Subdural effusion
Ventriculitis
Parenchymal changes (abscess, cyst or others)
Traumatized or asphyxiated infant, "battered child" syndrome, follow-up after surgery (shunt placement, etc.)
Suspicion of intracranial space occupying process, hypertension (tumour, cyst)

IV Older children (over two years)
Intra-operative monitoring or guide through a bone flap
Shunt placement
Biopsy (through bone flap or directly)

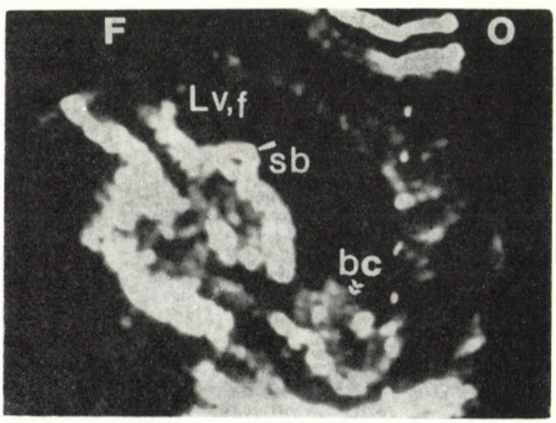

FIG 3. A three weeks old preterm infant of 2000 g birthweight had required CPAP for distress syndrome. He had intracranial hypertension, and the lumbar puncture showed sanguinolent CSF. Right parasagittal section. Enlarged ventricle. In the frontal horn of the lateral ventricle (Lv, f) the place of the germinal matrix, above the caudate nucleus. An echogenic area representing subependymal bleeding (sb) and in the temporal horn a blood clot are visible (bc). Subependymal and intraventricular haemorrhage, dilated ventricles

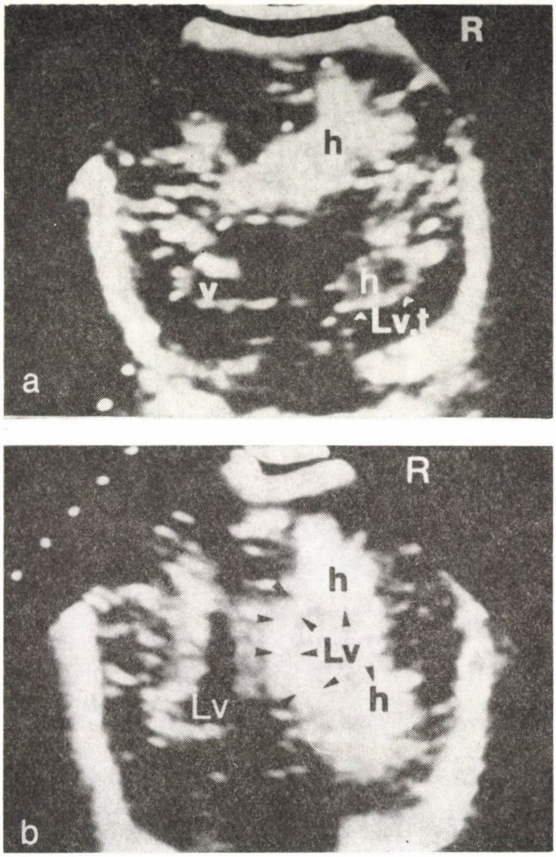

FIG 4. 5 day old full term infant after complicated delivery had had various neurological symptoms such as repeated apnoeic periods, convulsions. He required intubation, artificial respiration and became anaemic. a) The first frontal plane shows expressed intra and periventricular echogenicity (h-black) and in the temporal pole of the right lateral ventricle (Lv, t) a moderately increasing echodensity (hwhite). b) Intraventricular haemorrhage on right side. The expressed asymmetry of the ventricles in the third frontal plane is evident from the comparison of the echo-free left ventricle (LV-white) with the echodense right ventricle (LV-black). The full arc is filled with blood (h) (arrows). R: right side

To increase the proportion of successful interventions it is necessary to conduct regular and broad-scale examinations as early as possible. Haemorrhage is most likely to occur in the weight group under 1500 g born before the 32nd week of gestation. The frequency of intracranial haemorrhage in such infants is estimated at 40–45% [8, 10, 11]. In low birth weight prematures requiring artificial respiration the percentage is even higher, near 70% (Fig. 3).

In infants with a birthweight under 1500 g born before the 32nd week of gestation, sonographic examination should be done within 48 hours after birth and should be repeated at 7 to 10 days, this being the time when changes are likely to occur. Most haemorrhages occur at this time and may or may not progress.

Haemorrhage usually begins with subependymal bleeding in the area of the periventricular germinal matrix and may later break into the ventricles (Fig. 4). In survivors, hydrocephalus may often develop due to intermeningeal adhesion or to occlusion of the aqueduct [1, 10, 11, 15, 19].

Preliminary detection of intracerebral haemorrhage including most subependymal and intraventricular haemorrhages in the neonate should be verified by real-time sonography in the newborn ward. If a haemorrhage is detected, the infant should be monitored by sonography daily or every second day, and it is essential to follow it up for at least 12 months, in view of the danger of hydrocephalus and various necrotic processes caused by the bleeding [17].

Term neonates and infants

All neonates should be examined following complicated delivery, asphyxia or hypoxia, or any disorder involving resuscitation. Abnormal cranial ultrasound findings have been reported in infants with severe asphyxia [2].

Infants with suspected intracranial defects equally requires sonographic examination. Congenital hydrocephalus, intracranial cyst, porencephalis, arachnoid cyst, Dandy—Walker cyst, septum pellucidum cyst, etc., may be detected. Sonography may help to determine whether or not neurosurgical intervention is possible or necessary (Figs 5, 6).

Moderate ventricular dilatation in neonates and the dilatation almost always observable in premature infants as well as an asymmetric ventricular system should also be monitored. They may indicate idiopathic changes such as acute transitional dilatation, or may show the result of an earlier subependymal bleeding (Fig. 7).

Subdural effusion is a special type of infantile intracranial disorder. It is often a complication of meningoencephalitis or subdural haemorrhage, and may also be a concomitant of hydrocephalus. Since the subdural effusion usually takes a mantle-like form, its ultrasound diagnosis is reliable only if there is a large amount of fluid (Fig. 8).

Neonates with meningomyelocele

Only 29% of such patients show clinical symptoms of hydrocephalus while 97% actually have ventricular dilatation, smaller or larger in size.

It is necessary to clarify the neurological status of the patient as well as to determine the initial size of the ventricle prior to reconstruction surgery. In the postoperative period, sonography repeated every two weeks is in most cases sufficient to monitor even a rapid progression of the hydrocephalus but in some cases progression is extremely rapid and the examination must be repeated weekly. In these cases shunt surgery should be considered. If progression is not rapid, then monthly controls are sufficient to determine whether surgery is indicated, as in some cases a balance

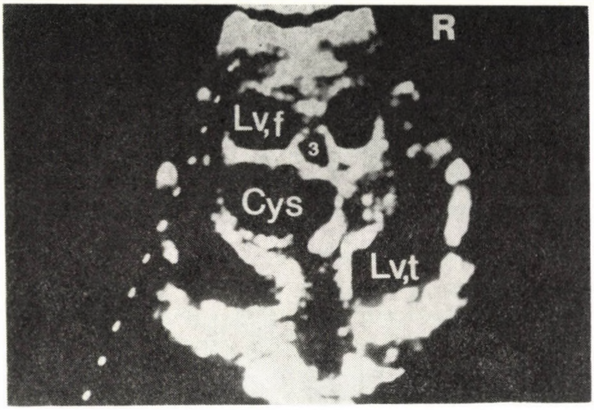

FIG 5. Arachnoid cyst (Cys) with hydrocephalus. Four months old infant with multiple defects (cleft lip, palatoschisis, internal hydrocephalus). On the coronal section enlarged frontal (Lv, f) and temporal (Lv, t) horns, moderately echo-free third ventricle (V3) with separate anechoic lesion pressing the third ventricle to close the CSF passage

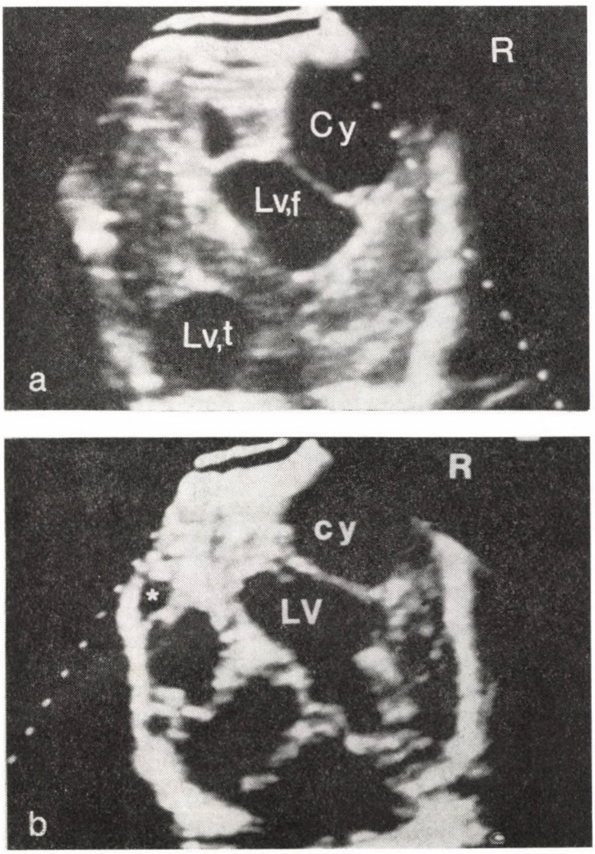

FIG 6. Three and half month old boy with neurological symptoms i.e. positive transillumination on right side and hypertensive macrocephalus. Cystic porencephaly complicated with internal hydrocephalus. a, b) The first and third frontal planes showe a moderately dilated ventricular system with asymmetric cyst (Cy) on right side and other cystic echo-free spots on left side (*) on the third section. Frontal (L, v, f) and temporal (Lv, t) horns of the lateral ventricles (LV)

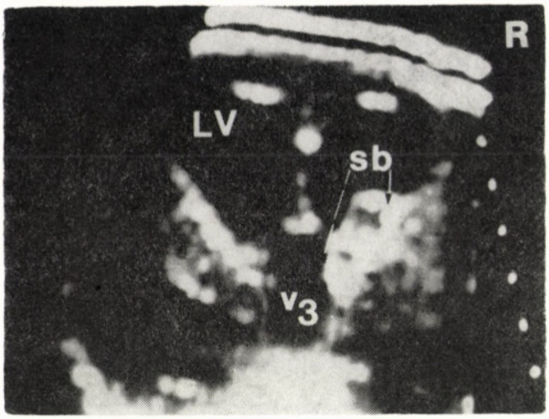

FIG 7. Subependymal haemorrhage and posthaemorrhagic hydrocephalus. Second frontal, plane of preterm baby with 2100 g birthweight, organic heart defect. After heart surgery ventricular haemorrhage and posthaemorrhagic hydrocephalus developed. Subependymal bleeding (sb) with arrows in the typical area. Lateral ventricle (LV), third ventricle (V3)

develops between fluid formation and absorption (Fig. 9).

All infants suspect of primary or secondary hydrocephalus should be screened since dilated cerebral ventricles due to delayed CSF outflow, prolonged elevated intracranial pressure, compression of the brain mantle, ischaemia and thinning precede the rapid growth of head circumference which earlier was the main sign of hydrocephalus (Fig. 10/a.) Early detection of the impending ventricular dilatation may help the surgeon to choose the time suitable for shunt surgery.

The degree of ventricular dilatation can also be monitored by sonography. Two weeks are sufficient to show even a moderate dilatation of the ventricles (Fig. 10/b). In cases of progressive hydrocephalus a ventriculo-atrial or ventriculo-peritoneal shunt should be implanted (Fig. 10/c). Then the ventricular dilatation declines during 18 to 36 days while the head circumference remains unchanged, due to expansion of the brain tissue (Fig. 10/d).

Sonography during the postoperative phase helps the detection of favourable changes in ventricle size and the recognition of eventual problems with the implanted shunt. Complete obstruction of the shunt produces symptoms of increased intracranial pressure, but diagnosis of a partial obstruction in the shunt system is more complicated. This is one of the reasons why long-term follow-up is required.

In cases of bacterial or viral CNS infections (meningitis, meningoencephalitis) ultrasound detection is possible if intermeningeal adhesion, secondary hydrocephalus or parenchymal change (cystic disorders or abscess) are present. Ultrasound results are somewhat better in the detection of moderate hydrocephalus and post-

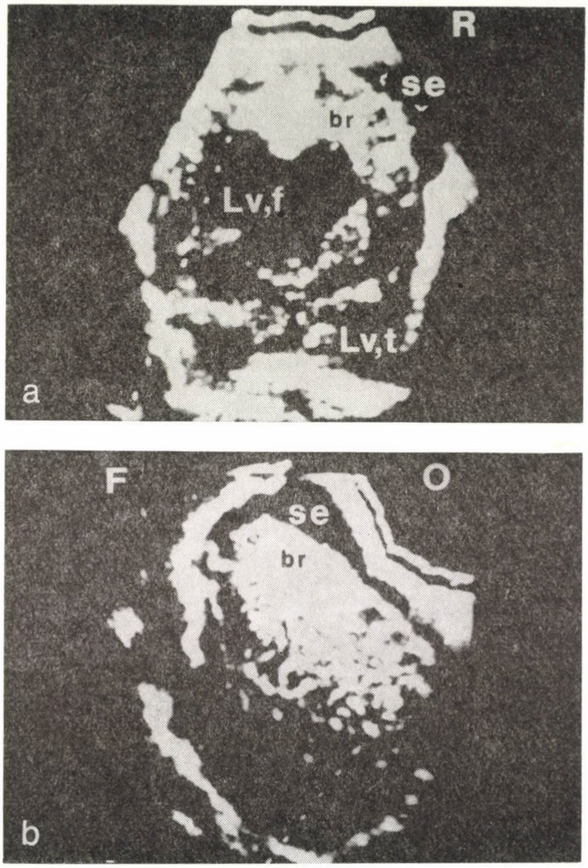

FIG 8. Large subdural effusion on right side with dislocated, enlarged ventricles in seven-month-old boy after reconstruction surgery because of myelodysplasia. a, b) Slight ventricular dilatation and expressed asymmetric subdural effusion (se) on right side (R) on the frontal section (a) and the right parasagittal section (b) above the brain mantle (br) as an echo-free space. Frontal horn of the lateral ventricle (Lv, f) and temporal horn of the lateral ventricle (Lv, t) with brain mantle on right side about 2 cm wide. The subdural fluid has dislocated the brain to the left side

operative ventriculitis. In some cases a change in echodensity indicates the subependymal reaction (Fig. 11).

Primary brain tumours are a rarity in infants. It is possible to detect them with ultrasound if there is a change in the normal echogenity of the brain tissue (an increase caused possibly by calcium deposition or a decrease due to cavity formation, etc.).

Emergency ultrasound examination should be considered in every case when there is a sudden deterioration in the neurological status of the infant, or convulsions or repeated apnoeic episodes occur, since ultrasound-guided ventricular punction or drainage may be necessary. Antibiotic treatment administered directly into the ventricle under ultrasound guidance

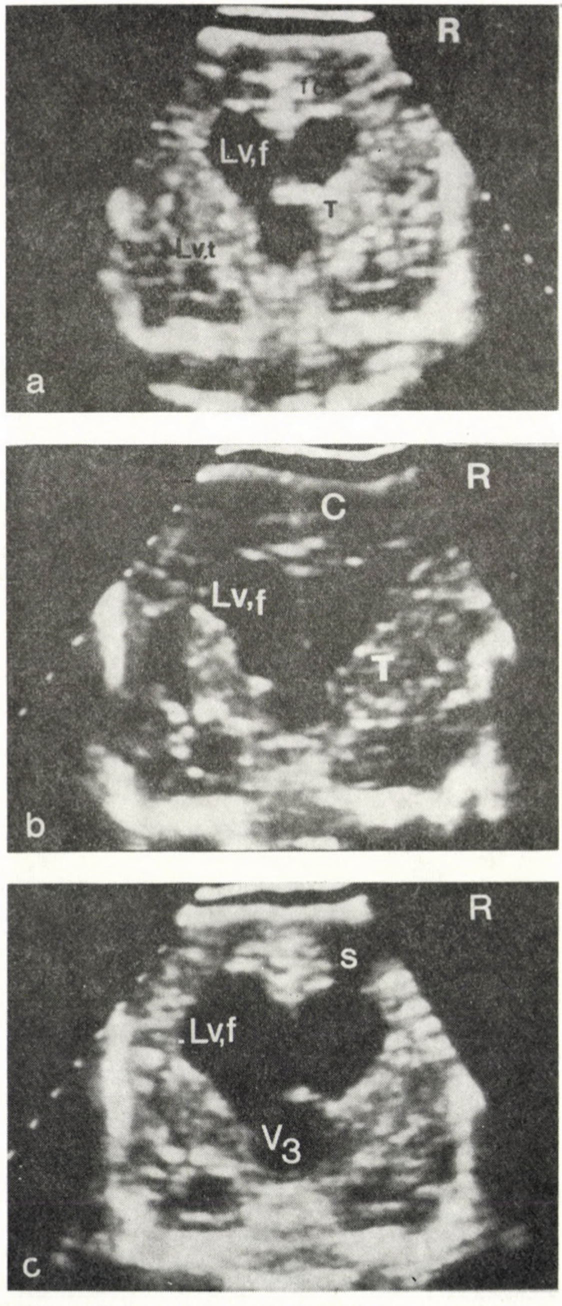

FIG 9. Progressive hydrocephalus. 19 days old boy after reconstruction surgery for lumbosacral myelodysplasia. a) The second frontal section shows slight ventricular dilatation. Frontal horn of lateral ventricle (Lv, f) and temporal horn near normal in size (Lv, t). Falx cerebri (fc) and thalamic area (T). b) Same section two weeks later, moderate hydrocephalus. c: brain mantle. c) four weeks later, at two months of age. The same section shows progression of hydrocephalus. Subdural effusion (s) is seen as an echo-free area on the right side (R). V3: third ventricle

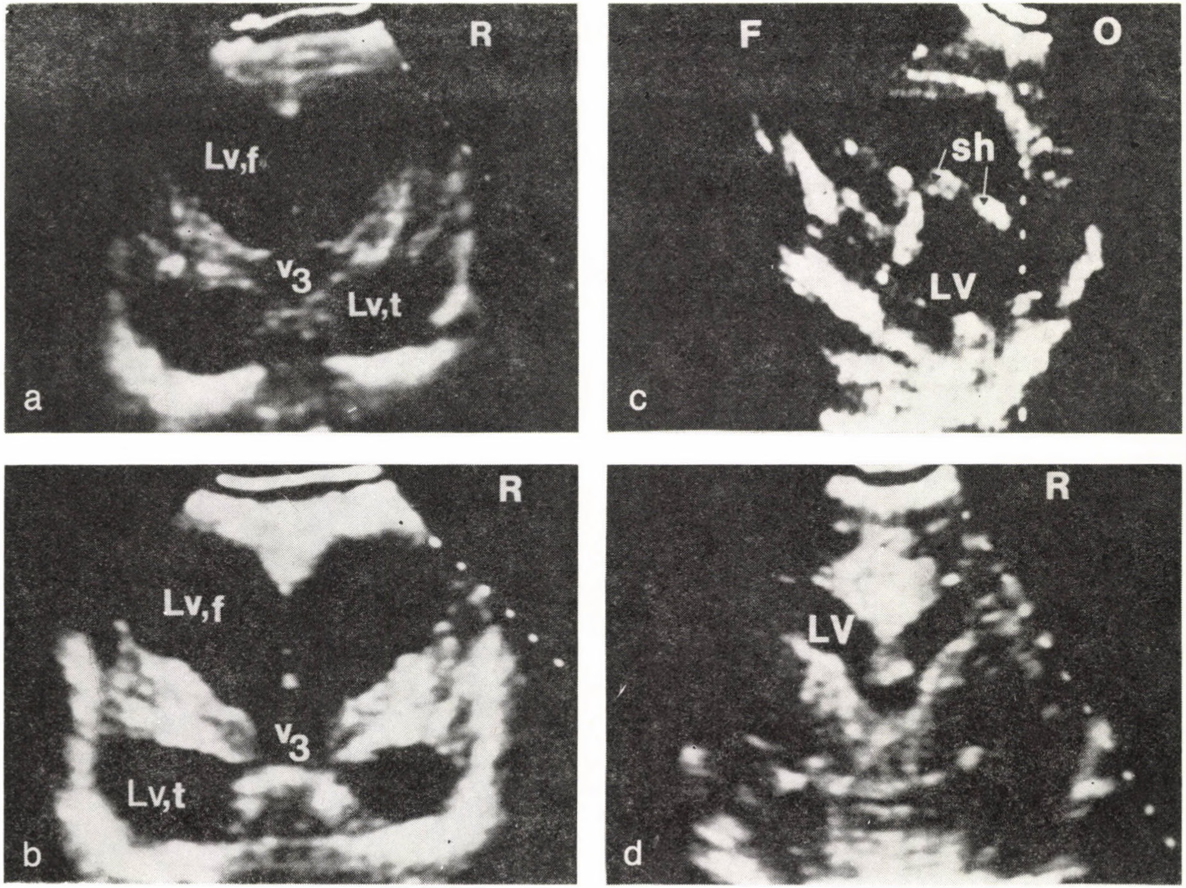

FIG 10. Hydrocephalus regression after shunt surgery. Three months old infant with macrocephalus and moderate ventricular dilatation. a) In the second frontal plane, dilated frontal (Lv, f) and temporal (Lv, t) horns of the lateral ventricles and the third ventricle (V3). b) The same section two weeks later. Large ventricular dilatation. After progression of hydrocephalus shunt surgery was performed. c) Three weeks after implantation of the ventriculo-atrial shunt. The shunt tube is visible as a double-walled echodense line (sh) in the right parasagittal section. Lateral ventricle (LV). d) Six weeks following shunt surgery. The intraventricular pressure has decreased. The coronal section shows near normal lateral ventricles (LV) and the brain mantle has expanded

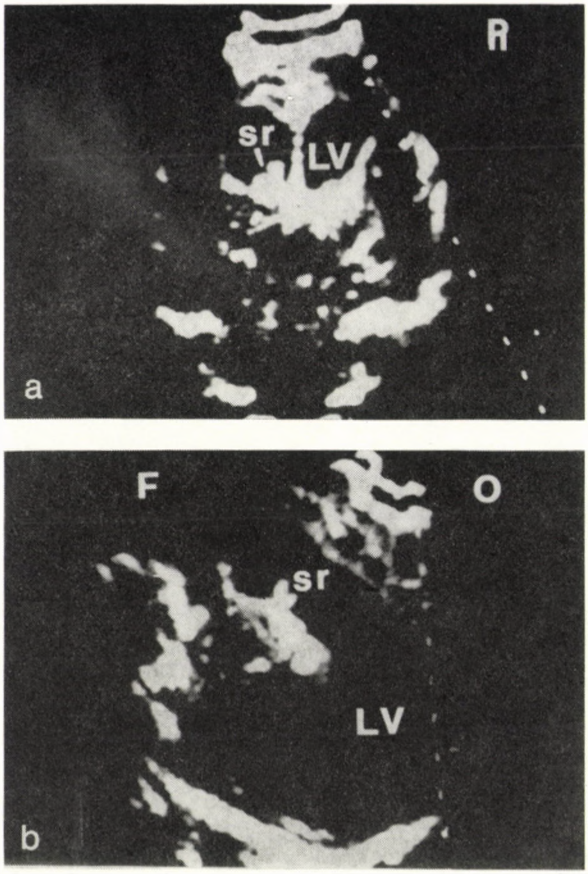

FIG 11. Ventriculitis and internal hydrocephalus in one month old infant with myelodysplasia. a, b) Diffuse low echogenicity in both lateral ventricles. On the ependymal surface of the left ventricle a fibrin clot is seen in both the coronal and parasagittal sections. Ependymal-subependymal fibrin reaction (sr)

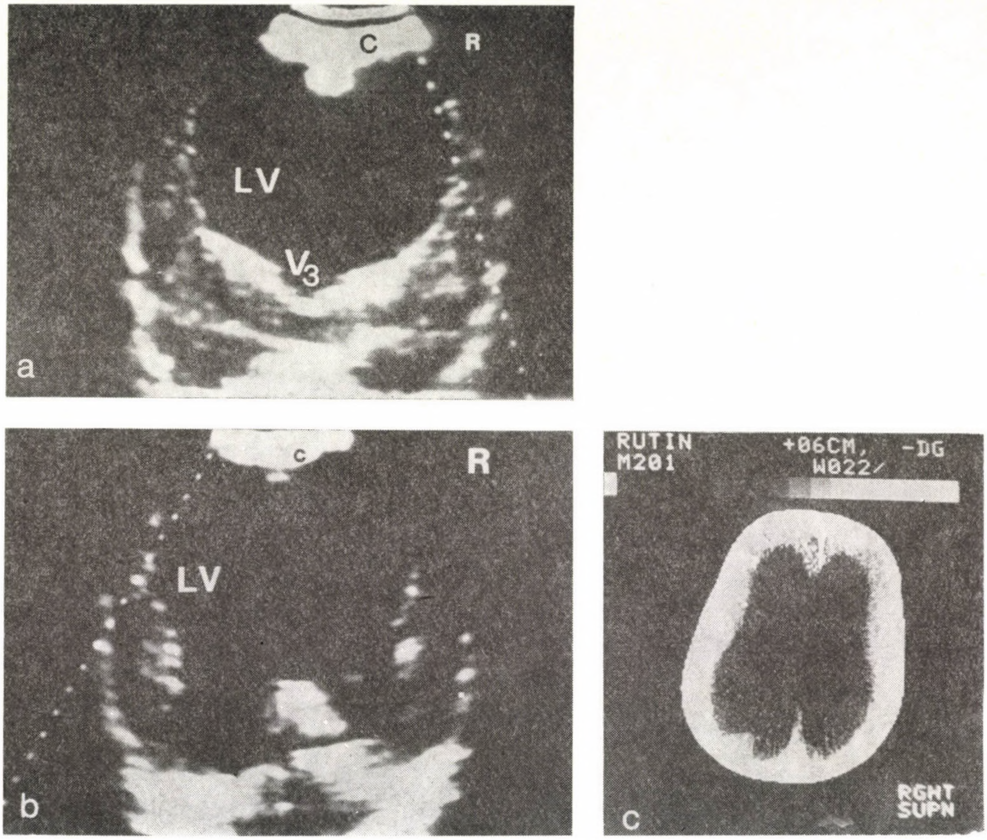

FIG 12. Large internal hydrocephalus in two years old boy with macrocephalus with consequential occlusion of aqueduct. a, b) The frontal first and third sections (lateral ventricle) (LV), C: brain mantle, c) Comparison with CT shows excellent agreement. R: right direction

is also possible if the ventricles are near-normal in size [14].

Sonography is the most harmless method for examining the intracranial space of an infant suspected of having hydrocephalus (Fig. 12).

Often one single examination at the outpatient clinic will allow to arrive at a final negative diagnosis and thus to save the costs of hospital admission.

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Received 9 February 1984

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