Detection of ventricular landmarks by two dimensional ultrasonography¹

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Visualization of the brain's midline structures or of an intracranial mass lesion and detection of ventricular landmarks are the main goals of the ultrasonic (US) techniques in clinical neurology. While investigating the structures in the mid-sagittal plane of the head responsible for the midline echo by A-mode or unidimensional techniques (see Fig. 1), Gordon (1959), and de Vlieger and Ridder (1959) reported a double echo corresponding to the fissure of the third ventricle and a single echo at a higher level corresponding to the septum pellucidum. This was confirmed by Jeppsson (1960) in infants, and by ter Braak, Crezee, Grandia, and de Vlieger (1961), using simultaneous US and pneumoencephalography (PEG). An experimental confirmation of these data was given by Lithander (1961) who introduced a needle indicator in proximity to the reflecting interfaces on excised brains. Ford and Ambrose (1963) described the behaviour of the A-mode echoes arising from the walls of the third ventricle in relation to air study and curved interfaces. Most recently Feuerlein and Dilling (1967) studied the range of the width of the third ventricle in normal subjects at different ages by A-scans.

The possibility of detecting other landmarks of the ventricular system was suggested also by Tanaka, Kikuchi, and Uchida (1961) and experimentally by Lithander (1961), who could identify the A-echoes arising from the lateral wall of the occipital horns and of the portion of the anterior horns just anterior to the foramen of Monroe.

Ambrose (1963) suggested a technique for localizing the walls of the lateral ventricles by A-scan. A more systematic search for specific landmarks pertaining to the lateral ventricular system was carried out by Ford and McRae (1966) with unidimensional techniques. These authors investigated the possibility of detecting the lateral walls of the anterior horns and the ultrasonic findings were

compared with measurements made on contrast studies.

For our part, the main motivation for developing a two-dimensional or B-scan was the hope that more landmarks of the ventricular system could be simultaneously visualized by this technique, both in normal and abnormal intracranial situations. We were hopeful that a technique permitting one to obtain a tomographic view of the brain, would lend itself more easily to specific rules and objective measurements than the current unidimensional or A-scan methods.

The initial results with two-dimensional scanning were reported in a previous paper (Galicich, Lombroso, and Matson, 1965), where we summarized the experience obtained in the first two years with this technique, and especially emphasized the value of this method for a more reliable midline determination, particularly in relation to intracranial mass lesions. This same material was made available to a larger audience by a subsequent paper (Hovind, Galicich, and Matson, 1967). At that time, we felt that only cases of rather advanced hydrocephalus permitted one to establish the dimensions of the lateral ventricles. However, wider experience, especially with younger patients, greater rigour in technique, the introduction of new scanning planes, and better acquaintance with the ultrasonic patterns in normal and abnormal subjects made us aware that much useful information regarding the ventricular system can be obtained by careful interpretation of multi-level two-dimensional sonograms. The aim of this paper is to suggest a new method of study of the anatomy of the ventricular system in different age groups, both in healthy and neurologically affected subjects and to propose a first attempt to standardize these techniques along lines used over the last two years.

EQUIPMENT AND METHODS

As in our previous work (Galicich *et al.*, 1965), we used

¹Support for this study was obtained in part from N. I. H. General Research Grant FR-05482-01 to the Children's Hospital Medical Center, Boston, Massachusetts.

a commercially built ultrasonic scanning system. The equipment permits both one-dimensional echo-ranging and two-dimensional intensity modulated contact scanning. Pulse damping, peak clipping, beam power, gain, range, and other parameters can be controlled independently. Pulse repetition rate is fixed at 379 pulses/sec. An electronic scale with markers corresponding to the time taken by ultrasound to transverse 2 mm brain tissue is provided, and the information is displayed on the face of a cathode-ray tube.

The transducers can be manipulated directly for uni-dimensional scanning or are mounted in the scanner on a swivel at the lower end of a vertical rod which is free to move up or down. The rod moves backward or forward in a straight line perpendicular to the ultrasonic beam, the rate of movement being controlled by an electrically-driven worm gear. The position of the transducer along this line is monitored on the Y-axis of the cathode-ray tube. In this way, using the B-mode presentation and making a time exposure of the full excursion of the transducer over the skull, a two-dimensional ultrasonic tomogram is created on the polaroid film (Fig. 1). The position of the transducer along the axis of the beam is also monitored and displayed on the X-axis of the cathode-ray tube; thus the curvature and irregularity of the surface over which the transducer moves may be visualized.

Usually a 2 Mc/sec, or less often a 1 Mc/sec, lead zirconate titanate transducer, 1 cm in diameter, was employed. Multi-level horizontal and coronal contact scanning was performed according to carefully controlled procedures to enable us to search systematically for landmarks contained between the subject's posterior-frontal and temporo-parietal areas, the regions most suitable for this type of contact scanning and the only ones we have so far explored.

As shown in Fig. 2, the horizontal reference plane is represented by a line connecting the external meatus of the ear and the outer canthi of the eyes. This line follows more or less the orientation of the floor of the intracranial cavity. All horizontal planes are parallel, while the coronal planes are perpendicular to the horizontal reference.

Our 'standard' horizontal plane is the one situated 5 cm above the reference. The 'standard' coronal plane coincides with the vertical reference and is determined by a line originating from the external ear meatus and intersecting the horizontal plane at 90°. We have been using these two planes as the 'standard' ones for scanning because they represent the positions where the midline structures, mainly the third ventricle and septum, are most easily recognized in all age groups. Other scanning planes, used more for the detection of landmarks pertaining to the lateral ventricles, are shown in Figure 2. Except for the standard planes, the distance from the reference lines will be specified in each case since the correct information about the level at which a two-dimensional cross-section is obtained is crucial. Anterior coronal scanning planes are usually obtained 3 or 4 cm anterior to the standard coronal, on a plane which originates in the proximity of the sellar region or immediately anterior to it. Posterior coronal planes are of

little importance in the determination of ventricular measurements. Hence, only anterior and standard coronal planes will be presented in this study.

FIG. 1. A-mode, B-mode scans and two-dimensional contact sonogram are shown from top to bottom for comparison. Each was obtained from the same temporo-parietal area, on the left.

FIG. 2. Multi level planes for two-dimensional contact scanning. The reference line connects the external meatus of the ears to the outer canthi of the eyes. The two standard planes are shown in solid lines. Other planes are shown in broken lines. The projection of these planes over a normal ventricular system, as obtained applying opaque landmarks on the head during PEG is also shown. At the point where any line of scanning intersects the 'standard' plane perpendicular to it, the time exposure is briefly interrupted in order to give a reference on the sonograms.

The different planes of scanning are drawn on the scalp, no shaving is necessary, only abundant coupling. The external head diameter, an important reference, is accurately measured at the point of intersection between the standard horizontal and coronal planes, using a calibrated pelvimeter. The point of intersection of any scanning plane with the orthogonal standard plane is represented by a dark line on each sonogram, as a reference for the relative position of intracranial landmarks.

Systematic multi level two-dimensional sonograms were obtained on each patient from symmetrical positions on either side of the head. Each scan was recorded together with its scale, a 2:1 reduction being generally used. To facilitate the reading, we arranged the scanning procedure so that the scale was presented at the bottom of the picture; the near side of the skull appeared on the right when scanning over the right side of the head and on the left when scanning over the left side of the head. In the horizontal sonogram the posterior region is represented in the bottom of the picture. In the coronal sonogram the bottom of the picture corresponds to the base of the skull.

MATERIAL Material for this investigation were subjects of all ages referred mostly from the neurological and neurosurgical services of the Children's Hospital Medical Center and of the Peter Bent Brigham Hospital.

The subjects examined were divided into the following categories:

1 A group of 750 patients with various neurological disorders in whom contrast study was not obtained but who showed easily recognizable normal or abnormal patterns; 282 of these had abnormal and 468 had normal sonograms.

2 Patients referred with suspected neurological disease in whom a satisfactory US scan and subsequently a normal air study were obtained. This group consists of 30 cases varying in age from 1 to 26 years, and functioned as a control group.

3 Fifty patients in whom abnormal findings were first described in the US scan and subsequently confirmed by a satisfactory air study.

4 Finally, a series of 150 consecutive subjects referred for two-dimensional sonar scanning over the space of about 12 weeks. These were unselected, and a large number of them had normal scans. Though all ages were included, the majority were under 20. By design, this unselected group was scanned by competent technicians along standardized criteria laid down by us in advance, while the scans themselves were read and measured by us after they had been outlined.

METHODS OF ANALYSIS For comparison between ultrasonic findings and radiological data, we made use mainly of brow-up anteroposterior views for the anterior portion of the third ventricle, the anterior horns and occasionally the temporal horns of the lateral ventricles, and of brow-down anteroposterior and lateral views for the trigone and temporal horns.

Since the values obtained by radiography are not

absolute measurements, and a variable degree of magnification was always present, we used a corrective scale based upon the difference between carefully measured external head diameter (obtained at the intersection of the two standard scanning planes or at higher level in cases of hydrocephalus) and the maximal skull to skull diameter on the radiographs used for the comparison. This enabled us to correct to an acceptable degree of approximation the variable distortion introduced in the air contrast study.

In patients who had contrast studies soon after ultrasonar scan, a duplicate of each brow-up anteroposterior view and lateral views of the ventricles were obtained after application of radio-opaque landmarks in correspondence to the standard horizontal plane and at the point of intersection with the standard coronal plane. These landmarks were usually applied only on the side on which the x-rays were projected. The x-ray beam for lateral view was centred over the mid-temporal area. By superimposing films showing different ventricular segments, an almost complete outline of the system in relation to the planes of scanning could be obtained. As is well known, there is no suitable way of measuring accurately the width of the trigone and initial portion of the temporal horns in the brow-down anteroposterior views and of comparing it with the corresponding structures visualized in the posterior quadrants of the horizontal sonograms. However, these sonic lines can be identified by tracing a radio-opaque line along the plane of scanning at the time of the air study (see Fig. 11). Another landmark useful for this identification is the distance between the skull and the external wall of the trigone, since the latter runs almost parallel to the inner table and represents a fairly constant parameter in x-ray regardless of the level at which it is measured, as shown by Taveras and Wood (1964). Schiefer, Kazner, and Kunze (1965) were the first to emphasize this measurement which is also obtained in unidimensional scans and called it the Brain Mantle Index or BMI. Satisfactory measurements of the anterior portion of the temporal horns when visualized both in the scan and in the contrast studies were obtained at times from the straight anteroposterior view.

Measurements of the width of the anterior portion of the third ventricle and of the anterior horns of the lateral ventricles could usually be obtained without difficulty from the straight brow-up anteroposterior views. Since the width of the third ventricle can vary along its axis, for matters of comparison, measurements should be taken at the proper level; again this can best be achieved by referring to the position of radio-opaque landmarks applied to the scalp.

The width of the anterior horns was measured on each side at two levels: (1) about 10 mm above the floor of the lateral ventricles; (2) at the point of maximal transverse diameter of the cavity where the lateral wall encounters the roof of the ventricle.

There is a justifiable objection to the method we used to compare the measurements on radiographs with those on our sonograms, since the x-ray anteroposterior views represent a projection on a frontal plane, while the sonogram represents a horizontal cross-section on a plane

which is inclined 70° to 80° with respect to the radiographic plane (Fig. 3). Thus we compared measurements taken from two planes almost orthogonal to each other.

In order to establish whether these potential sources of error constituted a significant obstacle to the comparison between radiological and ultrasonic measurements, all data on all subjects were processed by statistical analysis. Table I represents a sample of how the data available were tabulated. For each pair of the two measurements we computed the product moment (Pearsonian correlation coefficient r) and a similar coefficient was computed for the means of the two measurements ($Sm-Pm$) computed separately for each subject.

The results of the statistical analysis and the value of r or coefficient of correlation for each single pair of measurements will be reported in the text. In view of the very high values of r no further testing seemed to be necessary.

RESULTS

1. THIRD VENTRICLE The third ventricle is easily detected in a high percentage of normal and abnormal subjects. In most cases, its width can be measured accurately unless it is equal or inferior to the actual coefficient of resolution related to the wave length used. Figure 4 shows how sharply the walls of a normal third ventricle can be seen in low horizontal sonograms and how they relate to the anterior portion of the septum pellucidum, at the same level, and to the whole septum, in higher sonograms. If the third ventricle is very narrow, it may be difficult to differentiate from the septum. However, it will still give the position of the mid-portion of the midline which is most likely to be displaced in pathological conditions. One of the advantages in interpreting a two-dimensional

FIG. 3. Spatial relationship between the planes of the sonogram and of PEG (anteroposterior view). While the radiographic view represents a projection of a tridimensional structure on a frontal plane, the sonogram is more like a horizontal laminogram.

sonogram as compared with a unidimensional one is that, even in cases of significant shift or distortion, the third ventricle is often still easily identified by virtue of its morphology and spatial relationship to other elements present on the same plane and to the midline structures at higher levels (Fig. 5).

If areas of gliosis or of oedema are present, the increased absorption or reflection of ultrasound may render penetration difficult and may mask the adjacent interfaces of the third ventricle.

TABLE I

A SAMPLE OF TABULATION OF VENTRICULAR MEASUREMENTS FOR STATISTICAL ANALYSIS

Measurement No.	S1	P1	S2	P2	S3	P3	S4	P4	Sm	Pm
51	14	13	53	50	53	50			40	37
52			50	40	50	40			50	40
53	10	7	19	21	9	9			13	12
54					12	12.5			12	12.5
55	8	8			14	14	16	12	13	11
56					9	11	11	12	10	11.5
57	11	11	22	23			14	14	16	16
58			20.5	22					20.5	22
59	5	3.5			4.5	4.5	12	12	7	7
60					4.5	4.5			4.5	4.5
61	6	5	20	18					13	12
62	12	12	20	22					16	17
63	5	4	17	20					11	12
64	6.5	5			7	8	10	8	8	7
65					10	13			10	13
66					8	10			8	10
67			23	25	7.5	8			15	16
Mean total	9.7	9.5	28.6	28.7	13.0	13.5	13.0	13.4	18.0	18.2
Correlation Coefficient	0.97		0.97		0.99		0.97		0.99

FIG. 4. C.M.O., aged 10 years, 16 July 1965. The midline pattern of the standard horizontal scan in a normal patient is compared with the brow-up anteroposterior view of the PEG. The scale on the radiograph in this, as in other pictures, is corrected for the coefficient of magnification. At the top of the sonogram the two walls of the lower portion of the anterior horns are recognizable alongside the septum. At the centre of the sonogram is the third ventricle, 5 mm wide. (Note the slight asymmetry between right and left anterior horns seen both in radiography and sonogram.)

Figure 6 shows the frequency with which the various portions of the midline were recognized and the incidence of a well-defined third ventricle in 100 non-selected consecutive cases of B-scanning in subjects of different ages, both with normal and abnormal sonograms.

Hydrocephalus When the ventricular system is moderately dilated, measurements of the width of the third ventricle can usually be accurately obtained in horizontal tomograms at standard and lower level. The coronal views will most likely show the mid-posterior portion of the third ventricle in the same picture, and surmounting it another portion of the midline, probably mostly echoes from the interhemispheric fissure (Fig. 7).

When the third ventricle is greatly dilated, the lateral walls will be increasingly curved, presenting the convexity to the skull and the concavity to the medial sagittal plane of the head. From the well-known properties of reflexion of sound on curved surfaces, the resulting effect is an accentuation of the distal interface or contralateral wall and an attenuation or fragmentation of the proximal interface or homolateral wall. This often can be misleading in the unidimensional sonogram, as stressed by Jefferson (1959) and by White (1966).

This can also be misleading in two-dimensional sonograms, unless one knows the external head diameter at the exact location where the sonogram was obtained. In fact, if only the distal wall of the third ventricle is visualized, this might be mistaken for a shifted midline septum, and the presence of a very enlarged third ventricle may be missed. However, a comparison between the external head diameter and the sum of the distance of skull-to-contralateral wall of the third ventricle will reveal the overlapping portion corresponding to the actual width of the third ventricle. Coronal scans are also helpful in such cases because they more clearly show the contralateral wall and usually recognizable fragments of the proximal as well (Fig. 8).

In case of extreme hydrocephalus, the third ventricle is often displaced downwards and might become difficult or impossible to detect by ultrasound. In such cases, a satisfactory outline of the ventricular system often is impossible even in the

FIG. 5. L. Mo., aged 18 years, 15 November 1966. A large haematoma in the left thalamic region in an 18-year-old patient. Marked displacement of the midline was maximal in the low horizontal planes as shown at lower left. However, the third ventricle (7 mm) was still easily recognizable though markedly displaced. The left temporal horn (10 mm wide) is probably shifted in the opposite direction and somewhat deformed by the presence of the mass, which is represented by an echo-free area because of its nature.

FIG. 6. One hundred consecutive non-selected cases referred for ultrasonograms were divided by age and the frequency with which the third ventricle and the different portions of the midline structures were identified. Even when the two walls of the third ventricle cannot be seen separately, the mid-portion of the midline is recognized in almost all cases at any age.

PEG. However, the neat representation of the midline septum separating two enormous empty cavities obtained by multi-level two-dimensional sonograms provides conclusive evidence of anencephaly. Cross-sectional tomograms clarify such radical alteration of the normal brain structures better than A-scan, which is not infrequently indecipherable in such cases.

Statistics Statistical analysis of the ultrasonic measurements of the width of the third ventricle (S1) plotted against the corresponding measurements obtained in brow-up anteroposterior view of the PEG (P1) showed a very high coefficient of correlation ($r = 0.97$).

This analysis included all pairs of measurements available and thus dealt with an unselected pool of normal and abnormal cases. The results favour the assumption that ultrasonic and radiographic mea-

surements of the third ventricle are interchangeable.

From our experience, we have come to consider that the width of the normal third ventricle varies, in children to young adults, between 4-8 mm, and that widths of 10 mm or more are pathological. In ultrasonic tomograms we can usually see and measure both the anterior and the posterior portions of the third ventricle, as well as its superior and inferior portions. By widening the time base, we can study it in further detail. In this respect, the ultrasonic investigations appear to be superior to radiological studies. The rapidity with which an obstructed, dilated third ventricle responds to shunts or other relieving procedures is striking, and, although these observations are outside the scope of this paper, they are mentioned as potential tools for neurosurgical follow-up care, as well as for *in-vivo* anatomical studies.

2. LATERAL VENTRICLES Thus far, only a few portions of the walls of the lateral ventricles have been visualized by ultrasonography in normal subjects. The complexity of their spatial distribution, the variable orientation of their walls with respect to the ultrasonic beam and the interposition of bone, make it practically impossible to obtain a contour of the lateral ventricles with the ultrasonic techniques

FIG. 7. M.R.U., aged 3 years, 11 May 1964. Obstructive hydrocephalus. In the coronal planes the posterior portion of the third ventricle is crossed vertically. Above it are other midline structures (posterior portion of the septum, interhemispheric fissure), and the lateral walls of the body of the lateral ventricles can be recognized on each side.

currently in use. Exceptions to this are portions of their lateral and medial walls at the level of the body, of the trigone and of the anterior and temporal horns. Even within these stringent limitations, we have found our sonograms capable of giving reliable information as to the state of the lateral ventricles.

Anterior Horns We will describe first some landmarks of the anterior horns which are commonly seen in the two-dimensional horizontal sonograms. They coincide with the portions chosen by Ford and McRae (1966) for detection with their unidimensional technique—that is, the posterior part of the anterior horns or part 2 of the lateral ventricles. These landmarks are situated just rostral to the foramina of Monroe and provide a typical pattern for the anterior portion of the midline structure. They appear as two short but distinct sonic lines placed on each side and parallel to the anterior portion of the septum and represent the most narrow and inferior portion of the ventricles at the level of the anterior horns. This was demonstrated experimentally by Lithander (1961) in excised brains, and confirmed by Grossman (1966) four years later. They were studied by Ford and McRae (1966) with unidimensional sonograms and also by direct comparison with pneumoencephalograms. This

'triple line pattern' is best observed in horizontal two-dimensional sonograms at 4 or 5 cm above the reference plane, and it was seen without special searching in 80 of 150 consecutive cases of B-scanning (Fig. 9). Figure 10 shows that the chance of detecting this anterior triple midline increases somewhat with age. In patients with posterior fossa tumour and subsequent obstructive hydrocephalus, while the triple feature was scarcely recognizable anteriorly, it represented a typical pattern throughout the high level horizontal sonograms. This would suggest that, as a result of increased intracranial pressure, the lateral walls of parts 3 and 4 of the body of the lateral ventricle become more perpendicular to the beam. In the anterior portion, corresponding to part 2, they become more oblique.

More forward and more lateral to the septum, two other landmarks pertaining to the frontal horns and representing the junction of the lateral walls with the roof have been searched for and identified by Ford and McRae (1966) with A-mode sonography. These have also been recognized in our routine horizontal two-dimensional sonograms but much less frequently than the previously described landmarks. The most likely reason for this failure that in doing our routine horizontal scanning, we had not gone far enough frontally.

FIG. 8. Case of hydrocephalus with severe enlargement of the third ventricle. The contralateral wall, which presents the concavity to the sound beam, is enhanced while the homolateral wall, presenting the convexity to the beam, disappears almost completely. In horizontal scans the presence of a greatly enlarged third ventricle could be missed, especially if the head diameter is not known. The coronal scans show peculiar S-shaped midline and the picture obtained from the right is a mirror image of the one obtained from the left. The width of the third ventricle can be determined by superimposing the two images and knowing the head diameter.

Body The lateral wall of part 3 and 4 of the body can be detected in both coronal and high horizontal two-dimensional sonograms. For instance, scanning at 6 or 7 cm above the horizontal reference, two sonic lines, frequently not sharply defined, can be seen running parallel to the midline starting from a point slightly anterior to the vertical reference and extending posteriorly (see Fig. 14). Direct correlation between the sonogram and the PEG regarding these portions of the bodies is much more difficult, since absolute radiological values are hard to obtain. Our evidence here again is obtained by observing the projection of high horizontal planes over the ventricular body through the use of radio-opaque landmarks during the PEG.

Reviewing the same 150 consecutive cases of two-dimensional scans, the width of the body could be established in approximately 60% of the infants (Fig. 10). The chances of obtaining this measurement, however, progressively decrease with age, in almost opposite fashion to the chances of obtaining the triple line pattern representing the floor of the frontal horns. This suggests that the visualization of such landmarks depends less on the size than on a favourable orientation of the reflecting interfaces. Since normally these interfaces are very small, they can be missed in horizontal sonograms even when the latter are performed systematically

at different levels. However, a better chance of obtaining these landmarks is offered by the coronal two-dimensional sonograms, probably because in these the sonic distortion due to beam spread causes elongation of the targets in the direction of movement of the beam and thus will enhance the detection of the lateral wall. In normal subjects, the wall of part 3 and 4 of the body will appear in coronal planes as a short sonic line placed about 2 cm above the standard plane, usually quickly vanishing as the transducer moves upwards. These lines tend to be longer in normal young children, and much more so in cases of hydrocephalus (Figs. 7, 11, and 14).

Hydrocephalus A comparison between two subjects of the same age, one normal and one with moderate obstructive hydrocephalus will serve to emphasize the difference obtainable when two-dimensional scanning is performed according to standardized rules (Fig. 12). Thus, when scanning at the 7 cm horizontal plane, the lateral walls of the ventricles are barely seen or are not seen at all in the normal subject, while they are easily detected in the case with the posterior fossa tumour. In general, we feel that the appearance of clear sonic lines parallel to the septal midline in horizontal scanning at more than one level can be considered with confidence as indication of some degree of hydrocephalus. In this context, it should be pointed out

again that the significant variation here is not so much the total width of the body, but rather the different orientation of the lateral walls brought on by the increased intracranial pressure. In case of a moderate degree of obstructive hydrocephalus, as demonstrated in Fig. 12, only the inferior, more narrow portion of the body is widened and its walls flattened, while the superior portion becomes elongated vertically, causing little variation of its maximal transverse diameter. While in normal subjects the lateral ventricular walls can be fleetingly detected by the ultrasonar beam only at one level, in cases of hydrocephalus a clear-cut visualization of these segments can be obtained at several levels. Once more the importance of a programmed multi-level scanning has to be emphasized.

Statistics The width of the body obtained by the ultrasonic technique as described was plotted against the values of maximal width of the body measured on brow-up anteroposterior views. The correlation coefficient (r) for this pair of measurements (S2-P2) was 0.97. The same high degree of correlation could be established for the measurements obtained from the triple line pattern described previously in the anterior portion of the sonograms (S3) and the measurements of the narrow portion of the body as seen in the brow-up anteroposterior view on radiography (P3) (Fig. 4). The value of r for these

FIG. 9. The 'triple-line' pattern (anterior portion of the midline) in normal subjects at different ages. (See also Fig. 7.) Numbers 1-5 are children, 6-8 adults. Case 6 was a 22-year-old patient with repeated meningitis and slight hydrocephalus. The scan shows here the anterior portion of the third ventricle, the septum and the walls of the anterior horns, larger than normal.

FIG. 10. The age distribution of 150 consecutive, unselected cases referred to our service over a period of 12 weeks and the frequency with which the third ventricle and different segments of the lateral ventricles were recognized and measured.

two measurements was 0-99. This indicates that, as for the third ventricle, when ultrasound measurements of portions of the lateral ventricles described are available, they are interchangeable with the x-ray measurements. From our normal controls we feel that a width of 18-24 mm is the normal range for the bodies of the lateral ventricles. Curiously, the variation from normal infant to young adult is not as great as may be expected.

Trigone Another portion of the lateral ventricular system which was frequently seen in our two-dimensional sonograms is the area where the

body, the occipital, and the temporal horns join together (trigone or atrium). Although there are no direct criteria for comparison, we feel that the projection of the planes of sonic scanning over the ventricular system as seen in the lateral radiographic views gives convincing evidence that the two parallel lines often seen in the posterior quadrants of the low and the standard horizontal scans represent the trigone and/or the initial portion of the temporal horn. This again was best shown in those cases where a radio-opaque marking was placed along the path of the scanning probe at the time of the PEG (Fig. 13). In infants and young children, longer portions of the temporal horns can be frequently followed up to or even past the vertical reference line, probably because of the 'beam spread' effect, which will operate more effectively when the head is relatively small, and, also perhaps because of a different spatial orientation of the horns in the infant brain.

The distance between the outer table of the skull and the lateral wall of the trigone-temporal horn complex, as seen in the PEG, correlated usually very precisely with the corresponding measurements on the sonogram. In normal conditions, the distance between the skull and the trigone is about one quarter of the external head diameter. In certain cases, the temporal horns were abnormally dilated.

FIG. 11. Posterior fossa tumour and obstructive hydrocephalus. The black line on the radiograph corresponds to the horizontal plane where the sonogram shown on the right was taken. The coronal sonogram shows the sonic lines from the midline septum and the lateral walls of the ventricles as they often appear in case of hydrocephalus.

or distorted by an invasive or atrophic process and hence better evidenced and measurable in both contrast study and sonic scans (Fig. 5).

Statistics Statistical correlation between the ultrasonic (S4) and x-ray values (P4) for this portion of the lateral ventricles showed r equal to 0.97. Such value is highly significant, even though the degrees of freedom available for this comparison were considerably less than for the other measurements.

DISCUSSION

Two-dimensional ultrasonography can detect, not

only the midline structures and their regional variations, but also other useful intracranial landmarks pertaining to the lateral ventricles, and with the techniques described it was possible to secure reliable results through the guided efforts of competent technicians. Figure 10 shows how frequently the different portions of the ventricular system have been visualized in the group of 150 unselected consecutive subjects for whom a two-dimensional sonogram has been routinely requested in our hospital and performed by technicians.

The more severe limitations of the technique seem to be: (1) the skull barrier affects penetration and resolution, and greatly limits the information

FIG. 12. The black line crossing the two anteroposterior views of the ventriculograms corresponds with good approximation to the horizontal plane at which the sonograms shown on the left (normal subject) and on the right (obstructive hydrocephalus) were taken. Neither one of the two films is a straight AP view and this causes slight variation. However, both x-ray and ultrasonic findings are significantly different in the two subjects.

FIG. 13. D. An., aged 13 years. This patient had a normal third and lateral ventricles. Two standard horizontal planes taken from the right and the left show parallel lines in the posterior quadrants (lower quadrants in the picture). The distances between the skull and the outer line and between the two lines could be measured, as shown on the scales. The solid line over the lateral view of the ventriculogram represents the horizontal plane used for scanning in this case, and was obtained as described in Methods.

obtainable; (2) the lack of a standardized system and the difficulty in identifying the reflecting interfaces with the corresponding anatomical structures. While not much can be done with the present techniques to overcome the first limitations, there is room for decreasing the second.

The discussion is still vigorous as to whether two-dimensional ultrasonography is a step forward in the technique or an unnecessary complication of the unidimensional method. The B-mode presentation or 'intensity modulation' of the echoes used for two-dimensional sonograms represents a sequence of innumerable unidimensional determinations on one plane. Hence, all landmarks which can be visualized by B-scanning can also be detected by the A-scanning technique. The difference lies in the fact that, while the former records several landmarks at the same time and builds up an image from the sum of randomized information, the latter is more selective and the detection and recognition of certain landmarks is mainly based upon the personal skill of the examiner. The opportunity to manipulate the transducer while searching for the desired landmarks probably increases the ability of obtaining the echoes in the hands of an expert. At the same time, standardized criteria for diagnosis are more difficult to establish and personal bias is harder to avoid.

A-mode sonography depends essentially upon the geometry between transducer and time structures, and it is especially meaningful to the operator at the time the test is performed. It can be used very effectively when clearly identifiable targets are sought, but pathological distortion creates unsolvable riddles at times. However, it gives a dynamic impression of changeable intracranial parameters as stressed by Dreese, Hayes, and Kempe (1966), which predictably will be one of the interesting lines of development of A-mode ultrasonography, as work by Jeppsson (1964), McKinney, Thurstone, Avant, and Wallace (1966), and Freund (1965), among others, is already demonstrating.

In our experience, the multi-level two-dimensional scanning as described in this paper is already a standardized method, which does not require the presence of a specialized physician: it can be performed satisfactorily by a well-trained technician, provided basic directions are given, together with proper safeguards to ensure as full examination as possible and a minimum of artefact. We feel, also, that the interpretation of two-dimensional sonograms compared with unidimensional sonograms is facilitated and the frequency of error lessened, especially when the position of normal landmarks is greatly altered by pathological events. The reciprocal relationship of single targets can be fully evaluated,

and the examiner is given the benefit of longer and more thoughtful consideration of the results. Furthermore, the results are all recorded on paper and available for objective inspection by anyone.

The amount of information that in most cases we were able to obtain by applying systematically our multi-level two-dimensional ultrasonic technique was encouraging on the clinical ground. Such information and the knowledge that the visualization of ventricular landmarks up to a certain limit is proportional to the degree of dilatation was a considerable help in deciding whether a contrast study was warranted or not, in confirming or not a suspected hydrocephalus, especially of the communicating type, in follow-up studies, or in the differential diagnosis between the presence of atrophic involvement of the brain or mass lesions.

Clinical experience and long acquaintance with the technique secures not only more sophistication in clinical correlations but also the ability to recognize the level of scanning and the familiar features

FIG. 14. Seven-month-old baby with suspected incipient hydrocephalus ex-vacuo. Multi-level horizontal sonograms reveal in the two low-horizontal scans the third ventricle, measuring 9 mm, not shifted from the midline, the septum and the lateral walls of the anterior horns, and, less clearly, the trigone on the left. The higher horizontal scans reveal a single midline structure (septum and interhemispheric fissure) and the lateral walls of part 3 and 4 of the body. These walls are also well visualized in the coronal sonogram (bottom, right).

seen at different ages just by glancing at the tomograms (Fig. 14).

A standardized method for detecting multiple ventricular landmarks by ultrasonic techniques now in use will never totally substitute for pneumoencephalography because the former shows only portions of reflecting interfaces, while the latter outlines the contour of the ventricles and better reveals regional deformities. On the other hand, it should be noted that ultrasonic visualization of the brain can give not merely the same but additional information and has, of course, the decisive advantage of potentially innumerable examinations.

SUMMARY

We have described a multi-level two-dimensional (B-mode) ultrasonic method which has been used for systematic scanning of the head in subjects of all ages over a period of four years. The procedure can now be reliably performed by trained technicians. It is safe, can be repeated many times, and can be carried out without discomfort in 20 to 40 minutes at the bed of the patient.

This paper has dealt with the ventricular landmarks that can be detected by this method without specific searching for them, in contrast to the current one-dimensional (A-mode) techniques. These landmarks include the walls of the third ventricle in its anterior, posterior, superior, and inferior portions; segments of the walls of the lateral ventricles at the level of the anterior horns and mid-posterior portion of the body, and segments of the walls of the trigone and temporal horns.

Eighty subjects in whom both two-dimensional sonograms and pneumoencephalography were obtained in close proximity were used for correlation. The identification of the described ventricular landmarks was achieved in two ways: (1) visually, by applying radio-opaque landmarks along the lines of scanning during ventriculography; (2) statistically, computing the correlation coefficient r for the respective pairs of measurements obtained. The values of r were highly significant and confirmed the assumption that x-ray and ultrasound measurement, when available, are interchangeable.

In addition, a group of 750 patients with various neurological disorders were tested, in the absence of contrast studies, but with detectable ventricular patterns; 282 of these had abnormal and 468 had normal sonograms. The test has been instrumental in deferring pneumoencephalography in a number of patients on the neurological and neurosurgical wards.

In order to determine the frequency with which such ventricular landmarks can be visualized by

two-dimensional ultrasonography, this was done in 150 unselected and consecutive cases by technicians according to the method outlined and the results were examined by us and divided by age. While the detection of these landmarks is easier in the younger age groups, it is feasible also in the adult. The most rewarding results were obtained in a group of incipient obstructive hydrocephalus patients, in whom the earliest signs appeared to be a vertical stretching of the ventricular walls, rather than an absolute increase in the width of the lateral ventricles. Various degrees of hydrocephalus detected by this technique correlated well with values obtained by pneumoencephalography, and various types of ventricular anomalies were recognized.

The technique lends itself to anatomical surveys of the ventricular system both for normative purposes as well as detection of unsuspected anomalies in large populations.

The advantages and limitations of this two-dimensional ultrasonic technique are discussed in relation to one-dimensional ultrasonography.

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