Transverse-Section Radionuclide Scanning in Cisternography

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By applying the technique of transverse-section radionuclide scanning to cisternography, the structure and relationships of the basal cisterns and other subarachnoid spaces of the brain can be visualized more clearly and with more detail than is possible with routine imaging techniques. The ability of this method to separate overlapping areas of radioactivity ensures improved definition of space-occupying processes within the basal cisterns. In the evaluation by cisternography of patients with hydrocephalus and dementia, the transverse-section images clearly separated various normal and abnormal patterns, whereas the routine cisternogram images were equivocal.

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Radionuclide cisternography has the unique ability to show gross abnormalities of the circulation and reabsorption of cerebrospinal fluid (CSF). The main application of this method has been the provision of criteria distinguishing patients with dementia due to such irreversible processes as cerebral atrophy from the potentially treatable group with symptomatic occult hydrocephalus (*1–3*). Less attention has been directed to fine structural details in these studies since the anatomy of the CSF compartments around the brain strains the spatial resolution of conventional radionuclide imaging (*4*).

Transverse-section radionuclide imaging, by separating confusing overlapping images, has already been shown to provide better information about failure of the blood–brain barrier than ordinary scanning (*5,6*). The extension of these principles to transmission scanning by the introduction of computerized axial transverse scanning has clearly shown the advantages of this mode of brain examination (*7–9*).

Our project sought to determine the feasibility of adding transverse-section scanning to ordinary radionuclide cisternography and to define the details of anatomy of the basal cisterns, the subarachnoid spaces, and the intracerebral ventricles of normal and abnormal patients.

MATERIALS AND METHODS

In this study, 15 patients underwent both conventional and transverse-section radionuclide cisternography. Thirteen of these were being evaluated for possible obstructive hydrocephalus and dementia, but we included two patients with suspected CSF rhinorrhea. Also, a number of patients proved ultimately not to have hydrocephalus.

Conventional radionuclide cisternography in these patients followed the intrathecal injection through a lumbar puncture of 0.5–1.0 mCi of ^{111}In-DTPA in a volume of 1–2 ml. Multiple views with the scintillation camera (Picker Dynacamera 2C or Searle Radiographics Pho/Gamma III) were obtained at 2, 6, and 24 hr and, if indicated, at 24-hr intervals up to 96 hr.

Transverse-section scans were performed at 6 and 24 hr using the Mark III scanner (*10*). Each patient underwent multiple-section studies at different levels, usually with the section plane parallel to the orbitomeatal line. Section levels were chosen either by direct observation of rectilinear scans on the

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Mark III display, or by reference to the orbitomeatal line. Each section scan required from 2.5 to 20 min for completion, depending on the concentration of activity in the CSF. After processing of the transverse-section scan data (*11*), each transverse section produced a cross-sectional image of the radioactivity in a 1-cm-thick slice of the head at a known level. A series of these scans is then taken at 1-cm intervals to examine the larger volume of brain under study systematically.

RESULTS

Representative studies selected from the group of patients examined during this project are shown in this section.

Normal cisterns. Figure 1, right, illustrates the normal appearance of section scans through the basal cisterns at 6 hr after injection, when the activity in the basal cisterns is greatest. There is little activity in the overlying superficial CSF pathways. Notice (A) the clear display of the cisternal anatomy, unhindered by superposition of adjacent radioactivity; (B) the symmetry of these normal structures; (C) the configuration and location of the related cisterns and their communicating pathways; and (D) the absence of activity in the regions of the lateral ventricles.

Section 1a, the highest level, is taken through the superior extent of the quadrigeminal plate cistern and shows activity in the structures just above the tentorial incisura. This level at this time shows the earliest ascent of radionuclide from the infratentorial to the supratentorial pathways. No significant activity appears over the convexities; only the quadrigeminal plate region, the sylvian fissures, and the sagittal sinus regions are seen.

Section 1b is made through the deepest portion of the cistern of the quadrigeminal plate. The transverse section clearly shows the individual cisterns at this level, where the supratentorial and infratentorial compartments overlap.

Section 1c is 2 cm below the previous section and shows more of the structures in the posterior fossa and along the floor of the anterior fossa. At this level the configuration of the midline activity changes. Instead of activity in the sagittal sinus region, we see midline activity anteriorly, in the interhemispheric region where the falx cerebri meets the floor of the anterior fossa. The posterior border of this activity reaches the lamina terminalis. Activity in the sylvian fissure passes into the midline cisternal structures, showing the origin of these cisterns along the horizontal portions of the middle cerebral arteries. The cisterns of the middle cerebral arteries merge with the parasellar cisterns, which are prominent at

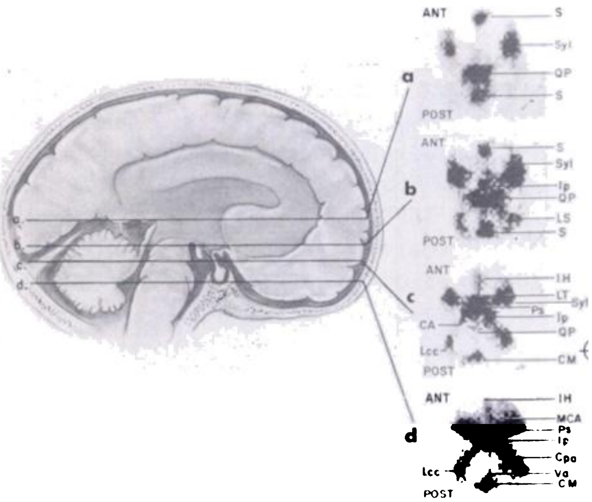

FIG. 1. Transverse-section anatomy of normal basal cisterns. Level of each transverse section is shown by horizontal line in accompanying diagram. (CA) Cisterna ambiens; (CM) cisterna magna; (Cpa) cerebellopontine angle; (IH) interhemispheric; (Ip) interpeduncular; (Lcc) lateral cerebellar; (LS) lateral sinus; (LT) lamina terminalis; (MCA) cistern of middle cerebral artery; (Ps) parasellar cisterns; (QP) quadrigeminal plate cistern; (S) parasagittal; (Syl) sylvian cistern; (Va) vallecula.

this level while barely visible in the level above. The more posterior activity in the midline is within the interpeduncular cistern. The weak activity extending posteriorly and laterally from the parasellar region is within the cisterna ambiens. Finally, activity is seen in the posterior fossa in the lateral cerebellar cisterns, the cisterna magna, and a small amount of activity in the most caudal region of the quadrigeminal plate cistern. A characteristic distinction between the supratentorial and infratentorial sections is seen at their interface; this is the configuration of the midline activity. While the supratentorial section shows the more posteriorly located rostral cistern of the quadrigeminal plate, this disappears in the infratentorial section, whereas the more caudal and anteriorly located parasellar and interpeduncular cisterns become more prominent. These features are better shown in Section 1d.

The lowest section here, Fig. 1d, is made through the center of the posterior fossa through the activity lateral to the cerebellar hemispheres, the cisterna magna and vallecula, and the cerebellopontine angles. This section shows most clearly the union of the many basilar cisternal compartments. Here the cisternal and CSF pathways along the undersurface of the brain stem come together at the interpeduncular and parasellar cisterns. This activity extends superiorly into the cisterns of the middle cerebral arteries, the sylvian cisterns, and the circular cisterns. Communication rostrally with the olfactory sulcus and interhemispheric and sagittal cisterns can also be seen. Finally, CSF anterior to the brain stem along

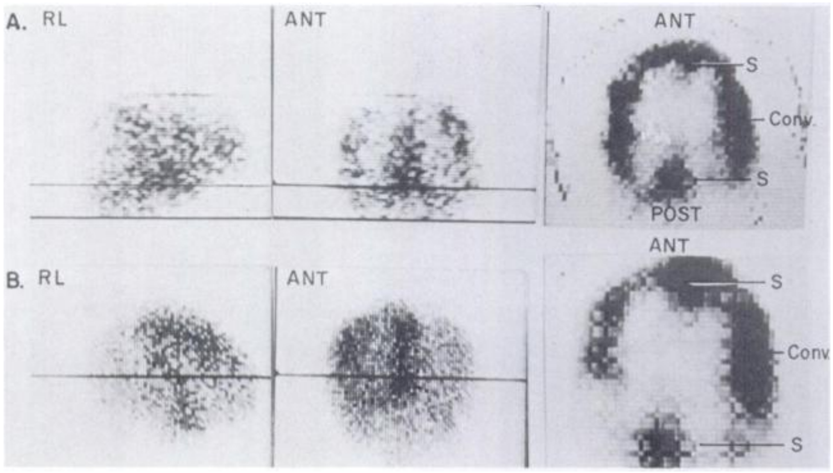

FIG. 2. Normal cisternogram at 24 hr shows only convexity (Conv) and parasagittal (S) activity. Horizontal lines through right lateral and anterior views of cisternogram show level of section. (A) Section views of cisternogram through basal cistern. (B) Transverse section through lateral ventricles.

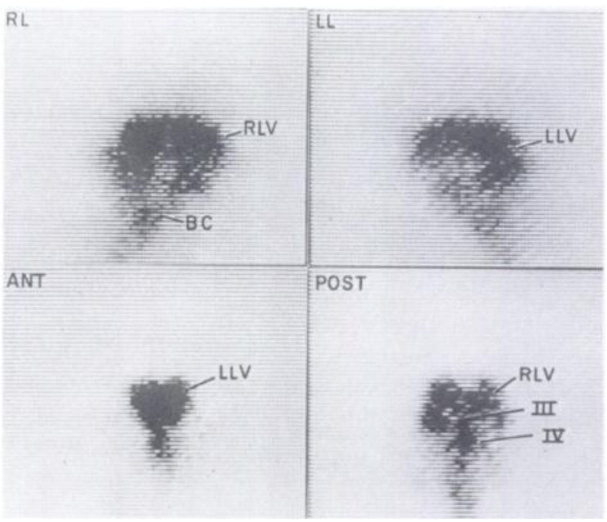

FIG. 3. In conventional 6-hr cisternogram penetration is seen into right and left lateral ventricles (RLV and LLV) and third and fourth ventricles. Some activity is present in basal cisterns (BC).

the clivus communicates with the CSF activity over the cerebellar hemispheres.

Normal cisterns in delayed scans. Section scans at 24 hr after injection differ considerably from the earlier versions. The major activity is now distributed about the convexity and in the sagittal sinus region, and no significant activity is noted within the basal cisterns (Fig. 2). In the normal patient, no activity will be seen in the regions of the lateral ventricles.

Ventricular penetration. In adult patients with hydrocephalus and dementia, the most common abnormality observed on the cisternogram is the appearance of radioactivity in the cerebral ventricles. This is almost never seen in normal patients (*12*). The following examples illustrate the value of section scanning in distinguishing those patterns associated with ventricular penetration of the tracer.

Early scans. The conventional 6-hr scans of a patient with normal-pressure hydrocephalus are shown in Fig. 3. Almost all of the activity is located within the ventricular system, although some is seen inferiorly in the basal cisterns. The persistence of this pattern beyond 24 hr indicates the presence of a block in the normal pathways of CSF migration and absorption and shows the alternate compensatory pathway of reabsorption through the ventricles.

Figure 4 shows the transverse sections made at 6 hr in the same patient as in Fig. 3. These sections are keyed in level to the posterior rectilinear scans at the left. Section 4a passes through the lateral recesses of the fourth ventricle. Even at this level

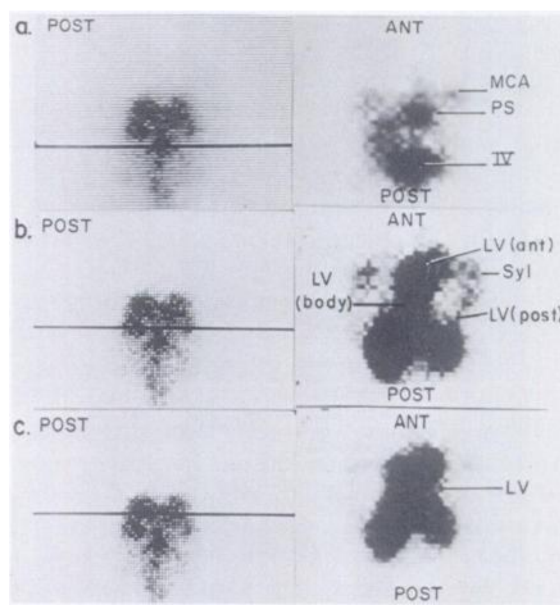

FIG. 4. Transverse-section appearance of activity within ventricular system. (a) Transverse section at level of fourth ventricle shows activity in fourth ventricle, parasellar cisterns (PS), and cistern of middle cerebral artery (MCA). (b) Transverse section scan through inferior portion of lateral ventricle shows most of activity within ventricular system. (c) Transverse section through superior portion of lateral ventricles.

most of the activity is in the ventricular system, separated from activity in the more anterior and lateral cisterns. Section 4b is made at a higher level and shows the inferior portions of the lateral ventricles, distinguishable from the basal cisterns at this level. Section 4c shows activity in the uppermost portions of the lateral ventricles and its failure to ascend into the adjacent cisterns, sagittal sinus, and the sylvian fissures. Compare the abnormal appearance of sections in this figure with the normal 6-hr appearance in Fig. 1.

The sections of Fig. 4 emphasize what is already obvious in the ordinary rectilinear views of Fig. 3. More commonly, the section study clarifies what is obscure in the rectilinear views; a vertex view can also help to visualize ventricular penetration. For example, in the cisternogram illustrated in Fig. 5, a diagnosis of ventricular penetration, inconclusive in all ordinary views, was clarified by the transverse-section scans. Note the difficulty of separating the ventricular radioactivity from other images in the vertex view, where all levels of structures are superimposed in one picture. The four transverse sections permit positive identification of ventricular filling, since the otherwise overlapping images of adjacent cisterns and ventricles are separated in the sections. Compare these sections to the normal anatomy shown in Fig. 1. Section 5a passes through the level of the caudal medullary structures. It clearly shows activity (A) within the posterior fossa along the clivus; (B) in region of the cerebellopontine angle; (C) in the cisterna magna; and (D) in the central area, which suggests activity either in the fourth ventricle or along the anterior surface of the medulla and pons. Section 5b is at a higher level and shows activity in the posterior fossa, the more rostral basal cisterns, and within the caudal extent of the quadrigeminal plate cistern. Section 5c is at the junction of the supra- and infratentorial compartments. This section clearly shows ventricular activity. The highest section, 5d, shows considerable ventricular activity and some additional activity in the sylvian fissures, but it is free from the otherwise interfering images of the basal cisterns.

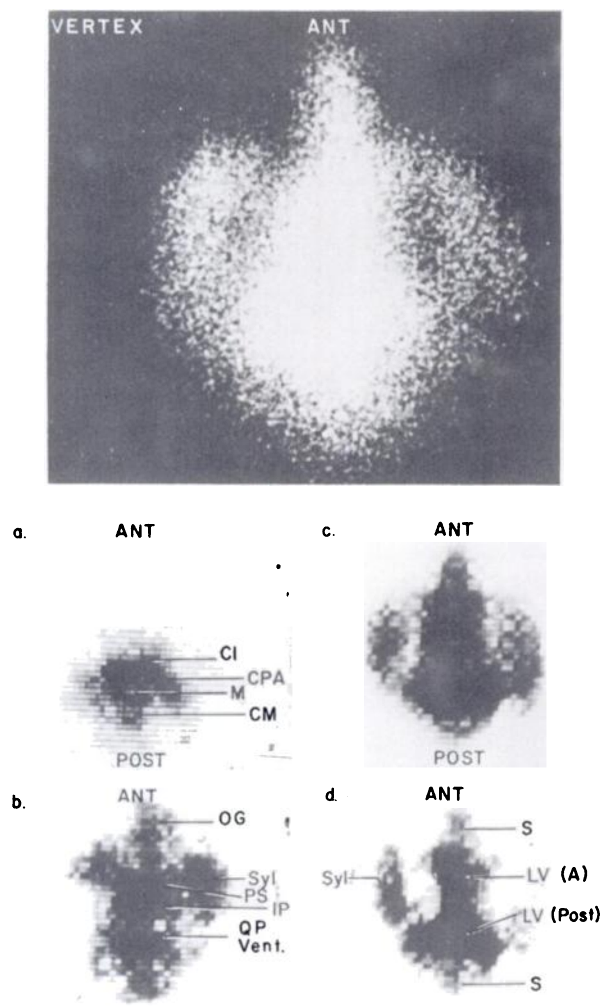

FIG. 5. Scinticisternogram vertex view (top) is contrasted with transverse sections done at approximately same time. Sections a through d are made at increasingly higher levels. (CI) clivus; (M) medulla; (OG) olfactory groove; (QP Vent) quadrigeminal plate and fourth ventricle activity.

Figure 6 compares 24-hr rectilinear and sectional views showing stasis of tracer in the ventricular system. As is often the case in delayed scans, the ventricular activity is somewhat obscured because of diffusion of ^{111}In-DTPA into the brain (*13*) and the confusing overlap of activity in the sylvian fissures and convexities. The transverse sections clearly identify the ventricular penetration and stasis of radionuclide, which might have been misinterpreted in those two cases.

Tumor-deformed cisterns. Less commonly, cisternography is used to identify tumor location by noting distortion of adjacent cisterns. These distortions are subtle at best when one is restricted to ordinary brain imaging (*14,15*). Section scanning can improve delineation of the abnormal cisternal boundaries, as illustrated in the following case.

A 60-year-old man underwent a right suboccipital craniotomy 1.5 years before for removal of a right acoustic neuroma. His presenting symptoms suggested recurrence. Pertechnetate brain imaging showed abnormal activity in the right posterior paramedian region (Figs. 7a and 7b), but there was confusion as to whether the abnormal uptake was due to recurrent tumor, to persistent postoperative artifact, or to a combination of both. A subsequent cisternogram (Fig. 7c) suggested decreased activity in the cistern of the right cerebellopontine angle. Figures 7a–7c show what can be accomplished with rou-

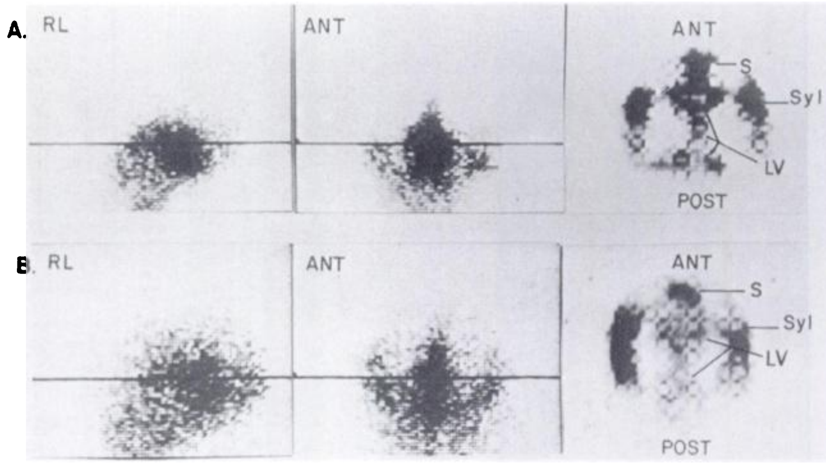

FIG. 6. Transverse-section scans reveal activity within region of ventricles, which is suspected from rectilinear views in patient A but obscured by adjacent activity in patient B.

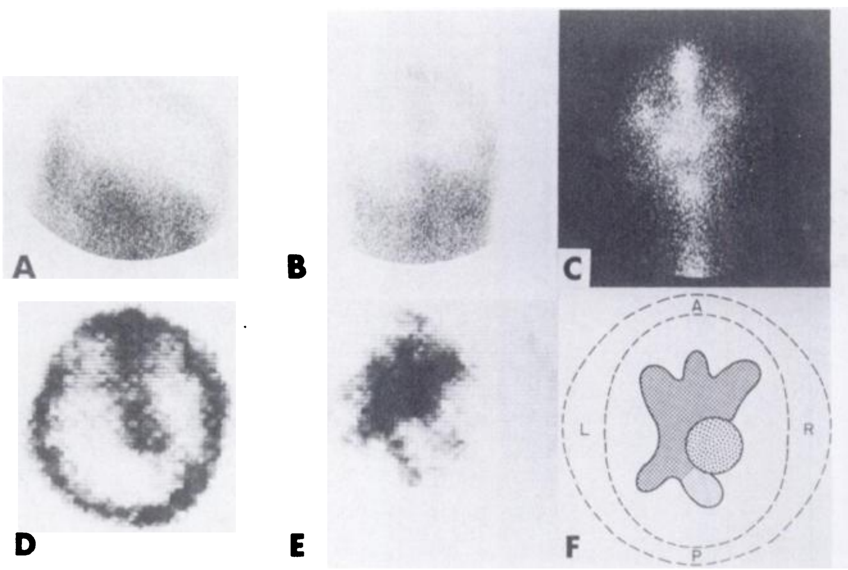

FIG. 7. Recurrent tumor of right cerebellopontine angle. (A,B) Intravenous pertechnetate brain scans show abnormal activity in right cerebellopontine angle. (C) Posterior scinticisternogram suggests decreased activity in cistern of right cerebellopontine angle. (D) Transverse-section pertechnetate brain scan shows increased uptake in right cerebellopontine angle. (E,F) Transverse-section cisternogram and accompanying diagram show relationship of tumor to deformed and displaced cerebellopontine angle cistern and anterior subarachnoid space.

tine brain and cisternal imaging alone, but each of these examinations was complemented by transverse-section scanning. In Fig. 7d the transverse-section pertechnetate scan clearly identifies a round region of activity in the right cerebellopontine angle, considered to be recurrent tumor. The section scan after cisternography (Fig. 7e) shows the corresponding displacement of activity from the cistern of the right cerebellopontine angle, with lateral displacement of the basal cisterns along the floor of the posterior fossa. This characterizes the lesion as being extra-axial and within the cerebellopontine angle.

This study shows the advantage of imaging both the tumor and its effects on adjacent structures and the use of the section scan to isolate the relevant images.

DISCUSSION

Computerized axial tomography of the brain (CT-scanning) has displaced pneumoencephalography and cerebral angiography in most neuroradiologic investigations of central nervous system disease, including the evaluation of hydrocephalus. However, radionuclide cisternography remains unique in its ability to show graphically the physiology of cerebrospinal fluid circulation, and it remains a valuable procedure in the preoperative assessment of patients with dementia and hydrocephalus (*16,17*). The ability of the radionuclide transverse-section scan to overcome some of the difficulties in the interpretation of the cisternogram has been dealt with in this project. With further refinements in technique and increasing clinical experience, and in conjunction with other tests of CSF function and clinical criteria of normal-pressure hydrocephalus, better patient selection can be expected and fewer patients subjected to the recognized morbidity of CSF shunting (*18*).

In patients with hydrocephalus and dementia who show ventricular penetration on cisternography, the transverse-section scan will provide better visualization of the ventricular activity. This has been achieved when the standard rectilinear scans and scinticisternograms have produced equivocal results. The transverse-section views have provided studies of diagnostic quality, particularly in such low-count situations as occur with leakage of radionuclide at the injection site, with expanded CSF volume leading to low radionuclide concentration, and with other factors related to technique and patient idiosyncrasy. In delayed scans detail is often lost due to diffusion of the chelated radionuclide out of the CSF and into the paraventricular tissues and dural spaces, but this has not been a problem when the transverse-section scans are viewed because of the improved separation of adjacent areas of radioactivity. Patients will benefit from the decreasing numbers of repeated procedures.

Routine radionuclide cisternography has generated occasional interest as a method of examining the subarachnoid space for space-occupying lesions. Reports of this application have been concerned with the infrequent abnormal collections of CSF and gross displacement or obstruction of adjacent subarachnoid spaces by local processes. These have included the demonstration of porencephaly (*19*), arachnoid cysts and other cystic lesions of the posterior fossa in children (*20,21*), the effect of cerebrovascular occlusive disease on the adjacent subarachnoid space (*22*), subdural hematoma (*23*), and lesions of the spinal canal (*24*).

Recently the application of the cisternogram for the diagnosis of tumors of the cerebellopontine angle has been evaluated (*14,15*). Transverse-section radionuclide cisternography has provided superior definition of these lesions because of its ability to separate the overlapping CSF compartments about the base of the brain, thus offering a relatively unobstructed view of the affected cisterns. The posterior fossa, the brain stem, the superficial regions of the cerebellar and cerebral hemispheres, and the adjacent subarachnoid spaces are difficult areas both for nuclear imaging and for radiographic contrast examination. This seems to be true also of computerized axial transverse-section transmission scanning. Transverse-section radionuclide cisternography should provide an additional benign method of obtaining useful anatomic information about these areas, similar in some respects to the information obtained with pneumoencephalography.

REFERENCES

1. Benson DF, Le May M, Patten DH, et al.: Diagnosis of normal-pressure hydrocephalus. *N Engl J Med* 283: 609–615, 1970

2. Harbert JC: Radionuclide cisternography. *Semin Nucl Med* 1: 90–106, 1971

3. Kieffer SA, Wolff JM, Westreich G: The borderline scinticisternogram. *Radiology* 106: 133–140, 1973

4. James AE, DeLand FH, Hodges FJ, et al.: Cerebrospinal fluid (CSF) scanning: Cisternography. *Am J Roentgenol Radium Ther Nucl Med* 110: 74–87, 1970

5. Kuhl DE, Sanders TP: Comparison of rectilinear vertex and transverse section views in brain scanning. *J Nucl Med* 11: 2–8, 1970

6. Kuhl DE, Sanders TP: Characterizing brain lesions with the use of transverse section scanning. *Radiology* 98: 317–328, 1971

7. Hounsfield GN: Computerized transverse axial scanning. Part 1. Description of system. *Br J Radiol* 46: 1016–1022, 1973

8. Ambrose J: Computerized transverse axial scanning (tomography). Part 2. Clinical application. *Br J Radiol* 46: 1023–1047, 1973

9. New PFJ, Scott WR, Schnur JA, et al.: Computerized axial tomography with the EMI scanner. *Radiology* 110: 109–123, 1974

10. Kuhl DE, Edwards RQ: The Mark III scanner: A compact device for multiple view and section scanning of the brain. *Radiology* 97: 563–570, 1970

11. Kuhl DE, Edwards RQ, Ricci AR: Quantitative section scanning using orthogonal tangent correction. *J Nucl Med* 14: 196–200, 1973

12. Kieffer SA, Wolff JM, Prentice WB, et al.: Scinticisternography in individuals without known neurological disease. *Am J Roentgenol Radium Ther Nucl Med* 112: 225–236, 1971

13. Harbert JC, Reed V, McCullough DC: Comparison between ^{131}I-HISA and ^{169}Yb-DTPA for cisternography. *J Nucl Med* 14: 765–768, 1973

14. Mamo L, Houdart R: Radioisotope cisternography contribution to the diagnosis of cerebellopontine angle tumors. *J Neurosurg* 37: 325–331, 1972

15. Otto H, Fiebach O, Sauer J, et al.: Cerebral scintigraphy in relation to roentgenological methods for detection of tumors situated in the sellar region and the posterior fossa. *Neuroradiology* 4: 30–35, 1972

16. Salmon JH, Gonen JY, Brown L: Ventriculoatrial shunt for hydrocephalus ex-vacuo psychological and clinical evaluation. *Dis Nerv Syst* 32: 299–307, 1971

17. Trotter JL, Luzecky M, Siegel B, et al.: Cerebrospinal fluid infusion test: Identification of artifacts and correlation with cisternography and pneumoencephalography. *Neurology* 24: 181–186, 1974

18. Samuelson S, Long DM, Chou SN: Subdural hematomas as a complication of shunting procedures for normal pressure hydrocephalus. *J Neurosurg* 37: 548–551, 1972

19. Front D, Beks JWF, Penning L: Porencephaly diagnosed by isotope cisternography. *J Neurol Neurosurg Psychiatry* 35: 669–675, 1972

20. Goluboff LG: Arachnoid cyst of the posterior fossa demonstrated by isotope cisternography. *J Nucl Med* 14: 61–62, 1973

21. Harbert JC, James AE: Posterior fossa abnormalities demonstrated by cisternography. *J Nucl Med* 13: 73–80, 1972

22. Halpern SE, Alazraki N, Hurwitz S, et al.: Changes in radioisotope cisternogram in cerebrovascular occlusive disease. *J Nucl Med* 13: 493–497, 1972

23. Rinaldi I, Harris WO, DiChiro G: Radionuclide cisternography in subdural hematomas. *Radiology* 105: 597–602, 1972

24. Otto H, Sauer J, Fiebach O, et al.: Myelo-scintigraphy in preoperative evaluation of space occupying lesions in the spinal canal. *Fortschr Geb Roentgenstr Nuklearmed* 116: 766–772, 1972