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The Comparison between Sensitivity and Resolution Based on a
Clinical Evaluation with the ACRH Brain Scanner

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The Argonne Cancer Research Hospital (ACRH) brain scanner, built in the early 1960's, was the first single organ scanner constructed (see Fig. 1). It is gratifying to note that this concept of devising one instrument for one type of examination has been expanded by other investigators [1,2,3].

This sophisticated scanning device is intermediate in sensitivity between most conventional scanners and stationary detector systems such as the Anger camera. In our 700 bed hospital complex at the University of Chicago, the demand for brain scans keeps the brain scanner in use on a full time basis. Virtually all of our patients are examined on this instrument, often in conjunction with dynamic studies on the gamma camera. A patient is rarely so ill that he cannot be scanned, but when this does occur, the gamma camera can still be used. We believe that diversification and specialization of instrumentation are not only desirable, but will eventually be considered routine in modern nuclear medicine facilities [4].

The ACRH brain scanner uses four collimated detectors arranged in opposing pairs which scan the head concurrently, and yield simultaneous lateral or anterior and posterior photoscans recorded with a data blending system. High resolution collimators are utilized (see Fig. 2), and the resultant loss in sensitivity is offset by the multiple detectors. Consequently, it is possible to obtain high quality brain scans in both laterals and anterior and posterior projections with as little as 20 minutes of

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Fig. 1.--The Argonne Cancer Research Hospital (ACRH) brain scanning system. The four collimated detectors displayed are arranged in opposing pairs to scan the head concurrently. A photoscan readout with a data blending system is used.

Right--the position of the patient for lateral scanning.

Left--the position of the patient for anterior and posterior scanning.

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A Comparison between Sensitivity and Resolution
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Fig. 1.

Top

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Fig. 1.

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Fig. 2.--Modulation transfer function (MTF) curves for a variety of different collimators. All were done in air, by taking the Fourier transform of a line spread function, and, except for the gamma camera, all were done at the focal point of the collimator. Although the MTF curves of the Picker 19 hole and collimator "A" are similar at the focal point, collimator "A" has a higher MTF at all other distances because its field of view is less divergent.

total scanning time per patient for all four views. It is our practice to use an adult dose of 10 mCi of technetium-99m pertechnetate, and to begin scanning 10 minutes after intravenous administration. In the last 9 months of the study, 0.5 gm of perchlorate was given orally immediately before the tracer was injected. Representative examples of a variety of lesions are shown in Fig. 3.

It is the purpose of this communication to present a clinical evaluation of the ACRH brain scanner to determine whether the detection of focal intracranial disease can be improved with better resolution as compared with conventional scanning systems, and to discuss the effect and clinical significance of improved resolution on the characterization of lesions.

Methods

All available autopsy and surgical reports were reviewed for the period August 1963 through September 1967, to yield cases with proven focal intracranial lesions exclusive of cerebral vascular accidents. Eighty-five cases were found in which brain scans had been performed, and these comprise the group in this study. Since scan diagnostic criteria were not well established in the early years, 41 normal cases spread over this time period were intermixed with the lesions and the entire series of 126 cases was reinterpreted by one of us (A.G.) without knowledge of the patient's history or physical findings, and with all identifying marks on the scans concealed. The diagnostic results are shown in Table I.

From August 1963 to October 1965, the collimators used were designed for mercury-203. The collimator had a focal length of 10 cm, a 2.5 cm diameter view, and a long depth of field. From October 1965 through September 1967, technetium collimators with a 7.5 cm focal length, a 1.73 cm diameter view, and a long depth of field were utilized. Both scanner and collimators are described in detail by Beck et al. [5]. When the technetium collimators were used, the count rate dropped to 0.77 of that with the ^{203}Hg collimators. To compensate for the decreased sensitivity, the scanning time was increased by a factor of two on the average so that the total counts collected per scan were greater by about 33% for the high resolution scans. This should permit even greater tumor detectability with the technetium collimators. The modulation transfer function of both collimators is shown in Fig. 2.

Results

The overall accuracy of the series as well as a comparison between both types of collimators is shown in Tables I and II. In some cases,

TABLE I

Breakdown of present series of autopsy or surgically proven brain scans
done with 10 mCi technetium-99m pertechnetate on the ACRH
brain scanner from August 1963 to September 1967

	Total	+	(-)
Astrocytoma	16	10	6
Glioblastoma	9	8	1
Meningioma	20	20	0
Metastases	11	11	0
Abscess	3	3	0
Chromophobe Adenoma	6	4	2
Craniopharyngioma	2	1	1
Acoustic Neuroma	5	3	2
A-V Malformation	3	3	0
Other	10	8	2
Total	85	71 (84%)	14

TABLE II.--Composite Data from 6 Institutions

SERIES		Total	A C R H "A" "B" Collimator		Quinn	Witcofski	Schmukler	Overton	Goodrich
<u>Lesion</u>									
Astrocytoma	+ total	10/ 16	4/ 4	6/ 12	22/ 30	13/ 18	7/ 12	5/ 5	19/ 21
Glioblastoma	+ total	8/ 9	4/ 5	4/ 4	83/ 85	23/ 24	10/ 10	23/ 25	16/ 18
Meningioma	+ total	20/ 20	10/ 10	10/ 10	51/ 55	5/ 5	11/ 11	23/ 24	16/ 16
Metastases	+ total	11/ 11	2/ 2	9/ 9	88/ 96	20/ 21	16/ 20	20/ 22	26/ 30
Overall Results	+ total	49/ 56	20/ 21	29/ 35	244/ 266	61/ 68	44/ 53	71/ 76	77/ 85
Overall Percentage		88%	95%	83%	92%	90%	83%	93%	90%
Instrument	))))		A C R H Brain Scanner		Pho/ Dot	Magna- Scanner	Magna- Scanner & Pho/ Dot	Magna- Scanner	Modified Nuclear/ Chicago 1705
Crystal Diameter			four 9.2 cm		7.5 cm	7.5 cm	7.5 cm	7.5 cm	7.5 cm
Collimator(s)			"A"	"B"	19 hole	19 hole, Low E 31 hole	19 hole	19 hole	Special 91 hole Low E
Agent			^{99m}Tc - Pertechnetate				Mercury - Chlomerodrin

Fig. 3.--Examples of scans on the ACRH brain scanner.

- No. 1: Normal posterior view--Note the excellent resolution of the transverse sinuses which are visible all the way down to the jugular foramen.
- No. 2: Normal lateral view--Note the visibility of the sagittal venous sinus in its posterior extent separated from the activity in the overlying skin of the scalp. In addition, note the detail in the region of the ethmoid and sphenoid sinuses, an area that is usually black on conventional brain scans.
- No. 3: Lateral view showing an acoustic neuroma (arrow).
- No. 4: Frontal view showing a left frontal astrocytoma above the left orbit.
- No. 5: Lateral view demonstrating a carotid siphon aneurysm (arrow).
- No. 6: Marked distortion of the skull on posterior projection caused by Paget's disease.
- No. 7: Lateral view showing excellent resolution of a tentorial meningioma growing as a sheet-like tumor between the cerebral hemispheres. This mid-line tumor is well resolved.
- No. 8: Lateral view showing a huge sphenoid ridge meningioma.
- No. 9: Anterior view showing a much smaller meningioma in the medial one-third of the sphenoid ridge (arrow).

however, it was possible to distinguish significant structure within the lesion. This consisted of a central area of diminished uptake (the "doughnut" configuration). The criteria for making this diagnosis were that the central cold area be clearly within the lesion, that the region of diminished uptake approximate uptake in the adjacent normal brain, and that the maximum diameter of the region of diminished uptake be at least one-fifth of the overall diameter of the lesion.

Eight such cases (i.e., 10%) were discovered. Seven of the eight were diagnosed with the technetium collimators, suggesting the need for high resolution if this configuration is to be appreciated. Recently a patient was studied with both sets of collimators (see Fig. 4). The low activity in the central portion of the lesion was readily apparent with the technetium collimators, but virtually obscured with the lower resolution collimators designed for mercury-203. This lends further support to this concept. Of these 8 cases, 4 were glioblastomas, one was a cystic astrocytoma, 2 were abscesses, and in one case 2 metastases--both presenting as "doughnuts"--were demonstrated. Examples of the "doughnut" configuration are shown in Fig. 5.

Discussion

The overall diagnostic accuracy of this series is directly comparable with that reported by other workers [6,7,8,9,10]. It is pertinent to recognize that these scans--interpreted without the benefit of history or physical findings--have been made to stand by themselves. The overall accuracy of the series would be slightly improved if available clinical data had also been utilized. For example, in reviewing the astrocytomas that were missed (scan normal), one case was found that was correctly diagnosed when reported initially. This brain scan, however, was supplemented with a dynamic study on the gamma scintillation camera--1600 channel multi-parameter analyzer complex which provided additional information [11,12].

Because the probes of the ACRH brain scanner are fixed, special angulated views of the posterior fossa are not possible, and it might be argued that this resulted in a lower diagnostic accuracy in this region, thereby increasing the chance of missing astrocytomas. The chin is routinely flexed for the anterior and posterior views, however, and the posterior fossa is usually well visualized (see example 1, Fig. 3). In addition, review of the six astrocytomas missed shows that only two were posterior fossa lesions.

For the last nine months of this series, it has been our practice to premedicate the patient with oral perchlorate. Welch and Potchen [13] have stated that with perchlorate there is an increased amount of pertechnetate in the vascular space in the first two to three hours following administration of the nuclide. They postulate that this increase in patient

Fig. 4.--Low and high resolution brain scans performed sequentially within one hour following injection of 10 millicuries of technetium-99m pertechnetate. The patient was pretreated with one-half gram of oral perchlorate.

- No. 1: Lateral view with the low resolution mercury-203 collimator. The lesion is easily seen, but the internal configuration of the lesion as well as its separation from the calvarium are obscured.
- No. 2: High resolution technetium collimator scan confined to the area of the lesion. The outline of the head is traced for orientation purposes. The "doughnut" configuration is more clearly displayed, and it is easier to separate the lesion from the overlying calvarium and sagittal sinus.

Fig. 5.--Examples of lesions with central areas of diminished uptake (the "doughnut" configuration).

Nos. 1,2,3: Lateral brain scans in patients with glioblastomas.

No. 4: Lateral brain scan in a patient with an abscess.

No. 5: Posterior brain scan, showing a right occipital metastasis adjacent to the sagittal sinus.

No. 6: Left occipital cystic astrocytoma.

background may have an adverse effect on tumor detection. We are unable to provide support for this thesis since, although these scans were made within the first hour after technetium injection, our series is equally divided. Three of the six lesions missed received no perchlorate.

Since two sets of collimators were used for these scans, the series itself provides data comparing low and high resolution collimators. Fig. 2 clearly shows the improved resolution in collimator B designed especially for technetium compared with collimator A designed for mercury-203. It is clear from Table II, however, that there is no evidence that the high resolution technetium collimators are superior. If anything, the data suggest the opposite. A controlled series utilizing both sets of collimators on all patients would have been ideal, but this was not possible since the technetium collimators were not available until midway through these studies, and at this time the clinical load was great enough to discourage the undertaking.

Because the numbers are small, an alternative analysis was also used. The results of this series were compared with those previously reported by others. Fig. 2 demonstrates that both of the collimators utilized on the ACRH brain scanner have equal or better resolution than the commercial collimators used by most of the investigators in the comparison series.

Table II and Fig. 6 show the results of this type of analysis. In order to study comparable groups of neoplasms, all the series have been standardized by including only astrocytomas, glioblastomas, metastases, and meningiomas. These data also indicate that the high resolution collimators used on the ACRH brain scanner provide no more accurate detection than those on conventional scanners.

To study these conclusions further, figures of merit were plotted for the two collimators in our series. The results are shown in Fig. 7. It is clear that the higher frequency components are better imaged by the high resolution technetium collimator. For example, at a distance of 7.5 cm from the collimator face, frequencies above 0.07 cycles per cm have a higher figure of merit. It is not clear why this does not provide an increase in detection rate for the brain lesions. At least two possibilities should be considered. The first is that the higher frequencies imaged best by collimator B are of little importance in visualizing brain tumors. At this time, the relationship between frequency content of images and perception is still unclear [14,15]. A second alternative is that by the time any lesion that can be diagnosed with currently available nuclides reaches a size significant enough to cause symptoms, it is so large that the lower frequency components of its visual spectrum predominate. Future research is necessary to better understand this problem. Appropriate phantom studies, for examples, might be highly informative.

Fig. 6.--Bar graphs showing the consistency of overall diagnostic accuracy for the detection of brain tumors from six institutions. Each series was standardized to include only astrocytomas, glioblastomas, meningiomas, and metastases.

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A Comparison between Sensitivity and Resolution
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Fig. 7.

Top

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Top

Fig. 7.--Figure of merit (Q) versus spatial frequency (ν) for collimators "A" and "B." The data were obtained from a line source in water with a 2 cm air gap between the water and the collimator face. Calculations were made from the equation

$$Q \propto G e^{-\mu_0 z_0} \text{MTF}^2$$

where

G = geometrical efficiency.

z_0 = depth of the source in water.

Top--figure of merit at 7.5 cm from collimator face.

Bottom--figure of merit at 5.0 cm from collimator face.

Significance of High Resolution Brain Scans

To assess whether the characterization of lesions improved noted in this series (as manifested by the "doughnut" configuration) was of clinical significance, the entire series of lesions with central radiolucency was reviewed with cerebral angiograms and/or pneumograms by our neurosurgical colleagues. It was their impression that the accurate definition of the lesion was of significant surgical help. In particular, it is extremely valuable to the neurosurgeon to have as much information as possible pre-operatively about the precise localization of any lesion in relation to vital structures such as the sagittal sinus, or tentorium. In addition, when the brain scan indicates that the lesion may be cystic, or have a necrotic center, this may radically alter the surgical approach. For example, in case 2 of Fig. 4, the lesion was diagnosed as a glioblastoma from its characteristic angiographic appearance. Since the lesion was located in the left temporal lobe, it would have been ordinarily considered inoperable. In this instance, because of its cystic nature an occipital approach with insertion of an aspirating needle would be feasible.

Although the etiology of the "doughnut" form of some lesions is not completely clear, particularly in metastatic disease, recent work by Scatliff et al. [16] has shown a very rich peripheral microvascular supply in glioblastomas which correlates well with appearance of the scan described in this paper. It remains a moot point whether nuclide uptake is due to this neovascularity per se or associated breakdown of the "blood-brain barrier."

Conclusions

A series of 85 proven brain tumors scanned on the ACRH brain scanner was analyzed to see if cases scanned with high resolution collimators were detected more often than cases scanned with lower resolution collimators. In addition, since both collimators had an equal or better resolution than a commercial brain scan collimator for a 7.5 cm diameter crystal (see Fig. 2), the entire series was compared with the results of other investigators using this type of detector. The data show that detection rate was not increased by using high resolution brain scans.

High resolution scanning, however, makes it possible to recognize intrinsic structure within certain lesions. In this series, a central area of diminished uptake (the "doughnut" configuration) was found in 10% of the scans. Of these 8 cases, 4 were glioblastomas, 1 was a cystic astrocytoma, 2 were abscesses, and 1 was metastases.

Since both the precise localization of a lesion in relation to vital structures and information about the possible "cystic" nature of a lesion

are of significant importance to the neurosurgeon, this series suggests that a rational approach to brain scanning with currently available nuclides will include: First, a preliminary multiview screening scan with high efficiency and low resolution collimators; next, in those cases where an abnormality is detected, a follow-up view with a high resolution collimator centered through the lesion. This type of study can be done readily on commercial scanners, using thyroid collimators for the follow-up views. This technique will provide maximum assurance that all of the relevant information available from brain scanning has been obtained.

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Figure Legends

Fig. 1.--The Argonne Cancer Research Hospital (ACRH) brain scanning system. The four collimated detectors displayed are arranged in opposing pairs to scan the head concurrently. A photoscan readout with a data blending system is used.

Right--the position of the patient for lateral scanning.

Left--the position of the patient for anterior and posterior scanning.

Fig. 2.--Modulation transfer function (MTF) curves for a variety of different collimators. All were done in air, by taking the Fourier transform of a line spread function, and, except for the gamma camera, all were done at the focal point of the collimator. Although the MTF curves of the Picker 19 hole and collimator "A" are similar at the focal point, collimator "A" has a higher MTF at all other distances because its field of view is less divergent.

Fig. 3.--Examples of scans on the ACRH brain scanner.

- No. 1: Normal posterior view--Note the excellent resolution of the transverse sinuses which are visible all the way down to the jugular foramen.
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- No. 1: Lateral view with the low resolution mercury-203 collimator. The lesion is easily seen, but the internal configuration of the lesion as well as its separation from the calvarium are obscured.

Fig. 4 (continued)

- No. 2: High resolution technetium collimator scan confined to the area of the lesion. The outline of the head is traced for orientation purposes. The "doughnut" configuration is more clearly displayed, and it is easier to separate the lesion from the overlying calvarium and sagittal sinus.

Fig. 5a.--Examples of lesions with central areas of diminished uptake (the "doughnut" configuration).

- Nos. 1,2,3: Lateral brain scans in patients with glioblastomas.
 No. 4: Lateral brain scan in a patient with an abscess.
 No. 5: Posterior brain scan, showing a right occipital metastasis adjacent to the sagittal sinus.
 No. 6: Left occipital cystic astrocytoma.

Fig. 5b.--Color readout generated from black and white brain scans on a flying-spot color television scanner.

Top Row: Colors shown with wide density intervals. Red is "hot," blue is "intermediate," green is "cold."
 Both cases are abscesses.

Bottom Row: Narrow intervals giving a "fine-line" color display. Red is "hot," green is "intermediate," blue is "cold."
 The case on the left is a metastasis, and the right is a glioblastoma.

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