OPTIMIZATION OF TIMING AND POSITIONING OF THE TECHNETIUM BRAIN SCAN

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We have undertaken kinetic and positional studies to determine the most effective methods for obtaining scintiphotographs of the brain with intravenous radiopertechnetate. Because of the rapidly increasing use of brain scanning, nuclear medicine laboratories must be prepared to meet a pressing load of requests for this procedure with optimal techniques. Over 20 brain scans a week are often performed in the Radioisotope Laboratory of the Cincinnati General Hospital. Intravenous ^{99m}Tc-pertechnetate is used in nearly all cases, and more than half are done on a gamma camera (Nuclear Chicago Pho/Gamma). With this combination of isotope and instrument, all four conventional views can be obtained within 15 min from the time photography is started, provided the patient is ambulatory and cooperative. More time is required to cope with unconscious or combative patients.

There is a tendency to start scanning soon after injection of the isotope. This inclination is less marked with rectilinear scanning because of the longer time required to set up, execute and develop each view. It is routine in some laboratories (*1*), but not all (*2–4*), to wait at least 30 min after pertechnetate injection before starting the first rectilinear view. Some workers (*5*) have pointed out the possibility of missing lesions by starting rectilinear scanning too quickly after injection. In view of the opposing pressure of tight scheduling, we wished to determine the optimum time to perform the examination. In a group of relatively normal patients we observed counting rates over the lateral aspect of the brain from the time of injection until at least 1 hr later. The rates were compared with blood levels and with the clarity and character of photographs taken at frequent intervals.

Positioning of the patient is critical in brain scintiphotography. Ideal positioning was determined by our experience at this laboratory, and effects of malposition were evaluated. Certain special views were tried and found useful.

METHODS

Cases were selected from brain-scan requisitions sent to this laboratory. Patients chosen for special evaluation were ones anticipated as most likely to have negative scans; kinetic studies reported are in 20 patients subsequently found to have normal scans. These individuals ranged in age from 15 to 71 yr (mean of 40 yr); the majority had idiopathic epilepsy or psychiatric abnormalities. There was no pretreatment with perchlorate or atropine.

Patients were positioned for lateral view supinely beneath the crystal of a commercial gamma camera (Nuclear Chicago Pho/Gamma Model 6401). Maintenance of this position is facilitated by having the individual rest on a wedge-shaped foam rubber cushion 36 in. long, 17 in. broad and 9 in. high. If the selected view is a right lateral, for example, placement of this cushion under the right side of the body diminishes the degree of head rotation necessary for a true lateral view. The surface of a 4,000-hole nonfocusing collimator was brought within ¼ in. of the patient's head. In most cases facial counts were excluded from the view of the crystal by a ⅛ in. lead shield applied over the face from the inferior edge of the crystal to the line between the external meatus of the ear and the outer canthus of the eye. The use of a shield is not a routine procedure. Shielding was applied solely for kinetic studies to minimize counts originating outside the cranial vault.

A short plastic Longdwel® catheter with obturator (Becton, Dickinson and Co.) was placed in a forearm or antecubital vein. After each blood specimen was taken, the obturator was dipped in heparin before re-insertion. Ten millicuries of ^{99m}Tc-pertechnetate were injected intravenously through a No. 20 needle in the arm not used for blood sampling. A timer and strip-chart recorder were started simultaneously at the completion of rapid injection. The

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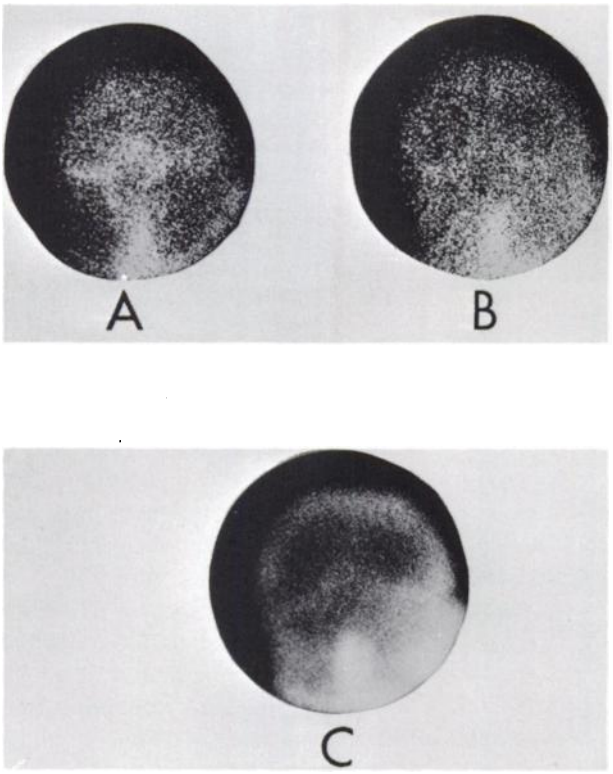

FIG. 1. Subject J.P. Three selections from serial right lateral views—unshielded for easier orientation. A: First 20,000 counts recorded; picture terminated 14 sec after completion of injection. Activity is seen in arterial structures (carotid, circle of Willis) and also in transverse venous sinus. B: 50–63 sec; technical settings unchanged from 1A. Detail is poor at this time and with this number of counts. Superior sagittal sinus visible (also outlined in a photograph taken from 16–30 sec after injection). Anterior projection is necessary for distinguishing carotid artery and parotid gland. C: 400,000 counts at 23 min after injection.

recorder, which monitored the counting rate from the pulse-height analyzer, was connected in series with a ratemeter set to a time constant of 0.5 sec. The window setting was 120 divisions, representing 24% of the maximum window width. Four to 6 Polaroid pictures were taken during the early seconds after injection; a setting of 10,000 counts (or 15,000–20,000 counts with facial activity included) was found to yield good pictures. After this initial period, the dot intensity was lowered and pictures with 200,000 counts (twice this many counts without facial shielding) were taken at 5–10 min intervals for at least 60 min after injection. The patients remained essentially motionless throughout the entire procedure. Blood samples (usually 10) were taken at intervals through the in-dwelling catheter needle with a disposable Tuberculin syringe. Each specimen consisted of 5 drops of blood delivered to a stoppered and heparinized serology tube which had been preweighed on an analytic balance. All blood specimens and a diluted aliquot saved from the injectate were counted for 1 min the following day in a shielded well crystal. Almost all blood counts fell within a range of 10,000–30,000 cpm/sample. The specimen tubes were reweighed and corrected for specific gravity according to the patient's hematocrit to give cpm/ml whole blood. On the basis of activity found in a diluted aliquot of injectate, results were normalized to yield % dose/ml whole blood. For purposes of interpatient comparison, whole-blood volumes were estimated by height and weight formulae proposed by Retzlaff (*6*). Blood counts could then be expressed as % dose in the patient's blood at a given time.

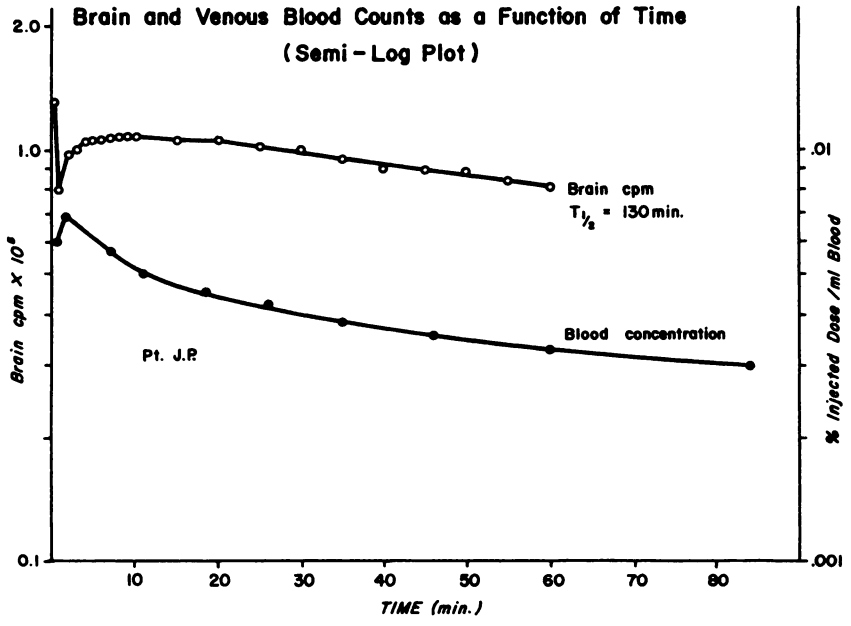

FIG. 2. Brain counting rates and venous blood concentrations for subject in Fig. 1 (J.P.). Maximum and minimum brain counts were recorded very early in 15-year-old individual (12 and 24 sec after injection). Plateau was relatively short and preceded a decline of half-time 130 min.

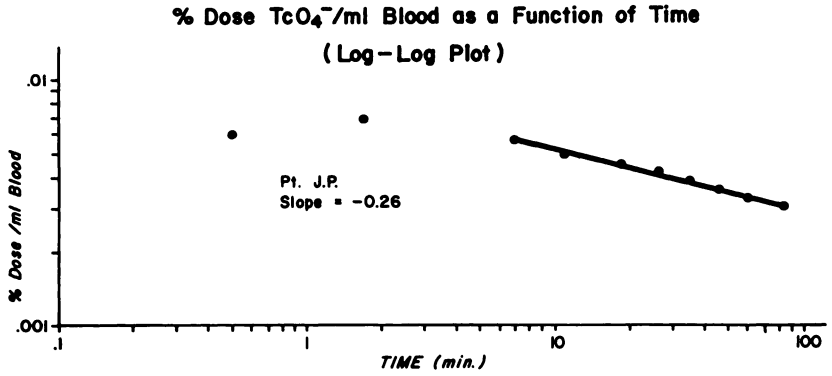

FIG. 3. Log–log plot of blood concentrations of subject J.P. Power-function decline may be compared with semi-log representation for individual in Fig. 2.

RESULTS

After injection of the bolus of pertechnetate, counting rates over the brain rose very rapidly to reach a maximum at 16 sec (Table 1). This counting rate, which was never again attained, already included counts from venous drainage of the brain. Shortly after this maximum was reached the lateral or transverse sinus was best visualized (Fig. 1A). Brain counting rates dropped rather precipitously (by 36%) to a minimum rate 42 sec after injection. Counts then rose to a plateau which lasted an average of 8 min before a gradual decline was discernible. The average effective half-time of this decline was 160 min. Thirty minutes after injection the observed brain counting rate was 89% of the plateau rate. Figure 2 depicts these events for the same subject shown in Fig. 1. In the four individuals whose salivary glands were within view of the crystal, there were no important differences in the timing of these phenomena. This similarity was found despite the fact that over half the counts on an unshielded view came from salivary glands. With shielding removed, a total of 450,000 counts were required to give an equal number of counts over the brain as were obtained on a 200,000 count view with facial structures excluded by lead.

TABLE 1. RESULTS AFTER INJECTION OF BOLUS OF ^{99m}Tc-PERTECHNETATE

Event (n = 20)	Mean	Std. dev.	Range	Median
Exponent of blood decline (applicable in all cases between 30 and 60 min)	−0.24	0.06	−0.13 to −0.33	−0.24
% fall from 30 min blood level between 30 and 60 min	14	4	7–21	16
% fall in observed 30-min brain cpm between 30 and 60 min	12	3	7–18	12
Half-time in minutes of brain cpm starting at 30 min	160	40	100–260	150
Time of maximum brain cpm (sec)	16	6	9–31	15
Time of minimum brain cpm (sec)	42	11	24–60	40
% fall from maximum to minimum brain cpm	36	11	10–54	38

Venous blood levels were highest 2 min after injection (range 0.6–5 min). Venous levels did not plateau as did brain counts but after reaching a maximum level declined in a manner well described in all cases by a power function with an average slope of −0.24 (time after injection expressed in minutes). The slope generally changed after 2–3 hr (7). Linear regression analysis revealed a significant age dependence at the 5% level for the blood-activity disappearance rate. With increasing age pertechnetate blood levels diminished more slowly, and the slope of decline became slightly less negative—by 0.25% for each year of age difference from 15–71 yr. Similar regression analyses revealed no significant age dependence for brain-kinetic phenomena. The curved decrement obtained by semilog plot and illustrated in Fig. 2 may be compared with the linear fit obtained on log-log plot and shown in Fig. 3. At 60 min 21% ± 3% (1 s.d.) of the original dose was still found circulating in blood, 29% ± 4% having been intravascular at 15 min and 24% ± 3% at 30 min. It might be anticipated that brain counts, partly capillary in origin, would correlate better with capillary blood concentrations than with antecubital vessel concentrations. No significant differences in levels were found, however, when fingerpuncture blood was compared with antecubital blood in the same patient.

Serial scintiphotos reflect the kinetic phenomena. After initial brief arterial visualization of carotids and circle of Willis, detail became poorest at the time when brain counting rates were lowest and the

TABLE 2. COMPARISON OF COLLIMATORS

Characteristic	Standard low-energy collimator	New low-energy collimator
Number of holes	1,000	4,000
Collimator thickness	1½ in.	1½ in.
Interior-hole dimensions	¼ in. dia.	3/32 in.[2]
Minimum thickness of lead septa	1/16 in.	1/32 in.
Rel. counting rate for $^{99m}Tc\ O^-_4$	1	0.25
Rel. exposure of crystal surface	5.6	1

venous blood level was still rising. Although prominent at 60 min, the transverse sinus was best visualized soon after injection (Fig. 1 A). The superior sagittal sinus area became outlined more slowly (Fig. 1 B) perhaps partly because of the greater contribution to this peripheral area by small emissary and diploic veins. Salivary-gland activity was apparent within 2 min and was intense by 15 min. Fifteen minutes after injection activity was also seen within the mouth and oropharynx.

Pictorial detail was improved by using a newly available low-energy collimator. Table 2 gives a comparison of this collimator with the standard low-energy collimator for the Pho/Gamma. The improved resolution of the new collimator is accompanied by a four-fold loss in counting rate; a 200,000-count lateral view of the unshielded skull can nonetheless be obtained in 2 min, ½ hr after injection.

Four of the 20 patients were studied a second time 90 min after oral administration of 200 mg of potassium perchlorate in a flavored vehicle. In these four cases there was much less of a decline in brain counts during the first minute. The ratio of counts recorded over the brain to counts recorded in the blood tended to be lower, but the point at which the maximum value was attained did not change after perchlorate. The choroid plexus, when apparent beforehand, was rendered invisible by the perchlorate pretreatment. It seems necessary to allow an interval of about 60 min between the oral perchlorate and intravenous pertechnetate to be certain of eliminating choroid activity.

Figure 4 illustrates the occasional need for special views to clarify the presence or absence of equivocal abnormalities on conventional views. Right-sided weakness in a man with bronchogenic carcinoma was probably caused by a metastatic lesion not seen on anterior view and only equivocally recognizable on left lateral view. With the patient seated, an abnormality was clearly visualized by inclining the crystal 30 deg down from vertical for anterior and left lateral views.

DISCUSSION

Although part of the brain counts recorded are intravascular (especially in early minutes) it would seem desirable to obtain scintiphotos when the camera brain count/antecubital blood count ratio is maximum. This point was generally approximated by 30 min although usually not actually attained until 45–60 min after injection. Oldendorf and Kitano (*8*) refined the analysis of brain counts for isotopes other than technetium by an approach in which an attempt was made to subtract from counts recorded over the brain those counts that are intravascular in origin. Supplementary phantom work would be necessary for a strict application of Oldendorf's method to our data. The rate of uptake of radioactivity by neoplasm is not indicated either by the course of observed brain count/blood ratios nor by brain counts corrected for blood content. The course of the ratio does, however, indicate the development of a relatively stable cranial distribution of radiopertechnetate 30–60 min after injection. If

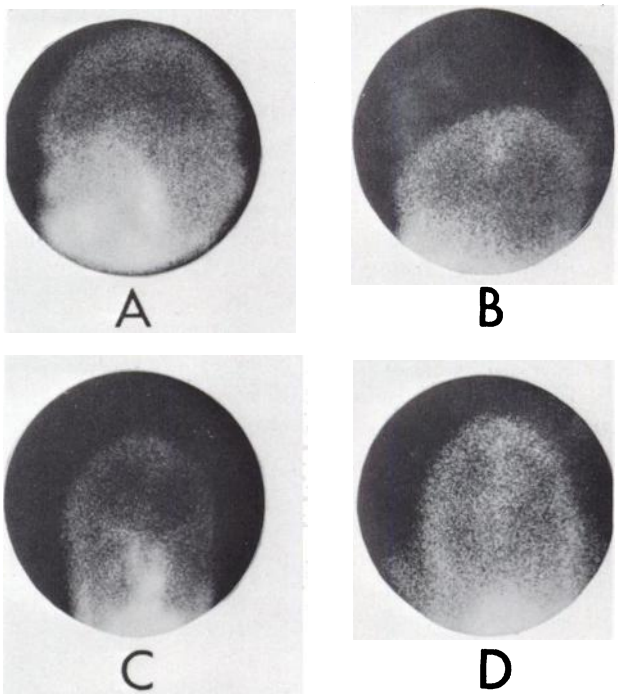

FIG. 4. Patient J.B. Right upper lobe lung mass, tissue-proven node metastasis and severe right-sided weakness. Patient received cobalt therapy to head subsequent to brain scan and positive angiogram. Patient expired but no autopsy was performed. A and C: Conventional left lateral and anterior views with patient seated and crystal face vertical. Usual camera prominence of temporal muscle may be noted in 4A. Metastasis to left cerebral cortex is brought out by inclining crystal down 30 deg from vertical toward patient's feet on left lateral (B) and anterior (D) positions. Equal number of counts collected for all pictures; no change in technical settings.

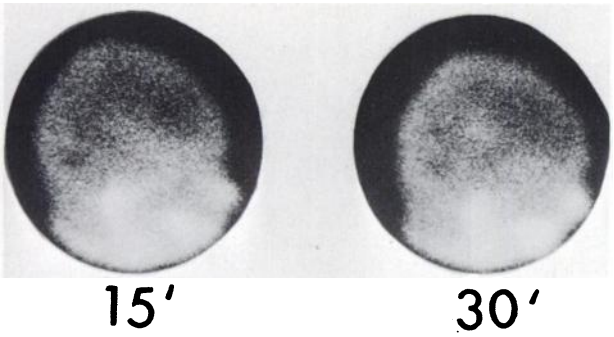

FIG. 5. Patient F.H. Marked improvement in demonstration of autopsy-proven metastatic lesion at 30 min compared to 15 min after injection. Equal number of counts collected; no changes in technical settings.

the study is performed during this interval, brain and blood levels will be falling almost proportionately —brain counting rates by 12% and blood concentration by 14% of the 30-min values.

Matthews (*9*) examined tissue content of pertechnetate in rats bearing either one of two types of sarcoma. Analysis of ratios of the data shows that while brain/plasma and brain/blood figures remained constant for one tumor (between 34 min and 4 hr), these ratios increased (between 50 min and 4 hr) for rats with the other tumor type. Disparity is also found between the two tumors in that tumor/plasma, tumor/blood and tumor/brain ratios rose in one group and fell in the other with the passage of time.

Figure 5 demonstrates the practical importance of insisting upon an interval between injection and examination. This record is one of several in our files of patients with a neoplasm which did not visualize for some time. Delayed visualization has also been noted with subdural hematomas. Some primary and secondary tumors have been noted to visualize intensely within the first 5 min after injection. On subsequent arteriography these lesions have thus far been characterized by marked tumor stain. Figure 6 illustrates one condition in which it is important *not* to delay scanning after injection. The patient has an arteriovenous malformation as shown by angiography. After injection of ^{99m}Tc-pertechnetate the lesion was noted in about 30 sec and best seen at about 3.5 min; at 31 min it was not well shown. In another case an arteriovenous malformation was best seen between 0.5 and 5 min. If this abnormality is suspected, it is advisable to inject the patient in front of or under the camera in the position deemed most likely to reveal the malformation. The first view should be started upon injection, and views of other positions should be taken within the first 5 min.

Afifi *et al* (*10*), working with ^{203}Hg brain scans, found a marked difference in mercury blood clearance between young and old individuals and established different optimum scanning times depending upon the age of their patients. In the case of pertechnetate the age-dependent differences are not of such a magnitude (at least over the range tested of 15–71 yr) to necessitate any adjustments in scanning time.

Some authors (*11,12*) have commented on the potential usefulness of data from the arterial phase soon after injection. We agree but wish to emphasize that this phase is very short-lived and unlike arteriography is not suited to repeat administration in case the initial positioning was not satisfactory. The highest counting rates found in the 20 patients reported here occurred at 16 sec. Venous activity is present before that time: the transverse sinus is prominently displayed within the first 10,000 counts after intravenous injection. Intracranial structures referred to elsewhere (*13*) as arterial as long as 19 sec after rapid injection may include significant venous activity. It is not understood why after intravenous injection venous levels of pertechnetate may occasionally require as long as 5 min to reach a maximum.

Compared to rectilinear scans, gamma-camera scintiphotos are more sensitive to minor degrees of rotation, especially in the posterior position. If the

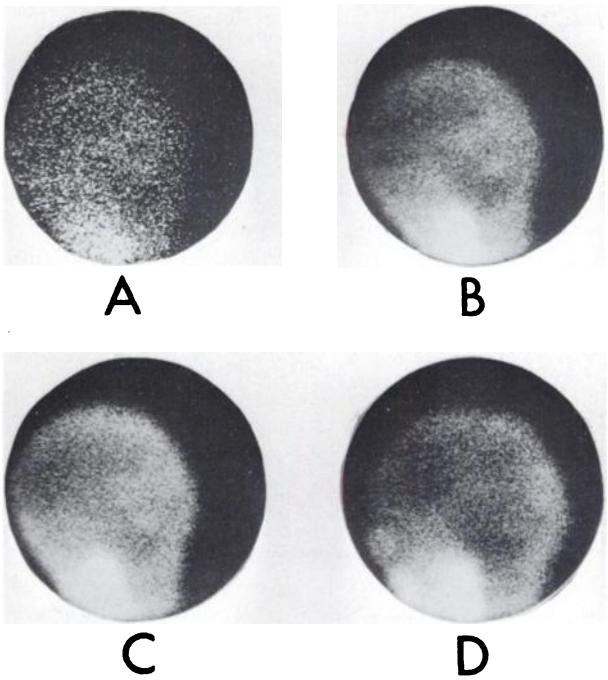

FIG. 6. Left occipital arterio-venous malformation (patient W.M.). A: Abnormality can already be identified with 8,500 counts taken 24–31 sec after injection. B: Optimum visualization with 200,000 counts at 3.5 min. C: 17 min after injection. D: Malformation is not well visualized at 31 min. No change in technical settings for 6B, 6C and 6D.

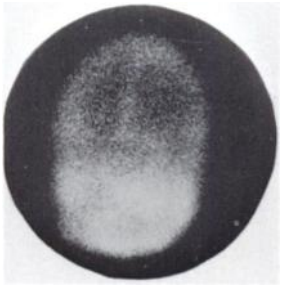

FIG. 7. Rotated posterior view with nose to right. Activity at superior portion of right hemisphere is accentuated with such malposition. Rotation is sufficient to displace torcula to left.

nose is rotated slightly to the right, there is increased activity over the superior portion of the right hemisphere. If rotation to the right is marked (Fig. 7), the superior sagittal sinus is displaced or bowed to the left because the area of the right hemisphere appears increased at the expense of the left. The concentration of radioactivity may even be greater on the right, simulating the appearance of a superficial lesion such as a right subdural hematoma. On posterior view the posterior fossa may be approached by a view in which (for a seated patient) the crystal is inclined down 45 deg (Fig. 8 A). This view contrasts with the positioning used for radiographic visualization of the posterior fossa where the x-ray beam is directed parallel to Reid's baseline. The comparable scintiphotographic view is (for a seated patient) inclination of the crystal 15 deg upward. Figure 8 B illustrates this position.

On anterior view if the nose has been turned to the right the left hemisphere appears more intense, especially inferolaterally where scalp musculature is thickest. On anterior view the hemispheres are best displayed when there is sufficient head flexion to keep the supra-orbital ridges from being clearly identifiable (Fig. 9 A). The intense activity in the region of the cavernous sinus and circle of Willis should not be separated from facial activity (Fig. 9 B) to prevent intrusion into the area of the cerebral hemispheres.

In general the most difficult view to interpret in brain scintiphotography is the lateral view. Temporal musculature is much more prominent with this technique than with rectilinear scanning (Fig. 10) where the contribution of superficial activity is diminished by a focusing collimator. The surface of a straight-bore collimator is the plane in sharpest focus, and as a consequence the transverse sinus and Temporalis muscle are more prominent in scintiphotography than in rectilinear scanning. With the Pho/Gamma it is also important to be certain that the center photomultiplier tube has been "detuned" to eliminate the central bright spot (*14*). Such a spot can accentuate the normal activity over temporal musculature to the point of simulating a lesion. The correctness of lateral positioning can sometimes be judged by inspection of oral cavity and parotid activities; if they are not well separated, the sagittal skull plane may not have been parallel to the crystal. If the head is rotated so that the nose is turned away from the crystal, there may be excess radioactivity diffusely over the posterior half of the skull.

An overhead or crown view is simple to obtain with a gamma camera, especially if the patient can sit upright, in which case the crystal can be lowered over the patient while he is seated in a chair. Because of the straight-bore collimation, it is necessary on a crown view to shield body radiation with an ordinary lead apron. Patients are examined in a chair rather than on a stretcher whenever possible. Installation of wheels on the examining chair has been of further help in positioning the patient rapidly. It is sometimes essential to steady the patient's head by holding it against the collimator or protective collimator cover during the exposure. One drawback of currently available gamma cameras is the lack of easily manipulable holding devices similar to those available for x-ray diagnosis. Immobilization requires that the patient's head be held manually by another person.

With rectilinear scanning, visualization of superficial lesions is improved by moving the crystal farther from the patient. Since the appropriateness of this maneuver may easily be overlooked, a camera device may be better for detecting a superficial lesion such as a subdural hematoma. Figure 10 illustrates the excellent resolution possible with superficial abnormalities. The patient had undergone craniotomy 3 years before for decompression after a subarachnoid hemorrhage. Increased activity has long been associated with post-operative states (*15,16*) but the scintiphotographic technique shows neovascularization very clearly in the precise area where the operative flap was raised.

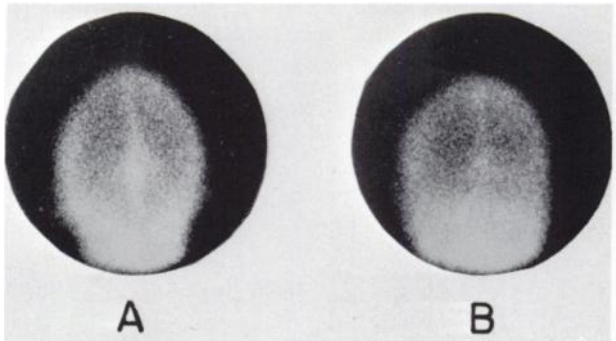

FIG. 8. A: Posterior view with crystal inclined down 45 deg. toward (seated) subject's feet. View might be preferred over that of 8B for posterior fossa visualization. B: Crystal is inclined upward 15 deg from vertical; subject seated. There is considerable interfering activity in posterior fossa area.

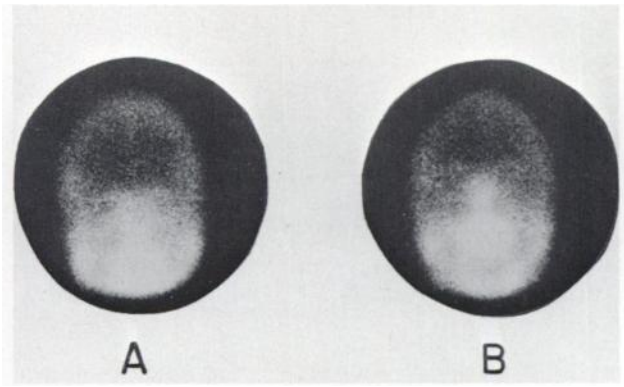

FIG. 9. A: Good anterior positioning with near-optimum view of area of cerebral hemispheres. Head is in slight flexion. B: Poor anterior-positioning as result of extension of head. Cavernous sinus and orbital areas impinge on region of interest (hemispheres).

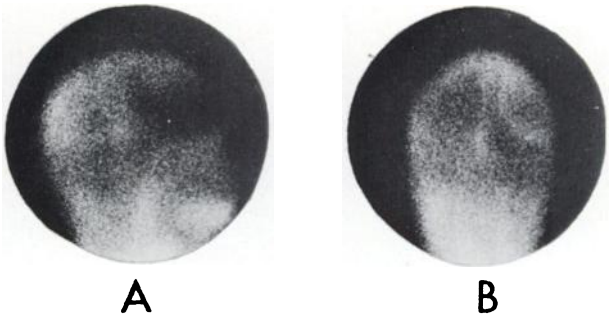

FIG. 10. Three years before brain scan patient had undergone craniotomy for decompression after subarachnoid hemorrhage. Excellent resolution of superficial neovascularization is apparent in right lateral (A) and posterior (B) views.

SUMMARY

Kinetic studies were performed with intravenous pertechnetate in 20 essentially normal individuals. Counting rates over the brain followed a consistent pattern which is described and compared with the decline in blood counts. At 30 min the observed brain counting rate was 89% of the plateau level and was falling at a single exponential rate with a half-time of 160 min. The ratio of counts recorded over the brain to counts in peripheral blood rose to a maximum 30–60 min after injection. This change in ratio and the observation that some neoplasms are not distinguishable before 30 min make it reasonable to insist on a waiting period of at least 30 min before examining the injected patient. In patients with suspected A-V malformations early views (0–5 min) are of value because late photos may not show the lesion. Spuriously positive scintiphotographs are easily obtained by imperfect positioning, largely because of the accentuation of superficial activity. Recommendations for routine and special views are given.

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