Dynamic Cranial Computed Tomography: Preliminary Results

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Recent software additions to a CT scanner with a continuously rotating tube-detector system allow uninterrupted data collection after rapid intravenous contrast material injection. The highly flexible computer program can accommodate as many as 16 consecutive 3 sec scans, or various time intervals can be inserted between individual scans. A variety of intracranial lesions was studied in 35 patients using this dynamic scanning technique and the enhancement of normal gray and white matter was evaluated. Potential applications of this technique are discussed, with emphasis on the possibility of differentiating certain cerebral lesions by their early enhancement patterns and evaluating cerebrovascular occlusive disease.

Many improvements in the design and performance of computed tomographic (CT) scanners have occurred since the first units were installed in the early 1970s. Changes in both hardware and software components have brought about better data acquisition and manipulation methods. With the advent of faster scan times and new computer programs, a scanning technique called "dynamic computed tomography" has become feasible [1–7]. Dynamic CT consists of performing multiple rapid-sequence scans after the injection of contrast material. The contrast agent can be injected either intravenously or intraarterially [8, 9].

We describe our initial experience using a CT scanner with a continuously rotating tube-detector system for rapid data collection after intravenous contrast material injection. We have studied a variety of intracranial lesions using this technique, and the results in differentiating characteristic enhancement curves for brain lesions have been encouraging. We have also begun to examine the potential application of this method in evaluating patients with cerebrovascular occlusive disease.

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Materials and Methods

A Varian V-360-3 body scanner was used, which completes a full revolution of the continuously rotating tube and detector system in 3 sec. A computer program has been developed which permits a flexible scanning sequence over a 5 min period. Up to 16 consecutive 3-sec scans can be performed, giving 48 sec of uninterrupted data collection, or arbitrary time intervals can be inserted between individual scans [4].

Our current dynamic scanning sequence consists of continuous scans for 15 sec, followed by single scans with gradually increasing time intervals between them. Most data collection occurs within the first 2 min. The sequence can be continued for as long as desired, with the limitation that no more than 16 scans are done within the first 5 min. The series can be terminated at any point, although we usually scan to 20–30 min with 5–10

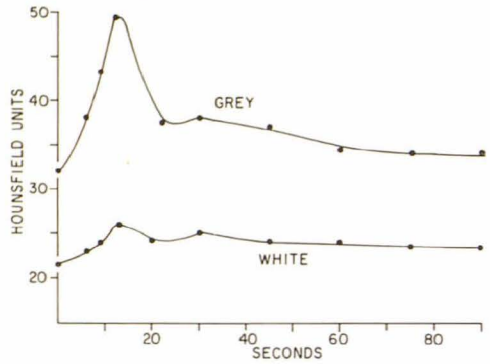

Fig. 1.—Comparison of gray and white matter attenuation coefficients versus time in normal patient. Gray matter has greater increase in attenuation than white matter after contrast material injection. Lower second peak is sometimes apparent, as in this case, reflecting recirculation of contrast agent.

min intervals between the last few images. A cursor is then used to outline the region of interest, after which statistics are automatically calculated. Time-density curves can be easily constructed with the data obtained by this technique.

Initially we injected 100 ml of 60% iothalamate meglumine (28.2 g iodine) as a rapid intravenous bolus through a 19 gauge needle or catheter in a large antecubital vein. However, it was difficult to inject this volume manually within a few seconds, and we feared that a mechanical injector might rupture an antecubital vein resulting in extravasation of contrast material. Consequently we have changed to a 50 ml bolus of 52% iothalamate meglumine and 26% iothalamate sodium (Vascoray, 20 g iodine) to facilitate rapid manual delivery of the contrast material, and the injection time is approximately 10 sec. The enhancement of intracranial lesions has been sufficient with this smaller volume.

It is generally useful to have a previous enhanced scan available to show the area of interest. A precontrast scan is made first, which is used to select the appropriate level for the dynamic sequence. The first scan in the dynamic series is begun about 8–12 sec after starting the injection of contrast material. This interval is within the average arm-to-head circulation time.

We have used this dynamic scanning technique to study 35 patients and have evaluated the following types of intracranial lesions: seven pituitary adenomas, six meningiomas, five infarcts, four astrocytomas, three metatases, two aneurysms, two arteriovenous malformations, and one contusion. Five patients had abbreviated (90 sec) dynamic scans as part of complete CT series to exclude brain pathology, and their normal scans were used for gray-matter comparisons. Graphs showing Hounsfield units versus time were plotted from data for each patient in an attempt to characterize the pattern of contrast material accumulation and disappearance in each type of lesion or in normal gray and white matter.

Results

The change in tissue attenuation coefficients is abrupt and prominent during the first passage of the bolus of contrast material through the brain. Both gray and white matter show a rapid change in attenuation, followed by slowly decreasing density thereafter (fig. 1). Gray matter enhancement is more pronounced than that of white matter. However, part of this difference is due to opacification of arterial branches over the cortex and within sulci.

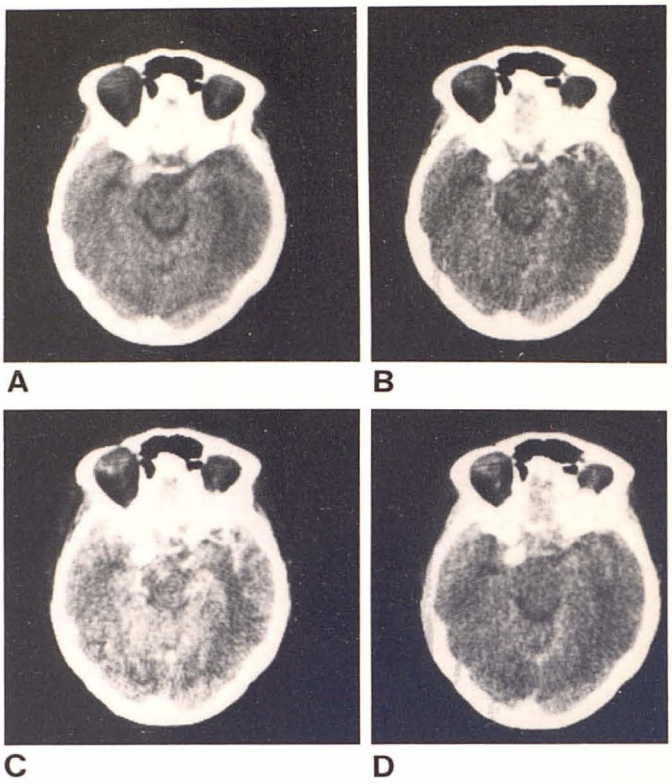

Fig. 2.—Posterior communicating artery aneurysm shown by dynamic CT. Note early, dense contrast material accumulation in the aneurysm. **A**, Precontrast. **B**, 9–12 sec. **C**, 17–20 sec. **D**, 4 min 45 sec.

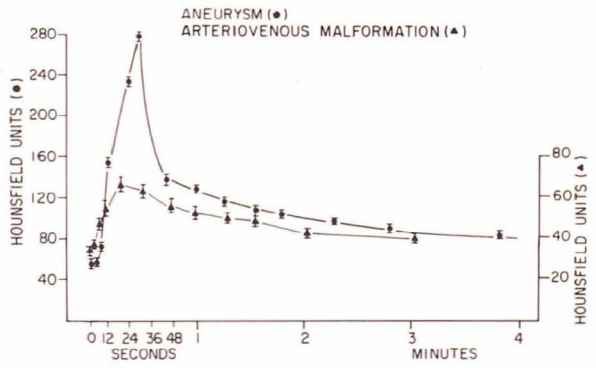

Fig. 3.—Time-density curves of aneurysm in fig. 2 and arteriovenous malformation have similar steep upslopes, narrow peaks, and rapid washout of contrast medium. Maximum enhancement of aneurysm exceeded arteriovenous malformation, but peak enhancement of malformation occurred few seconds earlier, probably because of faster blood flow through arteriovenous malformation.

Purely vascular abnormalities such as aneurysms and arteriovenous malformations show a rapid and often striking increase in attenuation coefficients during the arterial phase (figs. 2 and 3). The peak of the curve is narrow and the down-slope often very steep as the contrast material is washed out by unopacified blood. The main difference in the aneurysm and arteriovenous malformation curves is the intensity of enhancement with greater concentration of contrast medium in the aneurysm.

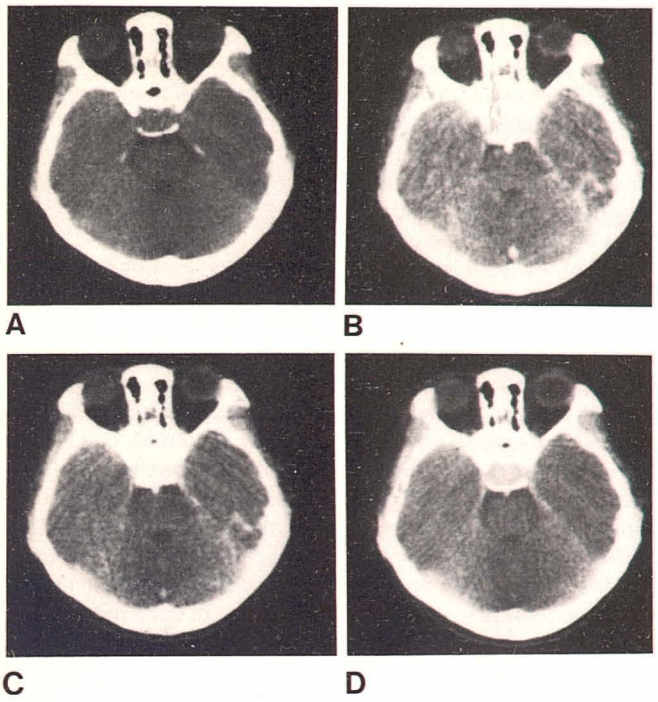

Fig. 4.—Pituitary adenoma shows early, dense contrast enhancement within first minute. **A**, precontrast. **B**, 17–20 sec. **C**, 57–60 sec. **D**, 25 min.

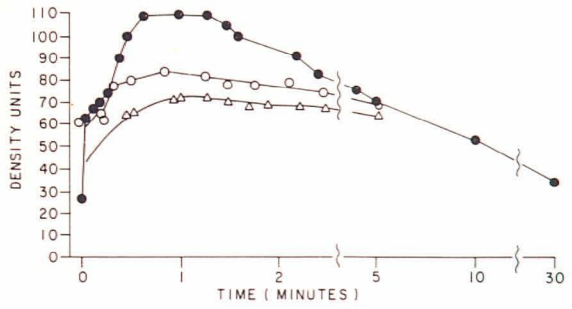

Fig. 5.—Time-density curves of three pituitary adenomas show similar early, broad peaks. Contrast enhancement is maximum in first 2 min, followed by gradually decreasing attenuation coefficients.

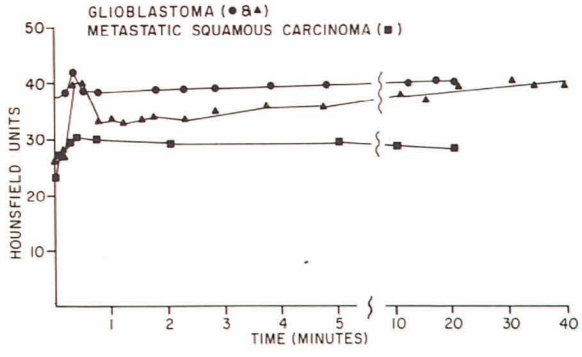

Fig. 6.—Dynamic CT scans in two patients with glioblastoma multiforme and one patient with a metastatic carcinoma produced similar curves. Graphs are basically flat after first arterial passage of contrast material, with slightly increasing or decreasing attenuation coefficients thereafter.

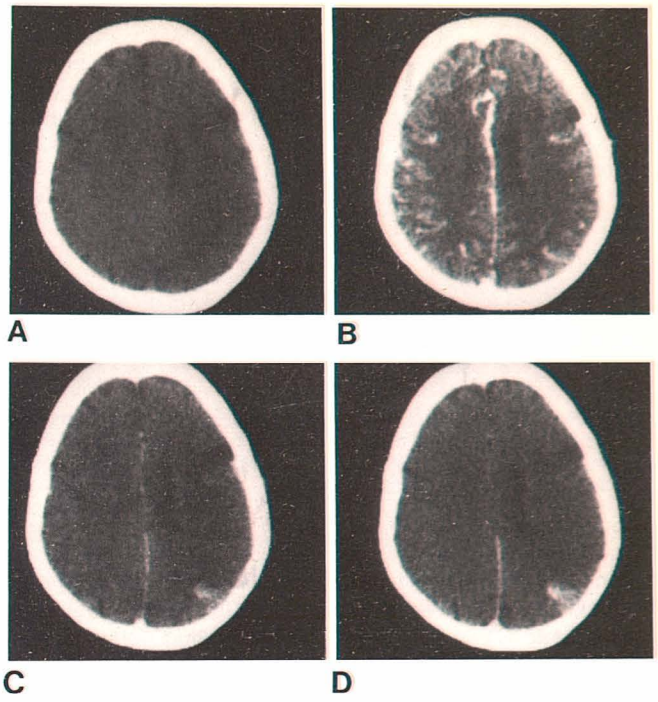

Fig. 7.—Small 14-day-old posterior parietal cerebral infarct. **A**, precontrast. **B**, 27–30 sec. Extravascular contrast material accumulates at 2 min (**C**) followed by increasing enhancement 10 min (**D**).

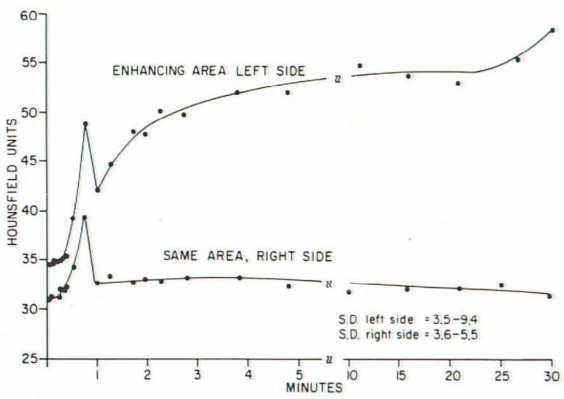

Fig. 8.—Time-density curves of cerebral infarct and same part of brain on opposite side demonstrate early, pronounced enhancement of infarct.

Pituitary adenomas produce a different type of time-density curve (figs. 4 and 5). The increase in attenuation occurs early but at a slower rate than the vascular lesions in figures 2 and 3. The peak of the curve is broad, and there is a more gradual decrease in attenuation coefficients.

Malignant brain tumors, both primary and metastatic, can produce a third type of curve. Although there may be an early blush on the first passage of intravascular contrast, the extravascular accumulation may produce slowly increasing enhancement (fig. 6) [10].

A 14-day-old enhancing cerebral infarct produced still a different curve (figs. 7 and 8). Pronounced extravascular accumulation of contrast was evident within the first few minutes after the initial intravascular bolus. This enhance-

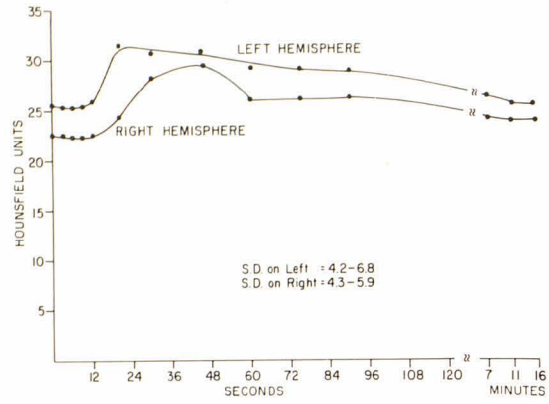

Fig. 9.—Graphs from dynamic CT series of patient with occluded right internal carotid artery and patent left internal carotid. Delayed flow to right hemisphere. Right hemisphere curve has lower Hounsfield unit (H) values because of two ischemic parietal infarcts.

ment was more rapid than that shown by the rather flat curves seen with the tumors studied (fig. 6).

Dynamic CT is capable of demonstrating delayed blood flow in patients with occlusive cerebrovascular disease. Figure 9 shows the curves from both cerebral hemispheres of a patient with an occluded right internal carotid and a normally patent left internal carotid. The flow in the left hemisphere is normal, while the flow to the right hemisphere is delayed. The up-slope of the curve begins later and is less steep, and the peak is broader, probably because of slower collateral arterial flow.

Discussion

The initial enthusiasm about the capacity of CT to accurately differentiate intracranial lesions has been mitigated by the fact that several different types of abnormalities may produce identical CT images. Supra- or parasellar masses and ring-enhancing lesions are abnormalities that occasionally defy specific histologic CT diagnosis. Purely vascular lesions such as arteriovenous malformations and aneurysms may be differentiated from tumor by visualization on radionuclide flow studies and nonvisualization on the latter static images, while tumors are usually more obvious on the static scans. Similarly, the rapid flow of contrast material into and out of a lesion on dynamic CT (figs. 2 and 3) indicates a vascular abnormality.

Although the number of patients we have studied to date is small, our initial data suggest that the rates at which contrast enhancement occurs in some lesions may differ in a distinctive fashion, while other lesions may produce similar time-density curves. Of course many more patients must be studied to see if there is in fact a "characteristic curve" for various types of brain lesions. If so, dynamic CT may help in the differential diagnosis of problem cases.

The application of dynamic CT to cerebral blood flow estimation has great potential, and preliminary results have been encouraging [5, 7, 11]. One technical problem is the accurate separation of contrast-filled arteries and veins from brain parenchyma during the flow sequence, especially when a large region of interest is being analyzed. A "smart region of interest" computer program has been developed which allows selection of pixels within a desired range of attenuation coefficients [7]. These pixels can be examined on sequential scans, and the time-density curves produced by this approach reflect the flow of contrast material through the vessels being examined.

Another technique is to use a cursor to measure a very small region of interest, for example an area of between 1–9 pixels. Discrete vascular structures can be evaluated in this manner, and the flow through arterial and venous structures can be analyzed separately.

Differences in flow through patent carotid arteries versus occluded vessels with collateral flow should be easily demonstrated. For detection of subtle differences in blood flow, the technique described can be improved in at least two ways. First, more rapid injection of contrast material using a mechanical injector, larger needle, or injecting bilateral antecubital veins simultaneously should result in a more abrupt change in density with the bolus of contrast material. However, mixing of the contrast through the heart, lungs, and carotid arteries will limit the rapidity and concentration with which contrast material can be delivered to the brain from an intravenous arm injection.

Second, the single revolution scan time for our CT unit is 3 sec. To evaluate density changes occurring in sub-3-sec intervals, another computer program has been developed which allows continuous data collection for 12 sec, after which images can be reconstructed with time differences between scans of 1 sec or less. This program has been used to image blood flow through the cardiac chambers, aorta, and pulmonary vessels [4].

The clinical utility and potential applications of dynamic CT of the head as well as other parts of the body are broad, but at present are unproven. As more CT scanners with similar capabilities are installed and used, it is likely that a large amount of information about this technique will be accumulated in the near future.

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