Journal of Computer Assisted Tomography (Computed Tomography), 1(1), 1977.

Variation with Time of the Attenuation Values of Intracranial Hematomas

Mats Bergström, Kaj Ericson, Bo Levander, Pål Svendsen, and Stig Larsson

Abstract: Fourteen cases of subdural, epidural, and intracerebral hematoma, in which the time of the trauma or bleeding was known, were selected. Attenuation of samples taken at surgery showed good correlation with attenuation values determined by computed tomography (CT). The decrease in the attenuation of the hematoma from the time of trauma or bleeding was studied. **Index Terms:** Brain hemorrhage—Computed tomography—Intracranial hematomas.

Computed tomography (CT) of intracranial hematomas has shown differences in attenuation values (1, 7, 8, 10, 11). According to some authors (2, 10), fresh hematomas have attenuation values of 20–40 Hounsfield units (HU: 500 scale). Scott et al. (10) have observed values up to 60 HU centrally in a hematoma.

Earlier reports (1, 7, 8, 10, 11) agree that the attenuation value of the hematoma decreases with time. During a period of 10–30 days after trauma, the attenuation of the hematoma is said to be about the same as the adjacent brain tissue and lower thereafter.

The purpose of this paper is to further confirm the changes in attenuation with time in intracranial hematomas and to show the reliability of attenuation values measured by preoperative CT in comparison to those obtained from surgical samples.

MATERIALS AND METHODS

The material is composed of six cases of intracerebral and eight cases of extracerebral hematomas (Table 1). In each case the time of the bleeding or the trauma was well defined and known. CT was performed in all cases. The time between trauma and CT was 0–77 days (mean, 14). Regions of interest were selected in the CT (Fig. 1) to represent (1) the hematoma, (2) centrally located brain tissue (an effort was made to include only white-matter districts, although in one of the two selected areas in one patient a partial inclusion of the basal ganglia region was unavoidable), and (3) normal brain tissue within a 6-mm-thick slice adjacent to the skull (meant to represent gray matter; see further under discussion).

The mean attenuation value of the respective regions were determined according to Bergström and Sundman (4). Central brain tissue attenuation was determined in all patients. Due to artifacts, the attenuation of cortical brain tissue was determined in 11 patients only.

Surgery was performed in all patients 0–11 days after CT. At surgery, samples of the hematomas were collected (>5 ml) and a minimal (< 0.1 ml) amount of heparin added. The hematoma samples

TABLE 1. *Fourteen cases of intracranial hematomas*

	Intracerebral bleeding	Subdural bleeding	Epidural bleeding
Trauma	0	5	1
No trauma	6	2	0
Total	6	7	1

From the Department of Neuroradiology and Neurosurgery, Karolinska Sjukhuset, S-104 01, Stockholm, and the Department of Neuroradiology, Sahlgrenska Sjukhuset, S-413 45 Gothenburg, Sweden. Address reprint requests to M. Bergström.

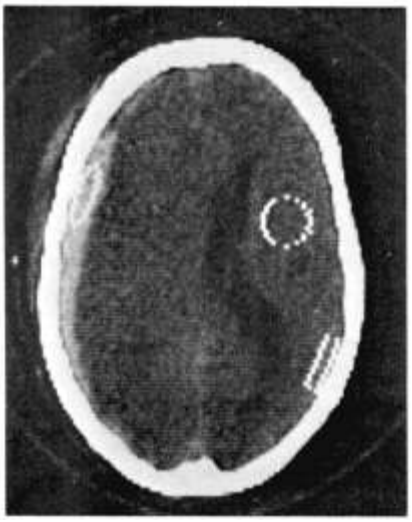

FIG. 1. Subdural hematoma scanned on day of trauma. Regions of interest are outlined to represent hematoma, central brain tissue, and cortical brain tissue.

were examined with CT in a syringe phantom, and the mean attenuation value was determined.

In order to determine the attenuation value of normal vein blood, samples of 5 ml were drawn from 25 patients without known hematological disorders. These samples were examined in the syringe phantom after adding < 0.1 ml heparin.

In order to study the changes of attenuation in unheparinized blood, a small container was filled with 30 ml blood and the process of coagulation was followed with repeated CT in two cases up to 6 days.

An EMI scanner Mark I was used for all CT examinations. The HU used refers to the system ranging from −500 to +500 units.

The syringe phantom (Fig. 2), made of polystyrene, has a cylindrical shape with a diameter of 18 cm and a thickness of 7 cm and with seven holes drilled in it. Five-milliliter syringes fit exactly into the holes. Polystyrene, having an attenuation number of +5, was chosen in order to give reasonable attenuation differences between the syringe and the surroundings. The phantom is mounted in the EMI scanner and scanned using the 0.8-cm-wide

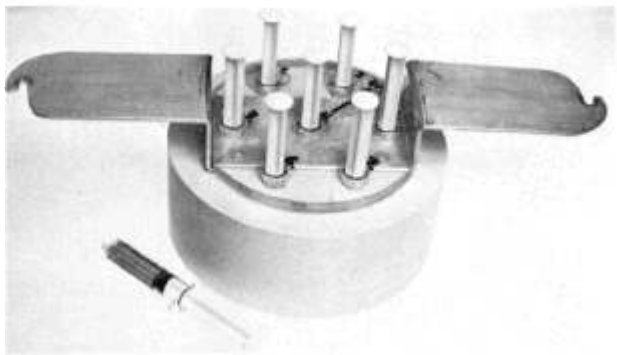

FIG. 2. Phantom used for determining attenuation values of blood and tissue samples.

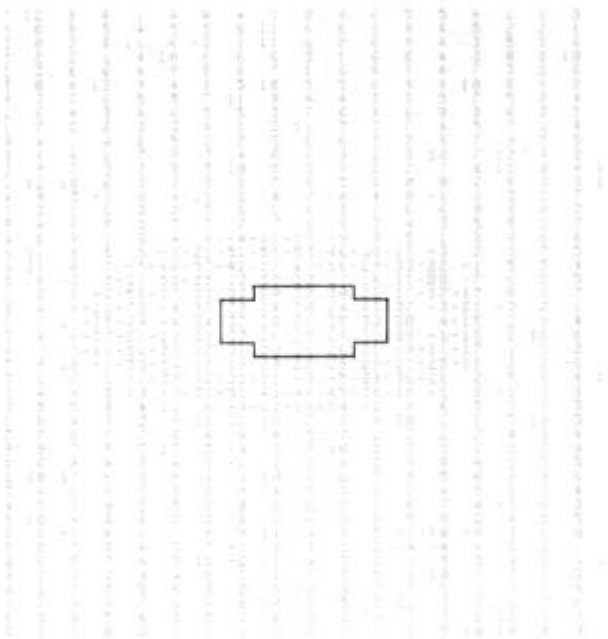

FIG. 3. Template used for defining region where mean value is calculated.

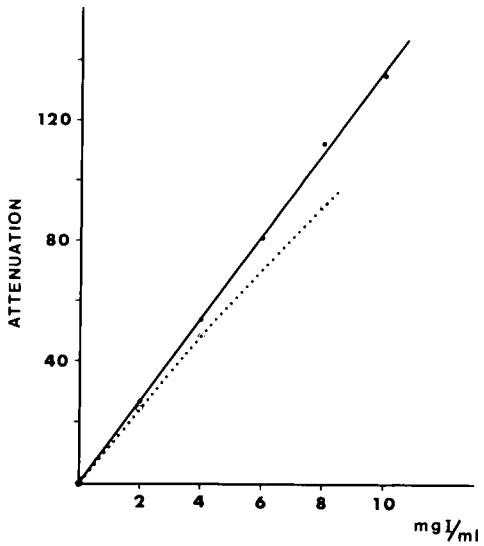

FIG. 4. Mean attenuation value plotted against concentration of iodine for syringe (•) and 1.5-liter phantom (○).

collimator. Printouts are made in 160 × 160 format, and using a template (Fig. 3), a mean value of the elements in the syringe is calculated. As an example of the applications of our syringe phantom, Fig. 4 shows a test (120 kV) with meglumine metrizoate (Isopaque Cerebral®) of different solutions in water. A close linearity is achieved between the attenuation number of the sample and the concentration of iodine. The standard deviation of each separate syringe is 1.1 attenuation number. Figure 4 also shows the attenuation numbers obtained using a pot with 1.5 liter of solution. We have used this syringe phantom extensively for attenuation coefficient determinations of blood samples after systemic administration of iodinated contrast material.

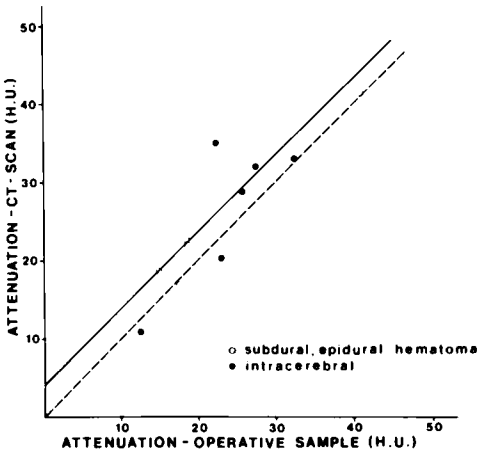

FIG. 6. Correlation of attenuation numbers measured by CT and surgical samples. Solid line represents linear regression. Points would be on broken line if measurements were equal.

RESULTS

The time variations of the attenuation values in the hematomas as determined by preoperative CT are shown in Fig. 5 together with the mean attenuation values of central and cortical brain tissue, respectively. The hematoma values have been fitted to a monoexponential function ($A = 30 \cdot e^{-0.079 \cdot t} + 10$). In Fig. 6 these attenuation values are correlated to the corresponding values of the hematoma samples drawn at surgery. It is noted that the attenuation is slightly higher in the preoperative CT than in the samples (mean, 3.5 HU). The attenuation values of the samples drawn from the hematomas at surgery are shown in Fig. 7. The decrease with time of the values has been fitted to a monoexponential function as in Fig. 6 ($A = 25 \cdot e^{-0.079 \cdot t} + 10$). In the following, the hematoma attenuation mentioned is from the determination of surgical sample. Fresh hematomas—not more than 24 hr old—have high attenuation values (mean, 37.4 HU); 4–9 days after trauma the attenuation has decreased down to the level of cortical brain tissue (as determined by us; mean, 22.3 HU; range,

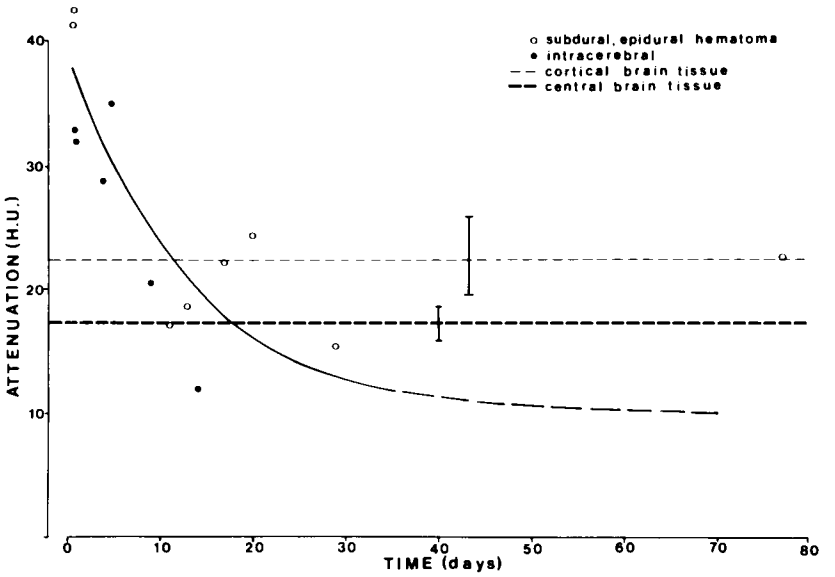

FIG. 5. Attenuation of subdural and intracerebral hematomas measured by CT and plotted against time. Solid line represents monoexponential function fitted to values. Broken lines indicate attenuation of cortical and central brain tissue.

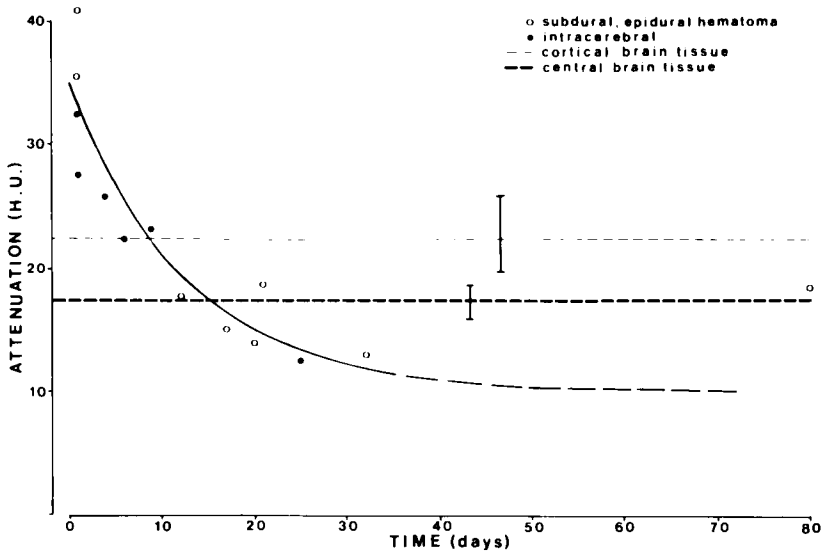

FIG. 7. Same curve as in Fig. 5 but with attenuation measured in surgical samples.

19.7–26.1). After 2–3 weeks, the still-lower level of central brain tissue is reached (as determined by us; mean, 17.3 HU; range, 16.0–18.8). Subdural hematomas of different age are shown in Fig. 8.

The attenuation of normal fresh human vein blood was found to be 23.9–32.4 HU (mean, 27.6), which is considerably less than in fresh hematomas.

The study of a container of 30 ml unheparinized blood reveals that a marked separation between a high-density clot and low-density serum is established within 3 hr. A profile through the CT of the container at 10 min and 44 hr (Fig. 9) clearly shows the separation. The successive retraction of the clot is shown in Fig. 10. The attenuation of the clot is increasing from 30 to a maximum of 38 HU in about 20 hr and thereafter remains practically unchanged during the observation time (Fig. 11).

Figures 9, 10, and 11 refer to one of two studied cases. In the other case the maximal attenuation reached 44 HU.

DISCUSSION

There is a good correlation between attenuation numbers measured by CT and surgical samples. However, the difference between the two measurements varies more than what could be expected from the accuracy of unaffected scans. One explanation for these variations is artifacts due to patients movement during examination.

Another factor may be uneven distribution of high-density blood clots. This may influence the choice of regions of interest and may also cause difficulties at surgery in obtaining a representative amount of blood clots for the samples.

As shown in Fig. 6, the attenuation of the hematomas is slightly higher in preoperative CT than in the surgical samples. This difference cannot be explained by changes in the hematoma between CT and surgery: in the seven patients who underwent CT and surgery on the same day, the mean difference was 3.5 HU, and when surgery was performed 1–11 days after CT, the difference was 3.6 HU.

The difference may at least partly be explained by an artifact in the image reconstruction of the sudden change from high attenuation levels in the skull bone to the low values of the tissue adjacent to the skull (5). This artifact will also influence the attenuation of cortical brain tissue as compared to central brain tissue. Thus, in this paper the attenuation of "cortical brain tissue" means an addition of the artifact and the actual attenuation of the cortical structures.

Attenuation measurements of normal vein blood show an individual variation over a range of about 8 HU. The distribution of the attenuation values of the surgical samples are close to those limits of variation at every given time. The added amount of heparin was too small to change the attenuation

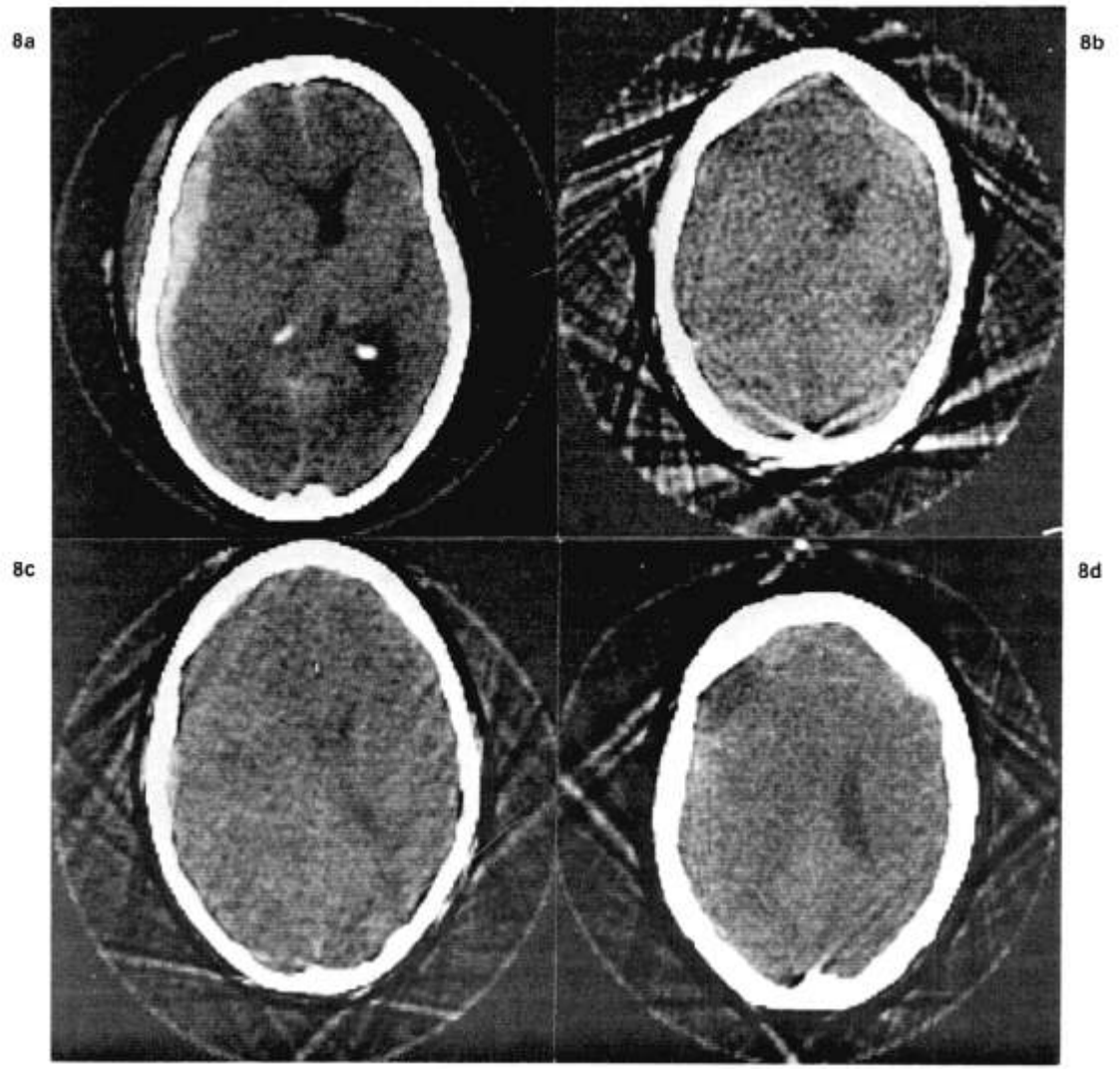

FIG. 8. Subdural hematomas of different ages. **a:** Scanning on day of trauma. Hematoma clearly visible. Attenuation of surgical sample 35 HU. **b:** Scanning 11 days after trauma. Ventricles displaced to right, but hematoma not visible with certainty. Surgery showed left-sided hematoma with attenuation 18 HU. **c:** Scanning 17 days after trauma. Ventricles displaced to right, but hematoma is not visible. Surgery showed left-sided hematoma with attenuation 19 HU. **d:** Scanning 28 days after trauma. Hematoma with decreased attenuation visible in left frontal region. Attenuation of surgical sample was 13 HU.

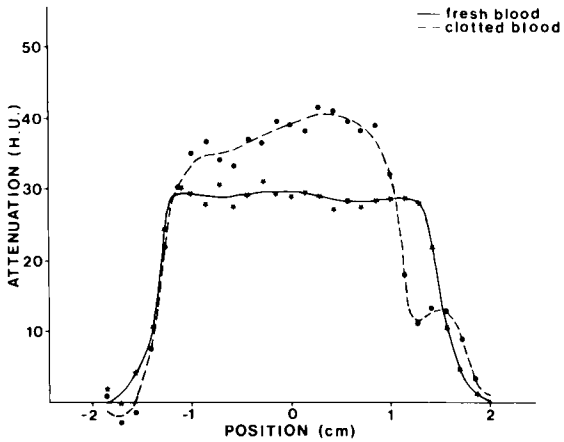

FIG. 9. Attenuation values across 30-ml container with unheparinized blood scanned at 10 min and at 44 hr after it was drawn.

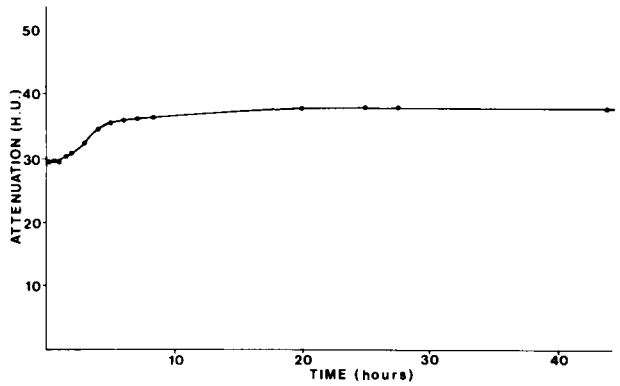

FIG. 11. Attenuation of blood clot as in Figs. 9 and 10 plotted against time. Sixty pixels centrally in clot were used for calculating the mean attenuation.

value of the sample but sufficient to prevent coagulation.

The study of coagulating blood indicates that the high attenuation values of fresh hematomas are due to blood-clot retraction. As shown in Fig. 11 it takes about 3 hr for the retraction to be established. In this series, no patient has been examined within 3 hr from trauma. It is unlikely that any process other than bleeding and coagulation will contribute significantly to changes in attenuation during the first 3 hr after an intracranial hematoma has occurred, and, therefore, the container study may be considered to resemble the events *in vivo* during this period.

The decrease in attenuation of the hematomas after the initial phase of increase may be attributed to several factors. Fibrinolytic resolution of the blood clot is known to occur. Fibrinolytic activity alone would, however, only decrease the attenuation to the level of normal blood. Any further decrease of attenuation must be caused by other factors, such as absorption. In a subdural hematoma without arachnoid tear, no absorption is said to occur until vascularized granulation tissue is formed around the clot. This is usually not noticed until after the first week (6). The absorption is likely to be different in epidural and intracerebral hematomas. Addition of CSF will decrease the attenuation of the hematoma in any stage.

Rebleeding may alter the decrease of attenuation. Ito et al. (6) have found a daily hemorrhage into chronic subdural hematomas of 2–27% of the hematoma volume. This bleeding may be continuous or intermittent and is caused by hyperfibrinolysis. In experimentally produced subdural hematomas, Apfelbaum et al. (3) have found passage of red

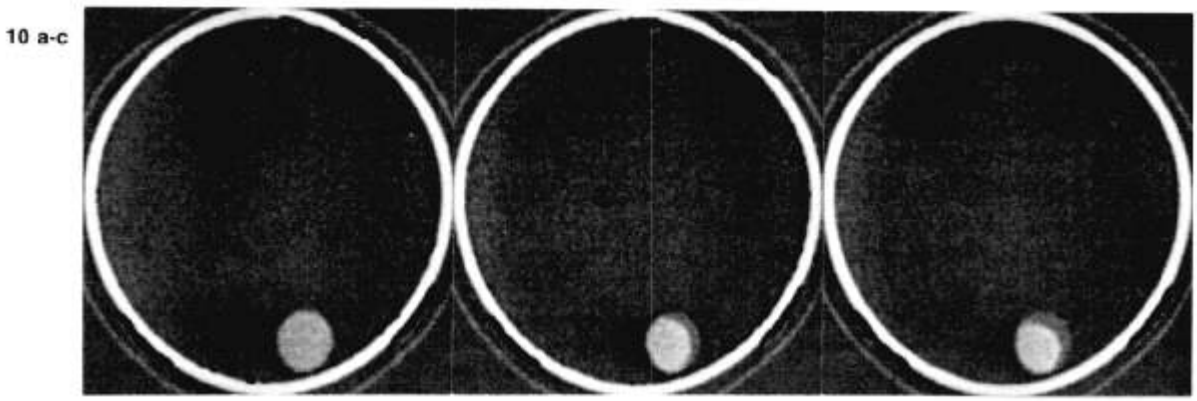

FIG. 10. Same container as in Fig. 9 scanned at 10 min **(a)**, 6 hr **(b)**, and 44 hr **(c)** clearly shows retraction of blood clot.

blood cells into hematomas with well-defined membranes. These findings have obvious implications as to the attenuation of subacute and chronic hematomas and may to some part be relevant also in intracerebral and epidural bleedings. A slight continuous rebleeding may reduce the speed of decrease in attenuation. A larger new bleeding will, of course, change the attenuation more. In this material, one patient with an interval of 80 days between alleged trauma and surgery, had a higher attenuation value in the surgical sample (18.6 HU) than would be expected (Fig. 12). This may be explained by rebleeding.

It must be stressed that Figs. 5 and 7 contain single observations of several hematomas of different kinds. The changes indicated may not be relevant for changes occurring in the individual case. It is, however, obvious from Fig. 7 that the results must be fitted to some form of exponential function and not to a linear. This must have implications on theory concerning processes involved in the resolving of the hematoma. The complexity and plurality of the processes involved are beyond the scope of this paper. A study of some of these problems in subdural hematomas—including the development of the individual hematoma—is in progress.

From Figs. 5 and 7 follows that there is a period when the hematomas are of the same density as the surrounding brain tissue. In the individual case, there is, of course, only one hematoma attenuation to be compared to only one attenuation of cortical or central brain tissue. In hematomas with a volume that might necessitate surgery, a difference of more than 2 HU to the surrounding tissue should be enough for detection of the hematoma. Applying this reasoning to the curve in Fig. 7 for the period of 5–20 days after trauma means that the hematoma may be impossible to distinguish from the surrounding brain tissue for about 5 days. During this "invisible period," the diagnosis must be based on indirect signs, such as the dislocation and deformity of the ventricular system (1, 7, 11) or on angiographic findings. Contrast enhancement may aid in excluding other causes for the dislocation of the midline structures and ventricles, although Messina (9) has noted uptake of contrast medium in subdural hematomas 6 hr after administration.

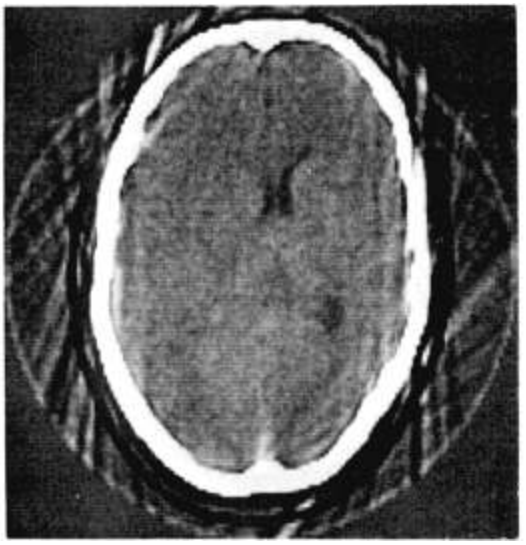

FIG. 12. Subdural hematoma scanned 77 days after trauma. Ventricles are displaced to right, but there is no visible lesion. Surgery showed left-sided chronic subdural hematoma with attenuation 18.6 HU. Hematoma was 2 cm wide and 16 cm long.

ACKNOWLEDGMENT

This work was supported in part by a grant from the Carl-Bertel Nathhorst Foundations for Science and Public Utility.

REFERENCES

1. Ambrose J: Computerized transverse axial scanning (tomography). Part 2. Clinical application. Br J Radiol 46:1023-1047, 1973
2. Ambrose J: Computerized X-ray scanning of the brain. J Neurosurg 40:679-695, 1974
3. Apfelbaum RI, Guthkelch AM, Schulman K: Experimental production of subdural hematomas. J Neurosurg 40:336-346, 1974
4. Bergström M, Sundman R: Analysis of regions of interest in EMI-scans. Br J Radiol 49:549-550, 1976
5. Gado M, Phelps M: The peripheral zone of increased density in cranial computed tomography. Radiology 117:71-74, 1975
6. Ito H, Yamamoto S, Komai T, Mizukoshi H: Role of local hyperfibrinolysis in the etiology of chronic subdural hematoma. J Neurosurg 45:26-31, 1976
7. Levander B, Stattin S, Svendsen P: Computer tomography of traumatic intra- and extracerebral lesions. Acta Radiol Suppl 346:107-118, 1975
8. Messina AV, Chernik NL: Computer-tomography: The "resolving" intracerebral hemorrhage. Radiology 118:609-613, 1976
9. Messina AV: Computed tomography: Contrast media within subdural hematomas. Radiology 119:725-726, 1976
10. Scott WR, New PF, Davis KR, Schnur JA: Computerized axial tomography of intracerebral and intraventricular hemorrhage. Radiology 112:73-80, 1974
11. Svendsen P: Computer tomography of traumatic extracerebral lesions. Br J Radiol *In press*