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Traumatic brain swelling studied by computerized tomography and densitometry

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Abstract

Two-hundred and fifty-two computerized tomography (CT) scans of 107 patients with head injuries were analyzed. The most frequent consequence of trauma was a diffuse swelling of the brain in 91% of the cases. The severity of brain swelling and its course can be estimated by the compression of (or absence of) the intracranial cerebrospinal fluid space. These observations may be of prognostic value as well.

By measurement of the HOUNSFIELD units (HU) in 52 cases the blood or water content in the brain tissues was assessed. An increase in blood content of the tissues (hyperaemia) can account for an increase in Hounsfield values. A decrease in HU suggests brain edema.

The density measurements showed that in the first hours and days following head injury, the diffuse brain swelling was caused by severe cerebrovascular congestion in the majority (53%) of the cases. Immediate brain edema without a preceeding hyperaemic phase occurs less frequently (32%).

Between the 1st and 4th day after injury, edema started to prevail, and between the 5th and 8th day the edematous type of brain swelling was present almost exclusively.

Keywords: Brain edema, brain swelling, CT-densitometry, head injury, hyperaemia.

1 Introduction

According to MONRO-KELLIE's doctrine concerning the relationships among CSF, blood and brain volume, increases of one of them occur at the expense of the other two. Computer tomography scans indicate that various degrees of compression of the outer and inner CSF spaces due to the increase in brain volume can occur within one hour after injury. This rapid increase in brain volume is called traumatic brain swelling [1, 6, 8, 10, 12, 15, 16, 17]. It results from the pathologic enlarging of the blood volume in the cerebral vessels [3, 7, 9, 13], of the water content of the brain tissue [brain edema, 5, 14], or both. Clinical examinations using CT-densitometry can detect these pathologic processes [1, 2, 12, 17].

2 Clinical material and methods

One-hundred and seven patients with head injuries (aged 4 to 86 years) were selected for this study. They were admitted to the Neurosurgical Department, University of Tübingen, Tübingen/FRG during the last four years.

CT examination with a Siretom 2000 or a Somatom DRH scanner was performed on admission and repeated when clinically indicated. Brain swelling was determined in repeated CT's using comparable slice levels.

Brain swelling was divided into two groups. Focal cerebral swelling was characterized by compression of CSF spaces of one cerebral hemisphere (Figure 1) and diffuse swelling by bilateral involvement. Diffuse brain swelling was classified, in a modification of ITO et al. [4] into 3 categories:

1. Mild, when the cortical sulci, Sylvian fissure, third ventricle and perimesencephalic cistern were compressed, but visible, in CT scans.
2. Moderate, when one or two of the above structures were not visible.
3. Severe, when three or four of these structures were not visible (Figure 2).

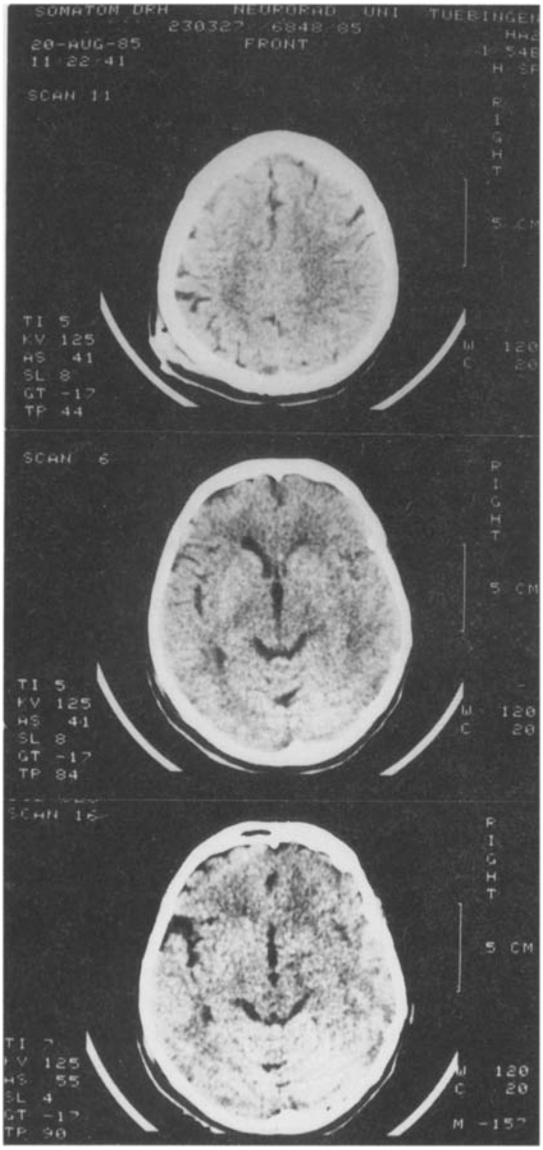

Figure 1. Focal brain swelling. Parietal subgaleal hematoma on the left side. On the right side the fissura Sylvii are almost entirely and the cortical sulci frontoparietal partly compressed.

CT scan density measurement: The mean value of Hounsfield units (HU number) was measured by the "region of interest" (ROI) program, and more frequently, the "high lighting" (HL) program. This program illuminates points (pixels) in a territory with a given density. Edema was diagnosed if the number of pixels illuminated was high (between 11 and 20 HU) and hyperaemia was found if the number of pixels illuminated was low (between 11 and 20), or very high (between 30 and 40 HU) (Figure 3).

3 Results

3.1 Brain swelling in native CT-scans

The CT scans of 97 of 108 patients showed signs of diffuse brain swelling. Only 10 patients had local swelling on admission (Table I). The mean age of these 10 patients was significantly higher than that of the patients with various grades of diffuse swelling. Age, clinical state (GCS), and outcome (GOS) did not differ significantly between patients with mild and moderate diffuse swelling. GCS was found to be the lowest and the outcome was poorest in the group with severe diffuse swelling.

Focal injuries were always associated with various grades of brain swelling (Table II). Extradural and acute subdural hematomas were more frequently accompanied by moderate (13 cases) and severe (20 cases) diffuse swelling than intracerebral hematomas. In cases of contusion and subarachnoid hemorrhage, there was no significant difference in the degree of brain swelling. Patients without hemorrhage suffered mainly from severe swelling.

3.2 CT-densitometry

Two separate forms of density were found using the HL program. When more pixels were illuminated between 11 and 20 HU, the swelling was defined as low density type (edema). When more pixels were visualized between 31 and 40 HU the swelling was defined as the hyperdens type (hyperemia) (Figure 3). Hyperdensity was found most frequently (30 cases). The patients with hyperdensity were characterized clinically by the highest mean age, the lowest GCS on admission, and poor outcome (Table III). Eighteen patients with low density showed lower mean age, higher GCS, and a better outcome than patients with hyperdensity.

The eight patients with mixed density types were similar to the group with low density.

No remarkable difference was found among the various grades of brain swelling using densitometry (Table IV). Greater differences were noticed

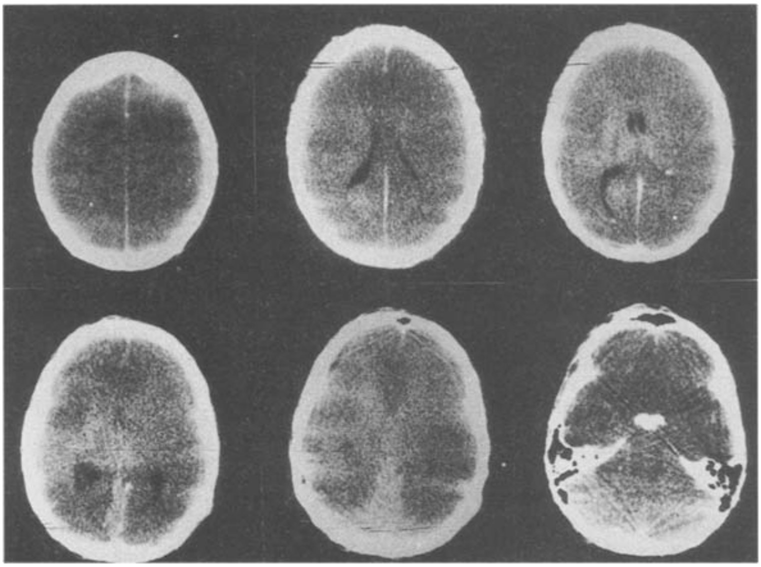

Figure 2. Severe diffuse brain swelling. The entire CSF space, except the lateral ventricles, is totally compressed.

Table I. Number, age, GCS⁺, and GOS⁺⁺ of patients with various grades of traumatic brain swelling.

Brain swelling		Nr. of patients	Age (mean ± SD)	GCS⁺ (average)	GOS⁺⁺				
					1	2	3	4	5
	mild	22	34 ± 16	8.8	13	3	3	–	3
Diffuse	moderate	28	33 ± 21	7.5	12	5	5	1	5
	severe	47	32 ± 19	4.4	2	3	2	3	37
Local		10	58 ± 12	7.6	4	–	–	–	6

⁺GCS = Glasgow Coma Scale on admission
⁺⁺GOS = Glasgow Outcome Scale
1 = good recovery
2 = moderate disability 3 = severe disability
4 = vegetative state
5 = dead

Table II. Focal injury associated with brain swelling.

Focal injury	Brain swelling			
	diffuse			local
	mild	moderate	severe	
Extradural hematoma	4	8	9	1
Acute subdural hematoma	1	5	11	1
Intracerebral hematoma	0	2	1	3
Contusion	11	8	19	3
Subarachnoidal hemorrhage	5	3	2	1
No hemorrhage	1	2	5	1

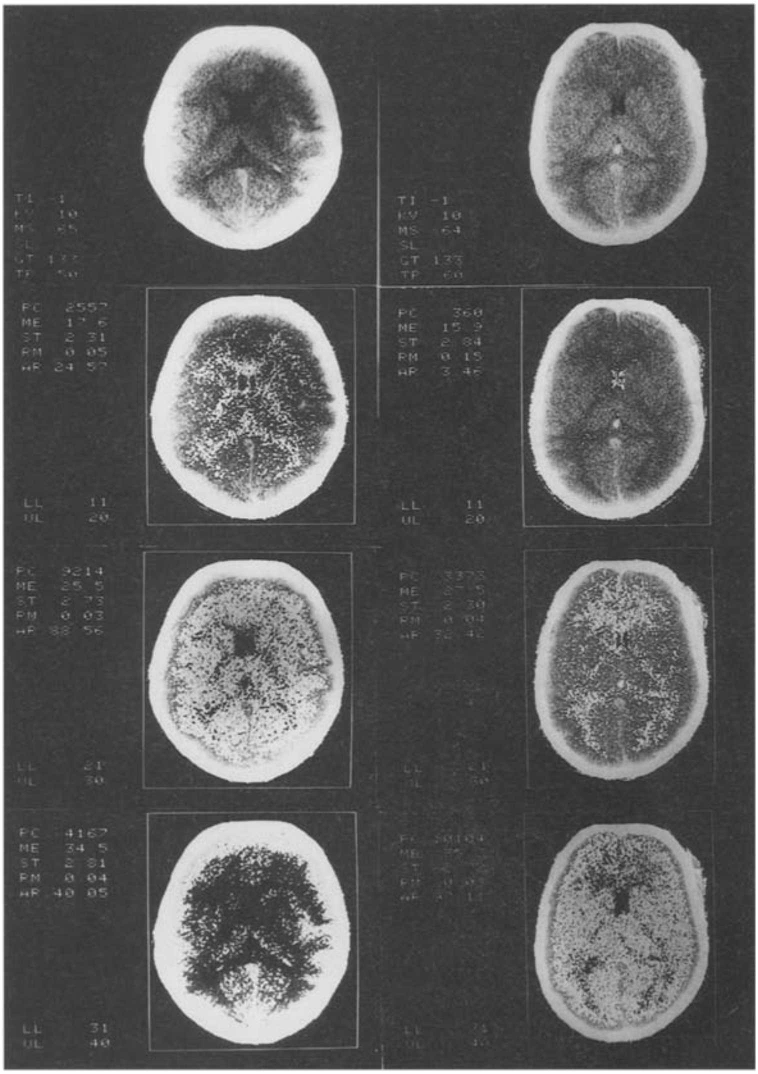

Figure 3. CT scans of edematous (on the left) and hyperemic (on the right) brain swelling using the "Highlighting" program. Between 11 and 20 HU, the number of pixels illuminated is high in edema and low in hyperemia. On the other hand, between 31 and 40 HU the number of pixels illuminated is low in edema and high in hyperemia.

in cases of focal injuries than in various types of brain swelling (Table V). Extradural and acute subdural hematomas were usually accompanied by hyperdensity (13 cases) and only two cases showed low density. In other focal injuries these density forms were analogous.

3.3 Follow-up densitometric studies

In 36 cases, densitometric measurements were carried out during 2 to 5 follow-up CT examinations. Thus, the absorption coefficients resulting from 140 examinations could be analyzed. Table VI shows the time distribution of the results. Hyperdensity occurred more often than hypodensity on the day of injury. Between the 1st and 4th day after trauma hypodensity prevailed, it was dominant especially between the 5th and 8th day when hypodensity was present almost exclusively (Figure 4). Mixed density can be detected during the whole process, however, its frequency is much lower. From the 9th day on, a picture of normal

Table III. Types of density and clinical data.

Density	Nr. of patients	Age (mean)	GCS (average)	GOS				
				1	2	3	4	5
Hyperdensity	30	39	5.8	6	4	1	2	17
Low density	18	30	6.8	6	2	3	1	6
Hyper- and low density	8	26	7.6	2	2	–	1	3

Table IV. Densitometry of various grades of brain swelling.

Brain swelling		Hyperdensity	Low density	Hyper- and low density
Diffuse	mild	7	3	3
	moderate	8	7	1
	severe	12	8	4
Local		3	–	–
	Total	30	18	8

Table V. Densitometry in focal injuries.

Focal injury	Hyperdensity	Low density	Hyper- and low density
Extradural hematoma	8	–	3
Acute subdural hematoma	5	2	–
Intracerebral hematoma	2	1	–
Contusion	10	10	3
Subarachnoidal hemorrhage	2	2	1
No hemorrhage	3	3	1
Total	30	18	8

Table VI. Time distribution of 140 densitometry examinations.

		Hyperdensity	Hypodensity	Mixed density	Normal
On the day of trauma		30	18	8	–
1. day	after trauma	4	6	2	–
2. day	after trauma	5	7	1	–
3., and 4. days	after trauma	5	3	4	1
5. to 8. days	after trauma	1	12	1	–
9. to 14. days	after trauma	6	6	–	2
15. to 23. days	after trauma	1	5	4	2
24. day to 6 months	after trauma	1	1	–	2
6 months to 1 year	after trauma	–	–	–	2
Total		53	58	20	9

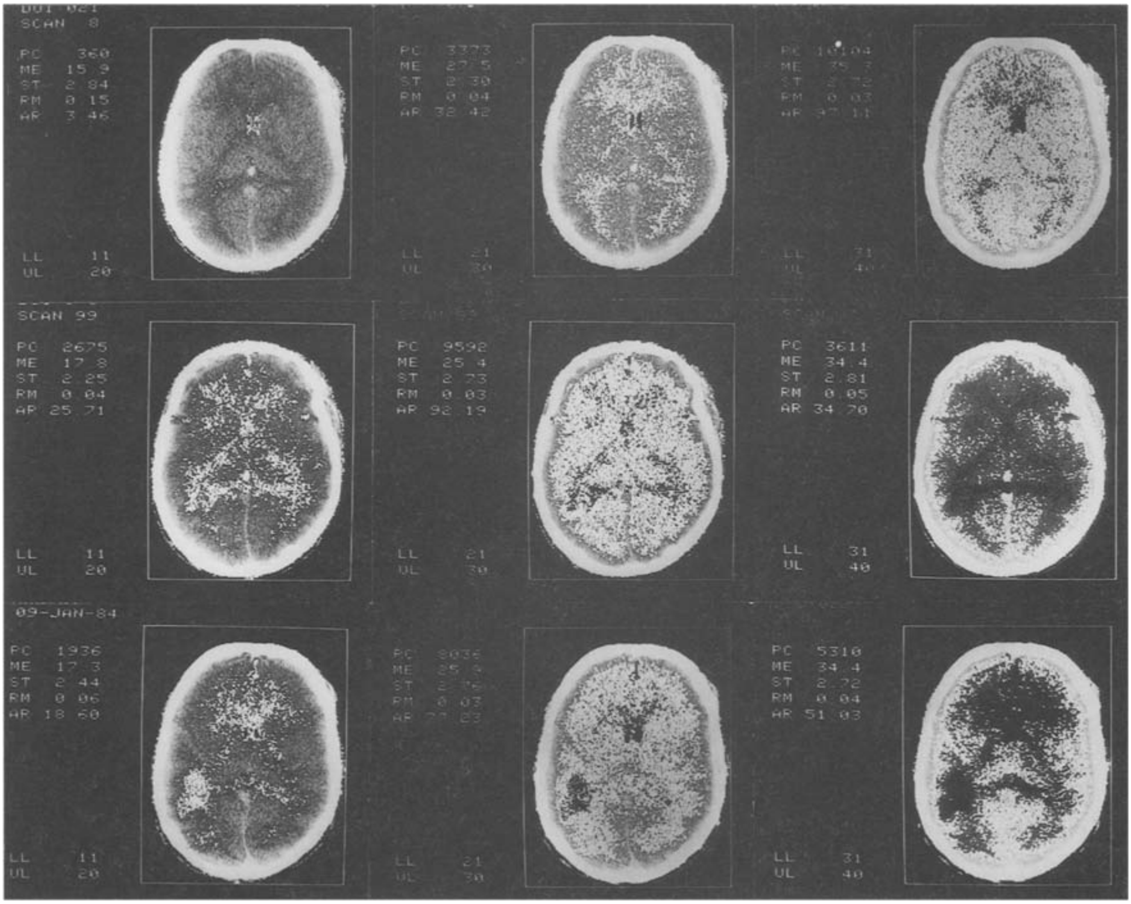

Figure 4. Density distribution corresponding to hyperemia (upper line) and to edema (middle line) on admission and 2 days after trauma. On the 8th day edema decreases (bottom line).

density appears. Although hyperdensity is more frequent at the day of trauma, hypodensity occurs most in 58 out of 140 cases referred to the total of examinations.

4 Discussion

The post-traumatic reduction of the volume of CSF spaces indicates a pathologic increase in brain volume and thus the presence of more or less severe brain swelling. The fact that after the removal of the space-occupying hemorrhage no hemorrhage is obvious in the control CT supports the note of brain swelling. The signs of brain swelling do not decrease, and may further increase, with concomitant raised intracranial pressure. Thus, the determination of the severity and classification of brain swelling is indicated.

Diffuse brain swelling was demonstrated in 97 of 107 CT scans. Local swelling alone was found in the remaining 10 cases. In the group of diffuse distribution, no difference was found for the mean age of patients (31 – 34 years), however, the mean age was significantly higher (58 years) in the group of patients with local brain swelling. The more severe the diffuse brain swelling is, the worse the patient's clinical condition on admission and the poorer the outcome. Consequently, the analysis of the CT scans performed on admission in order to determine the severity of brain swelling has an important, early prognostic value.

Diffuse brain swelling after head trauma was first described by ZIMMERMANN et al. [17] in children (as "acute general cerebral swelling"). On the basis of densitometry and CBF examinations it was attributed to hyperemia. Similar observations were made by the same team in 1981 (BRUCE et al. [1]) who consider diffuse brain swelling not to be characteristic in adults. This is attributed to the higher metabolic rate and higher vasoreactivity in children. Contrary to the observations mentioned above we found brain swelling in all age groups. However, we did see an age-related decrease in vasoreactivity. The mean age of patients with diffuse brain swelling without hemorrhage was 20 years, and that of patients with local brain swelling 58.

The change in water volume and blood volume in the brain tissue after head trauma was evaluated and followed up by CT densitometry [2, 5]. The "region of interest" program was adequate for the examination of smaller circumscribed territories; however the "high lighting" program was preferred because the entire CT scan slice can be analyzed. The HL program illuminated the pixels with a certain density in the given density field. Thus, both the presence and the localization of edema can be determined.

In the course of the first CT examination, which was performed within 24 hours of head injury, hyperdensity (indicating hyperemia) was found in 30 and hypodensity (indicating edema) was found in 18 of 56 cases. Higher mean age, poorer clinical condition, poorer outcome, and higher mortality was characteristic of the group with hyperemia than with edema.

Our densitometry examinations failed to confirm the observations of ZIMMERMANN et al. [17] and BRUCE et al. [1], i.e., hyperemic brain swelling is characteristic of children as the mean age of the hyperemic group was even higher in our material. Age cannot play a decisive role in the development of these two types of traumatic brain swelling. Our hypothesis is supported by OBRIST et al. [10] whose CBF examinations disclosed hyperemia in patients between 15 and 85 years.

A significant difference can be observed between space-occupying hemorrhages and non-space-occupying injuries in the course of the densitometric analysis of focal injuries accompanied by brain swelling. While the former are almost always accompanied by hyperemic brain swelling the latter ones showed just as much cases of hyperemia as of edema. However, no significant difference was found in the individual grades of brain swelling between the two density types.

According to 140 follow-up densitometric measurements on the day of injury, the hyperemic type of brain swelling occurred more frequently than the edema type. Between the 1st and 4th day after injury edema started to prevail and between the 5th and 8th day edema was present almost exclusively. Normal density distribution appears from the 9th day on, as is also shown in native CT scans as a decrease of compression of CSF spaces. In the majority of the examinations (58 out of 107), brain edema was observed. RIETH et al. [11] came to the same conclusion having examined the development of experimentally induced brain edema with densitometry and gravimetry.

Besides its diagnostic value in the confirmation of the real causes of brain swelling, densitometry is also of great importance in therapy. Dehydration cannot exert a beneficial effect in the hyperemic phase. On the other hand, hyperventilation can be dangerous in edematous brain swelling because it can further reduce the blood flow which is already below the normal level. Consequently, both hyperventilation and dehydration can only be applied according to patients with the appropriate type of brain swelling. Hyperventilation decreases the pCO_2 tension in the vascular bed, thus eliminating or moderating the pathologic vasodilatation and reducing the blood volume in the brain so that its application is indicated in the hyperemic phase of brain swelling. Dehydration can be successful in the reduction of edematous brain swelling.

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