Computer tomography in management
and prognosis of patients with severe brain injury

COMPUTER TOMOGRAPHY IN MANAGEMENT AND PROGNOSIS OF PATIENTS WITH SEVERE BRAIN INJURY

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE
AAN DE ERASMUS UNIVERSITEIT ROTTERDAM
OP GEZAG VAN DE RECTOR MAGNIFICUS
PROF. DR. J. SPERNA WEILAND
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KRIJN JACOB VAN DONGEN

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What's in a brain?

Ter nagedachtenis aan mijn vader.

VOORWOORD.

Bij de verschijning van dit proefschrift heb ik er behoefte aan mijn dank te betuigen aan hen die tot mijn medische vorming tot op heden en aan het ontstaan van dit proefschrift hebben bijgedragen.
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Introduction

The purpose of this study is to investigate the influence of computer tomography on the management and prognosis of patients with severe traumatic brain damage. To this end a consecutive series of patients with severe brain damage was investigated by means of serial computer tomography.

The first part of this study deals with the influence of computer tomography on diagnosis and treatment. The emphasis here is placed on questions arising in practice, such as: –

1. What is the distribution of computer-tomographic findings at the various times when the patients were examined?
2. To what extent is a diagnosis based on the computer tomograms confirmed by operation or autopsy?
3. When should patients with severe brain damage be examined by computer tomography?
4. Which patients with brain damage should be examined by means of computer tomography?
5. What is the influence of computer tomography on the frequency with which other diagnostic techniques are used and on the treatment of patients with severe brain damage?

In the second part of the study, the prognostic significance of computer tomography of comatose patients will be considered. To this end, the clinical course in 121 consecutive comatose patients was recorded, according to a protocol, at predetermined intervals after the accident. An attempt was made to produce computer tomograms at these same intervals. The outcome of each patient after one year was subsequently recorded according to the Glasgow Outcome Scale.

The purpose of this section is:

1. to determine whether a correlation exists between the computer-tomographic findings produced at various intervals after the accident and the outcome after one year;
2. to select clinical and computer-tomographic variables with prognostic value;
3. to examine the quality of the probability statements on outcome which were made using the variables selected.

Classifications and definitions

SEVERE BRAIN DAMAGE

This study concerns patients with "severe brain damage". What is understood by this term? Jennett (39, 42) has given a summary of this.

One starting point is to describe brain damage as serious if physical or mental symptoms persist. This, however, requires a doctor to be able to ascertain on admission whether a patient is likely to retain such symptoms. The extent to which this is possible must be considered.

Persisting symptoms can result either from the severity of the impact on the skull during the accident – primary brain injury – or from subsequently occurring phenomena such as cerebral hypoxia, disturbances in the microcirculation and complications such as intracranial haematomas and meningitis. Thus a patient with a relatively minor skull injury can still subsequently retain serious symptoms, or indeed die, from a complication such as an epidural haematoma or from serious brainswelling. On the other hand, a brain injury can appear serious immediately after the accident, due to the fact that the patient is deeply comatose, whereas the subsequent recovery may exceed expectations. Hence, in the initial post-traumatic phase, it is not always possible for the doctor concerned to predict which patients will retain physical or mental symptoms.

Nonetheless, the majority of patients with serious brain damage leading to persisting symptoms can be recognised on admission. This is because such patients show seriously impaired consciousness as a sign of diffuse brain damage and/or neurological deficit as a sign of focal brain damage. Consequently, for the purpose of this study, impaired consciousness on admission and/or neurological deficit were taken as the requirements for serious brain damage. The relatively small number of patients with brain injury which originally appeared to be slight, but later was seen to be serious, has not been included in this study.

In order to use impaired consciousness as an indication of the severity of brain damage, it must be classified in a satisfactory manner. Various methods exist, but often the categories used are only vaguely defined. The requirements which must be met by a proper classification of the level of consciousness are described by Avezaat et al (4).

The classification must:

1. be applicable to the various causes of impaired consciousness;
2. show a satisfactory spread, so that slight changes in consciousness, which only appear gradually, can also be registered;
3. be based on various criteria, so that the influence of focal brain injury in determining the level of consciousness can be eliminated as far as possible (for instance, on a scale based uniquely on verbal reactions, it

would be difficult to give an adequate assessment of the level of consciousness of a dysphatic patient);
4. be simple to apply by means of observation, without requiring the use of complicated apparatus;
5. be easy for less experienced personnel to use;
6. only include one valid interpretation for each reaction of the patient; in this way inter- and intraobserver variation rates would be limited to a minimum;
7. be able to be presented as an overview, so that the progression in level of consciousness can be seen at a glance.

THE GLASGOW COMA SCALE

A classification which meets many of the above – mentioned requirements is the Glasgow Coma Scale, developed in 1968 by Teasdale and Jennett (88). This scale is based on three different reaction patterns in the patient:

- eye opening
- motor response
- verbal response

These features are assessed according to the patient's responses to verbal stimuli and standardised pain stimuli, namely pressure on the nail-bed and supra-orbital pressure (9, 88). Each of these reaction patterns is subdivided into a number of levels, to which a point score is attributed (see table I).

TABLE I:
The Glasgow Coma Scale (= EMV scale).

Eye opening (E)	
– no response	1
– eye opening to pain	2
– eye opening to speech	3
– eye opening spontaneous	4
Best Motor response of arms (M)	
– no response	1
– extensor response	2
– abnormal flexion	3
– withdraws	4
– localizes	5
– obeys	6

Verbal response (V)

– no response	1
– incomprehensible sounds	2
– inappropriate words	3
– confused conversation	4
– orientated	5

The Glasgow Coma Scale, which was first used outside Glasgow in Holland (Rotterdam and Groningen), is now in use over the whole world, and is currently serving as a basis for virtually all English language publications about patients with seriously impaired consciousness.

Various other classification systems have been proposed (58, 74). The advantage of the Glasgow Coma Scale as opposed to other scales is its simplicity and the ease with which it can be reproduced, with only a limited inter- and intraobserver variation rate. (9, 89). Furthermore, reactions can be simply scored at the bedside without the aid of complicated apparatus. Nursing and paramedical personnel can also use the scale very efficiently after a short period of instruction. Here, too, the degree of inter- and intraobserver variation remains limited (87).

Each of the three aspects of the scale is scored separately. Moreover, a sum score can be obtained by adding together the point score of each of the reactions.
Hence a coma sum score of 3 means that the patient does not open his eyes, has no motor response in the arms and gives no verbal response, whereas with a sum score of 15 the eyes open spontaneously, commands are obeyed and the verbal response is also normal. Although the sum score is based on different observations and some information is accordingly obscured, nonetheless such a sum score is of prognostic significance (90).

It is not always possible to assess the verbal response in the early post-traumatic phase as a number of patients are then intubated. Consequently, instead of the full sum score (E+M+V), the sum score of eye opening and best motor response (E+M) is used.

CLINICAL COURSE:

In order to record the clinical course, a standard scoring form was used on which the clinical condition was reported on admission, after 1, 3, 7, 14 and 28 days after the onset of coma.
In addition, both the worst and best scores were noted for a number of symptoms in the periods between the fixed times of assessment. For instance, in the period 4 - 7 days, the worst pupil response recorded was one nonreacting pupil, and the best response two reacting pupils.

Approximately 70 demographic and clinical parameters were recorded in this way. Some, such as age, sex, and presence of fracture, were scored only once, but most symptoms which could vary in the course of time such as pupil response, blood pressure, respiration and level of consciousness were continually reassessed at the predetermined times.

The current study can be compared with an investigation carried out previously by co-workers for the "multinational databank", who were researching into the correlation between clinical findings at various intervals after the accident and the outcome after 6 months. (10, 46). During that investigation, much experience was gained of reporting and statistical methods (10, 46, 47).
The data of a number of the patients examined in this study were also included in the multinational databank investigation.

This multinational study was started by Jennett in 1968. It was joined in 1972 by co-workers from Rotterdam, in 1973 from Groningen and in 1974 from Los Angeles. The co-workers from these centres collected data on a speculative basis from as large a series possible of patients with severe traumatic brain injury. Thus, by 1981, a multinational databank was established with information gathered from 1400 patients, all of whom had been in coma for a minimum of 6 hours. The clinical course of these patients and their condition 6 months after the onset of coma were assessed according to a previously determined procedure.
The purpose of this multinational study is:

1. to identify the clinical symptoms which are of prognostic significance in these patients (10, 45);
2. to study the potential relationship between prognostically significant symptoms (10, 43, 47);
3. to investigate the possibility of making a prediction about the outcome of each new patient as soon as possible after the accident. This would be done by using a limited number of prognostically significant data (44, 46).

OUTCOME

The Glasgow Outcome Scale, developed in 1966 by Jennett and Bond (40), was used to determine outcome. This scale is subdivided as follows: death, persistent vegetative state, severe disability, moderate disability and recovery. The definitions of these categories are:

1. Death.
2. Persistent vegetative state (non-sentient survival):
   the patient gives no verbal response, does not obey commands, sometimes shows a sleep/wake rhythm. There is no observable interaction with the environment, although some patients appear to be able to follow with their eyes.
3. Severe disability (conscious but dependent):
   the patient is dependent on others with regard to all or many of his daily routines. Verbal contact is sometimes possible.
   Serious disabilities prohibit the resumption of pre-traumatic activity.
4. Moderate disability (independent but disabled):
   the patient is independent as far as normal daily activities are concerned. However, he functions at a lower level than before the accident, or at an equal level, but then for shorter periods or with the help of special measures.

5. Good recovery:
   there are no post-traumatic complaints or disabilities which can inhibit resumption of pre-traumatic activities. Less significant complaints or symptoms may be present, which do not impede normal functioning.

Again, in using the Glasgow Outcome Scale, there appears to be only slight intra- and interobserver variation (41, 59).

COMPUTER-TOMOGRAPHY

The computer-tomograph was developed in the EMI-laboratories in 1967 (33, 34). Originally it took 9 hours to produce one image (66). After the apparatus was improved, one image could be produced per hour. In 1972, the first patient was investigated using this technique. In 1973, the CT came into use clinically following the publications of Ambrose (2). From then onwards the great value of this form of investigation in the diagnosis of intracranial abnormalities became apparent. (21, 25, 52, 73). In February 1977, an EMI CT-1010 machine was installed in our hospital and systematically used in the diagnosis and examination of patients with severe brain damage. The scanning time of this machine is 80 seconds per 2 slices. The images are reproduced by means of a 160 x 160 matrix. Eight to ten slices of 13 mm. thickness were usually made, using the orbito – meatal line as plane of orientation. Occasionally – in the case of an emergency owing to the patient's clinical condition – only 2 or 4 slices through the temporal region were made.

A machine such as the EMI-scanner takes about 20 minutes to warm up. "Warming up" is, however, not really essential, and so the minimum time required for scanning, excluding transport of the patient, is about 10 minutes.

The EMI CT-1010 computer-tomograph is a second generation scanner, in which use is made of an alternating translation and rotation movement of the frame on which the X - ray tube and detectors are mounted. Among the limiting factors with this generation of scanners were the scan time, the slice thickness and the matrix used. Third and fourth generation scanners have since come into use, with finer matrices, shorter scan times and the means of making thinner slices. The plane of orientation can now be varied and better adjusted. Such improvements have led to more accurate diagnoses (98).

Iodine contrast compounds can be administered intravenously to improve visualisation and delineation of lesions which are not visible or not clearly visible on a plain scan. Administration of iodine contrast compounds can make a statement about the nature of a lesion possible. This enhancement is caused by a greater accumulation of iodine in the lesion, due to increase in the local cerebral blood flow and/or disturbance of the blood – brain barrier. Normally, contrast compounds are administered as a bolus in a dose of 400 mg/kg body weight.
Occasionally, on specific request (for example with an isodense subdural haematoma), higher doses are administered to a maximum of 76 g. iodine (30, 94).

In a limited number of cases, the application of contrast compounds contributes to a better information yield. On the other hand, such measures can have a negative effect. Slight side effects have been described in 5-10% of cases (32). According to the literature, the frequency with which fatal reactions occur varies between 1 : 100.000 and 1 : 40.000 (3).
There seems to be a tendency towards an increase in the number of fatal reactions over the last few years (78). Bearing these considerations in mind, it was decided not to administer contrast compounds as a routine procedure in this series of patients. Contrast compounds were only administered in cases where doubt remained on the plain computer-tomogram as to the presence of an abnormality which required surgical intervention.

INTERPRETATION OF COMPUTER TOMOGRAMS

The scans produced were studied and analysed according to the classification given in tables 2 and 3.

TABLE 2
Classification of CT-findings in first month after injury.

PARENCHYMATOSE LESIONS
- normal
- contusion type I
- contusion type II
- contusion type III
- intracerebral haematoma
- central contusion(s)
- brainstem lesion(s)

EXTRACEREBRAL PATHOLOGY
- normal
- subdural haematoma $\leqslant$ 8 mm
- subdural haematoma $>$ 8 mm
- epidural haematoma $\leqslant$ 8 mm
- epidural haematoma $>$ 8 mm
- subdural effusion

BASAL CISTERNS
- normal
- partially obliterated
- completely obliterated
- complete obliteration + infarction

VENTRICLES AND SHIFT

ventricles normal, no shift
ventricles small, no shift
ventricles compressed, shift $\leqslant$ 5 mm
ventricles compressed, shift $>$ 5 mm, $\leqslant$ 10 mm
ventricles compressed, shift $>$ 10 mm

MISCELLANEOUS

ventricular blood
subependymal blood
herniation
radiological delayed pictures

TABLE 3

Classification of CT-findings 1 month or more after injury.

normal
unilateral supratentorial atrophy
bilateral supratentorial atrophy
infratentorial atrophy
infratentorial atrophy + unilateral supratentorial atrophy
infratentorial atrophy + bilateral supratentorial atrophy

The scans were interpreted without access to information on the clinical course and outcome of the patient concerned.
Artefacts occur in the temporobasal and infratentorial regions when the patient is restless. Such artefacts may result in computer tomograms which can only be partially interpreted.
When a computer tomogram could not be satisfactorily interpreted, it was assumed for the purpose of this study that there were no abnormalities present. The following definitions were used in the study of the computer tomograms:

PARENCHYMATOSE LESIONS:

Contusion

Only since the introduction of computer tomography has it been possible, to a limited extent, to differentiate between parenchymatose traumatic lesions. The classification used in this study is that of Lanksch and Katzner (53, 54, 55).

Contusion type I

This type of abnormality is characterised by a region of hypodensity. This hypodensity represents local oedema and/or necrosis as a reaction to the trauma. The hypodensity is vaguely defined and located both in white and grey matter. The lesion occupies space to a slight extent. The image is often soon visible (a few hours after the trauma) and reaches its maximum after 12 - 14 hours (65). Differentiation between this type of contusion and infarction or local encephalitis is not possible without knowledge of the patient's history.
In time, the lesion decreases in circumference, in order to make way for a local atrophy after an average of 3 - 4 weeks.

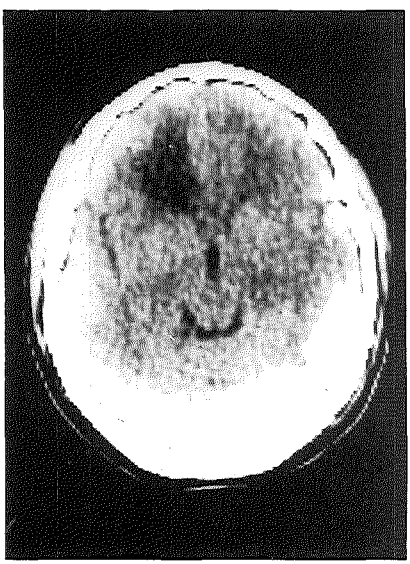
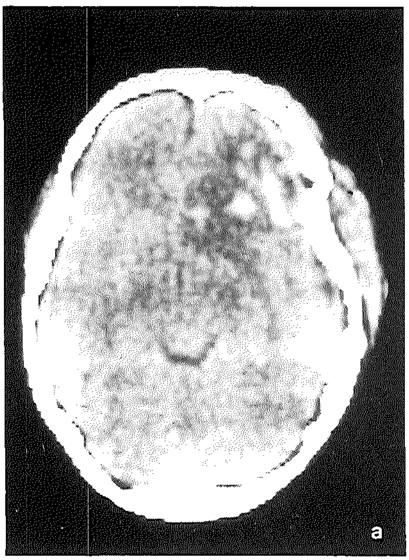


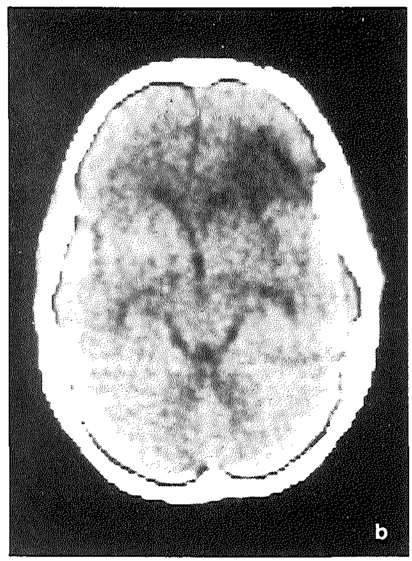
Fig. 1. Male, aged 35 years. On admission impairment of consciousness. Outcome: recovery. Scan made 3 days after admission: Type I contusion on left side.

Contusion type II

In a hypodense zone, the dimensions of which can vary, irregularly formed, patchy, hyperdense regions occur, which are sharply defined and varied in size (pepper and salt appearance). Some of these small, hyperdense regions can be confluent, and thus form relatively large regions. The hyperdensity represents small haemorrhages in the oedema and the necrosis. The space-occupying effect is in general more pronounced than in type I contusions.

Differentiation between contusional bleeding and traumatic intracerebral haematoma is often difficult. The image of a type II contusion changes in time, due to a decrease in density and a reduction in volume of both hypodense and hyperdense regions. Within 4 - 6 weeks the (non - specific) atrophy results.





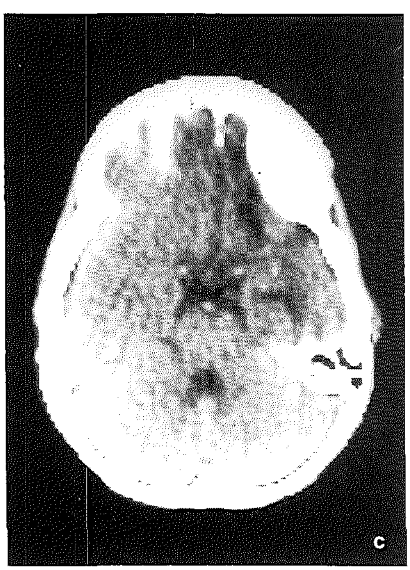


Fig. 2a. Female, aged 10 years. On admission comatose. Outcome: recovery. Scan made 3 days after admission: Type II contusion in right frontal region.

Fig. 2b. Same patient. Scan made 1 week after admission: Remains of right frontal contusion.

Fig. 2c. Same patient. Scan made after 1 year: local atrophy in right frontal region.

Contusion type III
This covers all multiple contusions known as coup and contrecoup lesions. The site of impact is usually revealed by the subgaleal haematoma. The contrecoup lesion is often more extensive. Due to the often bilateral localisation of this type of contusion, there need not be any midline shift.

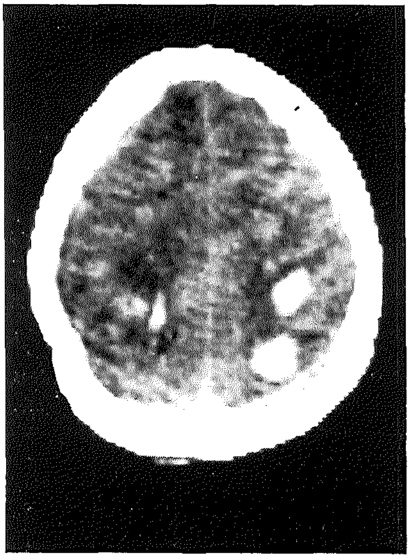
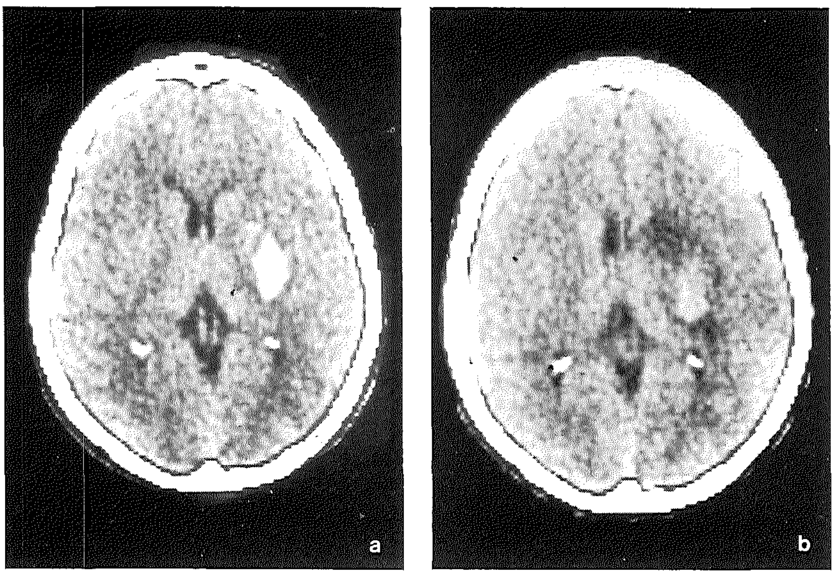


Fig. 3. Male, aged 15 years. On admission comatose. Outcome: death. Scan made on admission: Type III contusion. Note depressed fracture on left side.

Intracerebral haematoma

In this study, the term "intracerebral haematoma" is only used when a homogeneous, hyperdense lesion with a space-occupying effect is visible on the computer tomogram. Such a haematoma will generally be slowly reabsorbed in time. This is revealed by a reduction in density, beginning at the edge of the haematoma. The surrounding oedematose region increases relatively at first, and then later decreases in size. The isodense stage can be observed between the 20th and 30th day after the onset of the haematoma (8, 65, 85). The exact speed of reabsorption depends on the size and location. After 6 to 7 weeks a local atrophy then occurs; this is not applicable to smaller haematomas, which are often no longer visible at a later stage on the computer-tomogram.



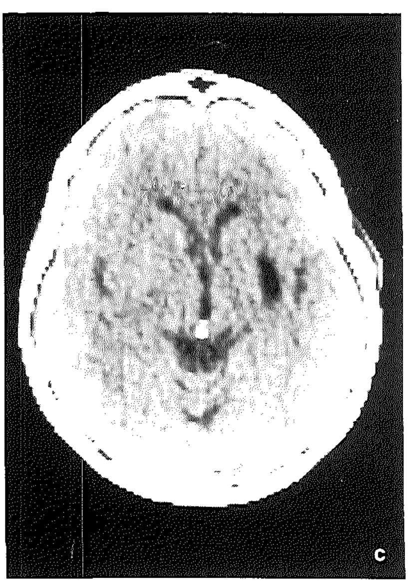


Fig. 4a. Female, aged 24 years. On admission comatose for a short period. Hemiparesis on left side. Outcome: recovery. Scan made on admission: small intracerebral haematoma in right hemisphere.

Fig. 4b. Same patient. Scan made 1 week after admission: Resolving haematoma in right hemisphere.

Fig. 4c. Same patient. Scan made 1 year after admission: local atrophy in right hemisphere.

Central contusion

These are contusions of type I, II or III which are situated in or near the basal ganglia or in the corpus callosum (101).

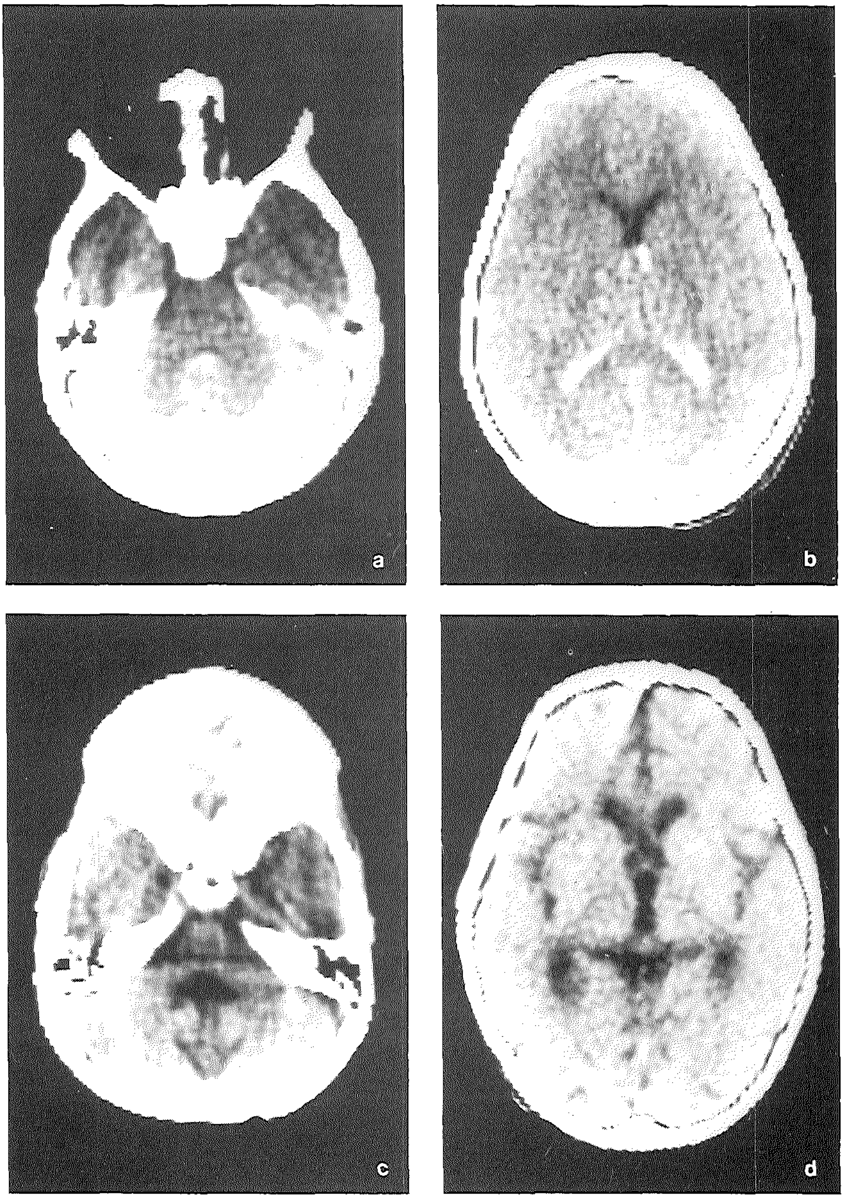


Fig. 5a. Male, aged 44 years. On admission comatose. Outcome: severely disabled. Scan made on admission: pons and brachium pontis are hypodense. CSF-spaces compressed. Possible brainstem contusion.

Fig. 5b. Same patient. Scan made on admission: Central contusion in left hemisphere. Intraventricular blood.

Fig. 5c. Same patient. Scan made 1 year after admission: Infratentorial atrophy.

Fig. 5d. Scan made 1 year after admission: Diffuse supratentorial atrophy.

Brainstem contusion

These are hyper- or hypodense lesions, situated in the pons or the mesencephalon. They are revealed firstly by the difference in density compared with their surroundings, and often, secondly, by compression of the surrounding cerebrospinal fluid spaces (95).

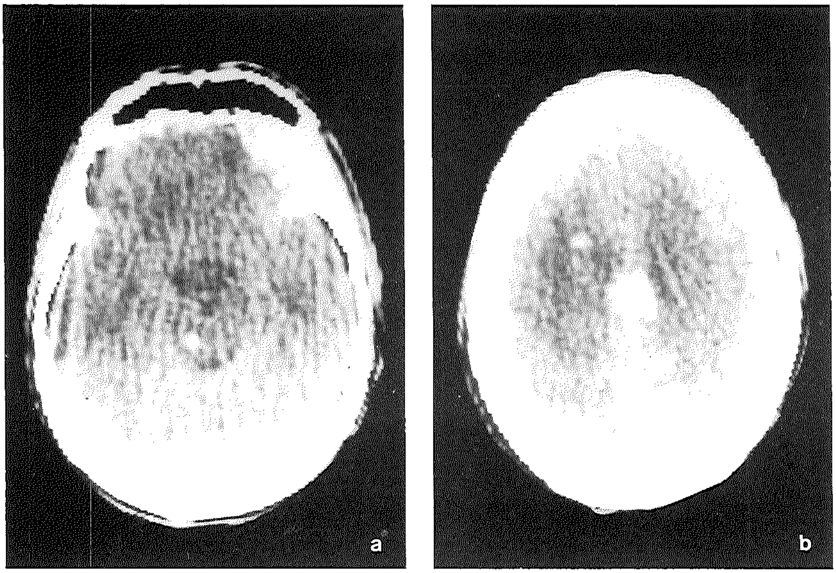


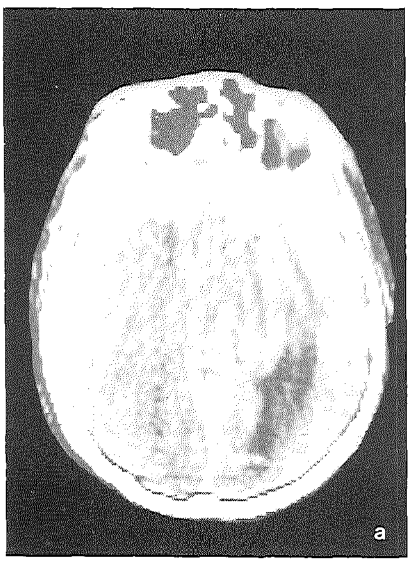
Fig. 6a. Male, aged 12 years. On admission comatose. Outcome: death. Scan made on admission: brainstem contusion.

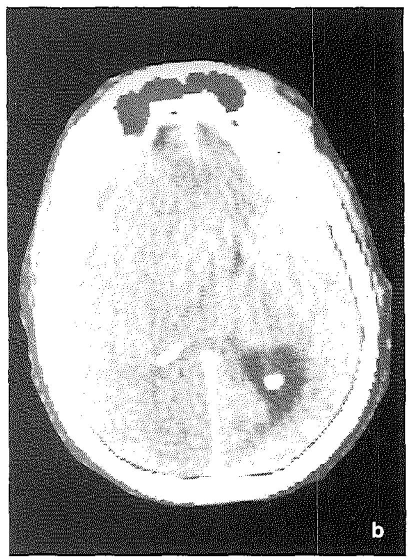
Fig. 6b. Same patient. Scan made on admission: contusion in corpus callosum and in left hemisphere.

EXTRACEREBRAL PATHOLOGY

Acute subdural haematoma

A subdural haematoma is visible as an extracerebral, usually sickle-shaped, hyperdense mass of varying thickness (76). The degree of midline shift is often more pronounced than the thickness of the subdural haematoma would lead one to expect, because such a haematoma is frequently accompanied by contusions (20). In a patient who has not undergone surgery but still survives, the haematoma appears on the computer tomogram as decreasing in density and ultimately in volume, until it finally disappears (86). It is possible for a chronic subdural haematoma to remain, in which case it appears as a hypodense, sickle-shaped or possibly lens-shaped extracerebral abnormality.





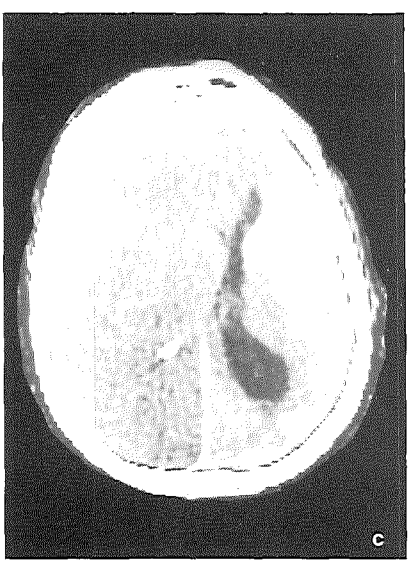


Fig. 7a. Male, aged 47 years. On admission comatose. Outcome: death. Scan made on admission: obliterated cisterns, midline shift to the right, radiological signs of herniation. Subdural haematoma over left hemisphere.

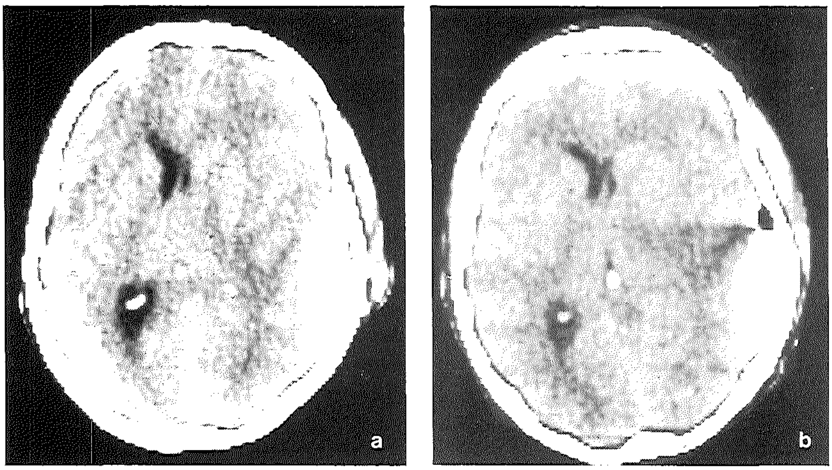
Fig. 7b. Same patient. Scan made on admission: Subdural haematoma and radiological signs of herniation clearly visible.

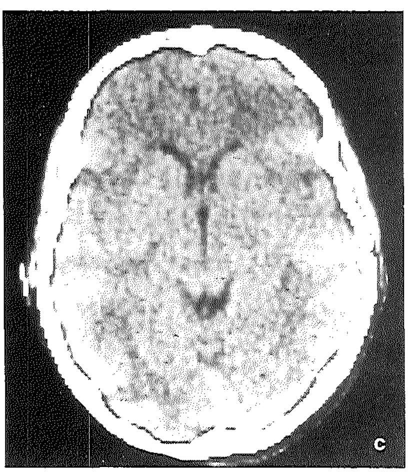
Fig. 7c. Same patient. Subdural haematoma and compressed ventricles with midline shift.

Autopsy (Dr. S. Stefanko) showed contusions in left temporo-basal region and in brainstem, in addition to subdural haematoma and signs of herniation.

Epidural haematoma

On the computer tomogram one sees an extracerebral, bi-convex (occasionally plano-convex) lesion which is homogeneous, hyperdense and space-occupying. The boundary between haematoma and cerebrum is sharply defined and smooth. Very occasionally an epidural haematoma can take on a different form (14, 86). Parts of the haematoma may not be hyperdense, but iso- or even hypodense. Indeed, the whole haematoma can be iso- or hypodense, especially in patients suffering from a serious form of anaemia. This applies, moreover, to all types of intracranial haematomas (49, 79). In these cases, diagnosis can present problems. The frequency of accompanying intracerebral abnormalities is noticeably lower with an epidural haematoma than with a subdural haematoma.





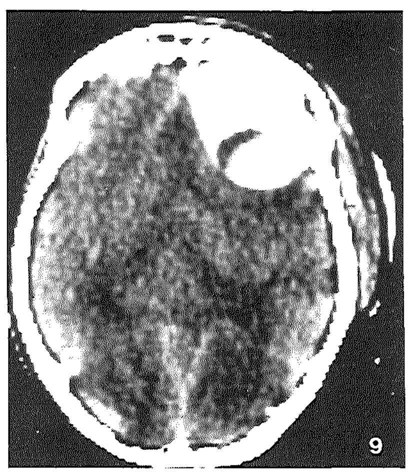


Fig. 8a. Male, aged 36 years. On admission impaired consciousness and hemiparesis left. Outcome: recovery. Scan made on admission: Epidural haematoma right temporal.

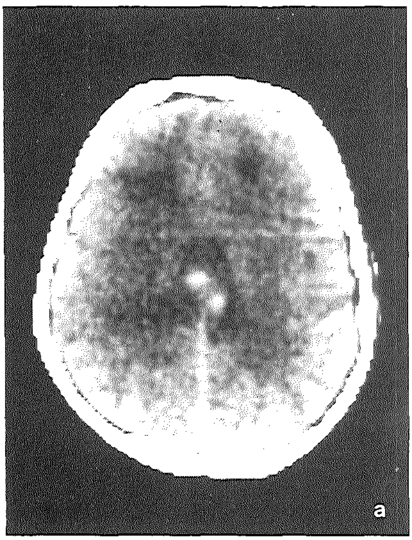
Fig. 8b. Same patient. Postoperative scan: remains of epidural haematoma. Hemiparesis disappeared, now conscious.

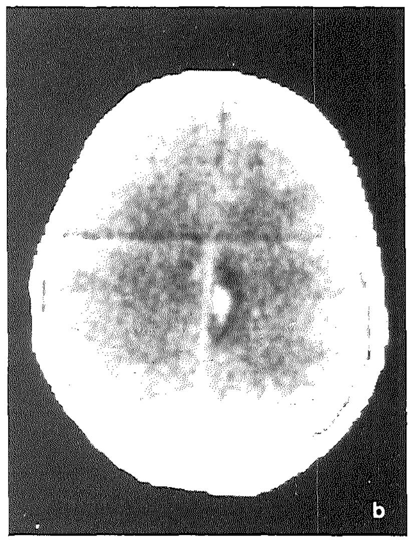
Fig. 8c. Same patient. Scan made 1 month after admission: normal.

Fig. 9. Female, aged 16 years. On admission comatose. Outcome: death. Scan made on admission: epidural haematoma right frontal. Not quite homogeneous. Operation showed that the haematoma had resulted from a tear in the carotid artery in the parasellar region.

Subdural effusion
On the computer tomogram an effusion can be seen as a hypodense, extracerebral fluid collection, usually with only slight space-occupying effect (23, 100, 102). For the purpose of this study, the diagnosis of subdural effusion was only made if no hyperdense, extracerebral abnormality was present on previous scans at the site of the effusion.

Extracerebral haematomas were also subdivided according to their thickness. This was in order to investigate whether the thickness of the subdural haematoma in particular was of prognostic significance.
The patients with extracerebral haematomas were accordingly divided into two approximately equal groups; one group emerged of patients with a subdural haematoma of 8 mm thickness or less, and another group with a subdural haematoma which was thicker than 8 mm.
The boundary of 8 mm was only arbitrary.





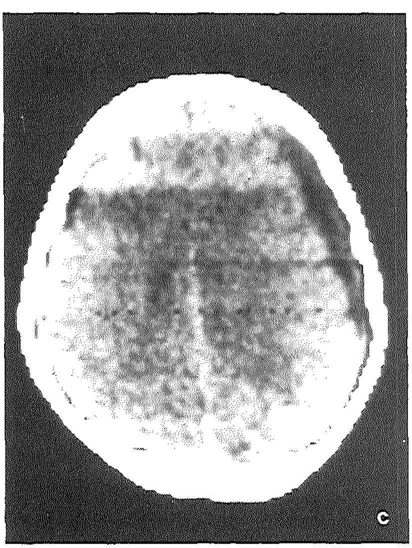


Fig. 10a. Male, aged 4 years. On admission comatose. Outcome: severely disabled. Scan made 24 hours after admission: contusion in corpus callosum. Hypodense contusion right frontal.

Fig. 10b. Same patient. Scan made 1 week after admission: remains of contusion in corpus callosum.

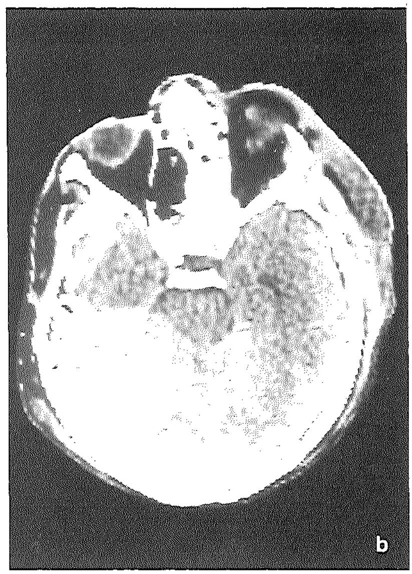
Fig. 10c. Same patient. Scan made 2 weeks after admission: remains of contusion hardly visible. Subdural effusion over right hemisphere.

BASAL CISTERNS

Special attention was paid in the study of these structures to the suprasellar and perimesencephalic cisterns (12, 21, 99).

Partially obliterated cisterns

Partially obliterated cisterns are characterised by a certain asymmetry, which is not attributable to the patient's position.



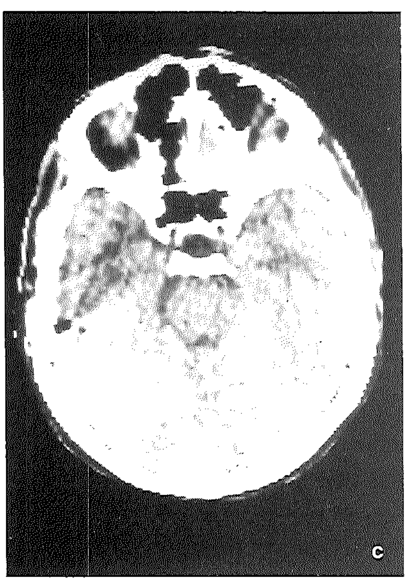


Fig. 11a. Male, aged 16 years. On admission comatose. Outcome: recovery. Scan made on admission: partially obliterated cisterns. Pneumocephalus externus.

Fig. 11b. Same patient. Scan made a few hours after admission: partially obliterated cisterns caused by extracerebral haematoma located on left side in infratentorial region. On operation an epidural haematoma was found.

Fig. 11c. Same patient. Scan made 1 year after admission: normal configuration of perimesencephalic cisterns. Some local atrophy in left temporal region.

Totally obliterated cisterns

The basal cisterns can here no longer be identified as CSF-spaces.

Very occasionally, it is difficult to distinguish the basal cisterns, although in fact there is no obliteration. This occurs when a certain quantity of blood is present in the CSF, such that when these have mixed together differentiation between basal cisterns and brain tissue is no longer possible.
Usually, however, the diagnosis of partially or totally obliterated cisterns is not a problem with the help of a good computer tomogram. It is rarely the case that the basal cisterns are isodense due to the presence of blood; if this is so, then there will be other radiological signs of blood elsewhere in subarachnoidal space. Similarly, when the basal cisterns are not visible due to a space-occupying effect, there would be other signs of space-occupying effect elsewhere.

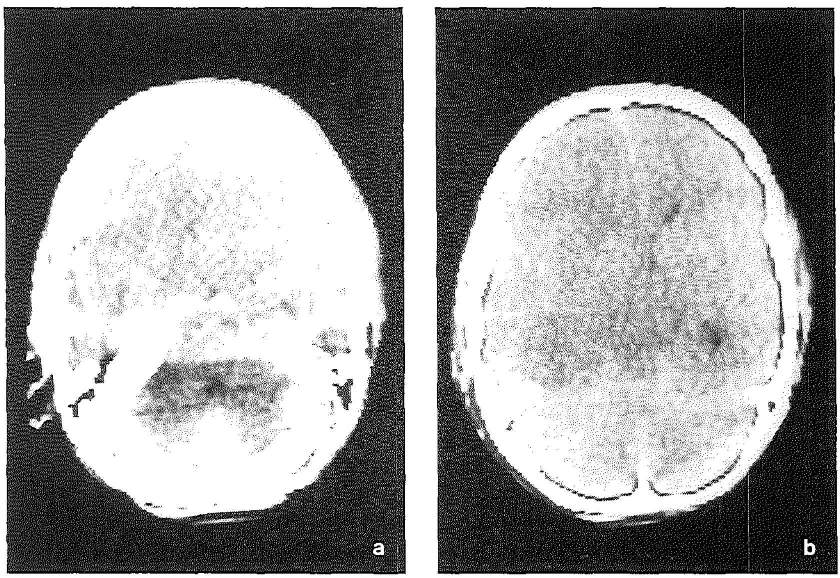


Fig. 12a. Male, aged 13 years. On admission comatose. Outcome: death. Scan made on admission: completely obliterated basal cisterns.

Fig. 12b. Same patient. Scan made on admission: completely obliterated basal cisterns. Midline shift to the right. Small subdural haematoma over left hemisphere. Probable left temporal contusion type II.

Infarction in the territory of the posterior cerebral artery
Such an infarction is shown as a wedge-shaped hypodensity which also covers cortical structures and is located on the medial side of the occipital lobe.

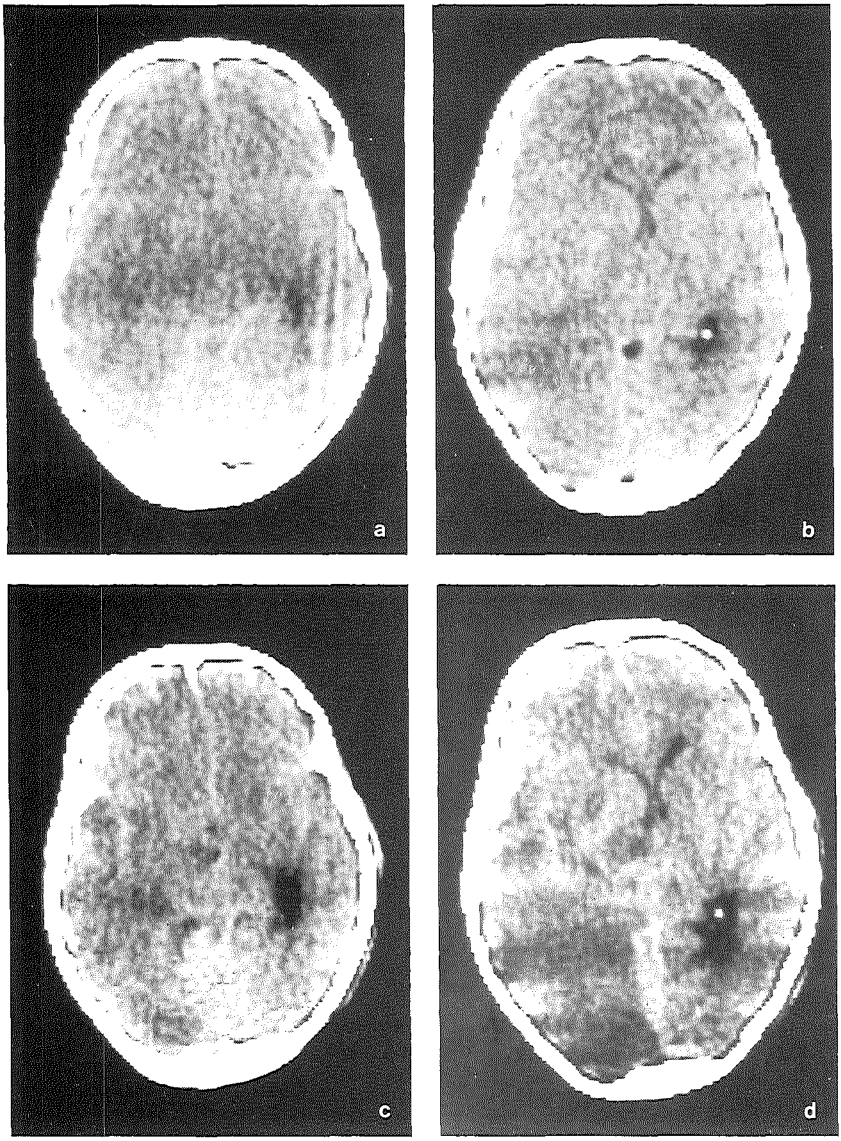


Fig. 13a. Male, aged 8 years. On admission comatose. Outcome: death. Scan made on admission: obliterated cisterns. Small subdural haematoma over left hemisphere.

Fig. 13b. Same patient. Scan made on admission: subdural haematoma over left hemisphere. Midline shift to the right.

Fig. 13c. Same patient. Scan made 24 hours after admission: obliterated basal cisterns. Dilation of trigonum of right ventricle.

Fig. 13d. Same patient. Scan made 24 hours after admission: infarction of left occipital lobe visible.

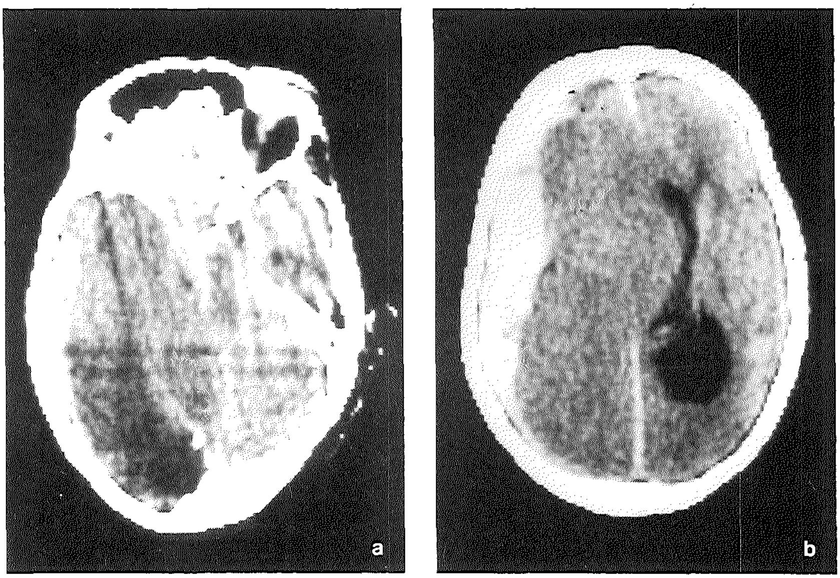


Fig. 14a. Female, aged 83 years. On admission comatose. Outcome: death. Scan made on admission: obliterated cisterns; subdural haematoma over left hemisphere. Infarction of the left occipital lobe.

Fig. 14b. Same patient. Scan made on admission: large acute subdural haematoma over left hemisphere, massive midline shift to the right. Radiological signs of herniation.

VENTRICLES AND MIDLINE SHIFT

Small ventricles

These are ventricles which are initially small but increase in size within a period of between a few days and a week, and so regain their normal dimensions. "Normal" is defined as belonging within the norms described by Meese et al (61).

Sometimes the ventricles finally become too big according to these norms (12, 26, 36, 56).

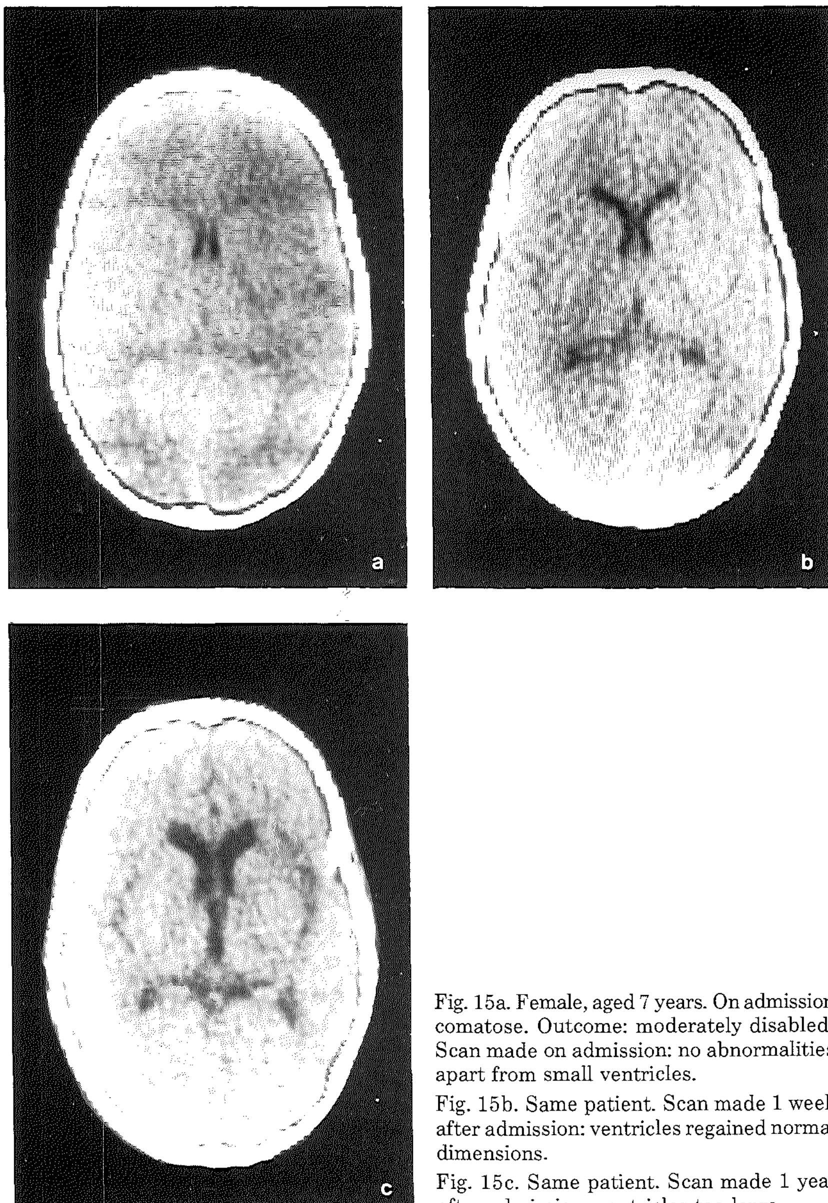


Fig. 15a. Female, aged 7 years. On admission comatose. Outcome: moderately disabled. Scan made on admission: no abnormalities apart from small ventricles.

Fig. 15b. Same patient. Scan made 1 week after admission: ventricles regained normal dimensions.

Fig. 15c. Same patient. Scan made 1 year after admission: ventricles too large.

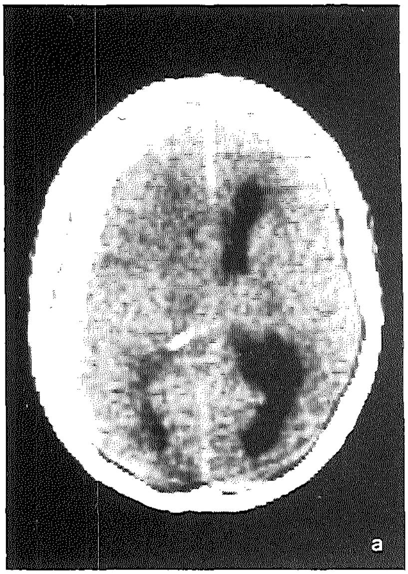
Compressed ventricles
In this case the lateral ventricles are small in dimension and abnormal in shape. This change in shape usually leads to asymmetry of both lateral ventricles, and is normally accompanied by midline shift.

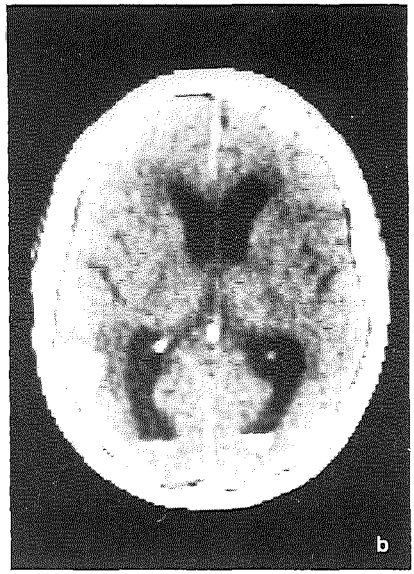
Midline shift
The degree of shift was measured according to the displacement of the septum pellucidum.
Douglas Miller and co-workers used the boundary of 5 mm displacement consistently in their distinction between "diffuse injury" and "mass lesion" (7, 64).
The term "diffuse injury" was used if a patient showed seriously impaired consciousness as the result of a brain injury, and if a displacement of 5 mm or less of the midline structures was present on the ventriculogram or the computer tomogram.
According to these authors, patients with a displacement of more than 5 mm came into the category of patients with mass lesions. In this study, a distinction is made between displacement of between 5 mm and 10 mm, which is taken as a moderate degree of midline shift, and displacement of more than 10 mm, which is considered to be a serious degree of midline shift.

MISCELLANEOUS

Intraventricular haemorrhage

With intraventricular haemorrhage, there is hyperdense material which is usually situated in the lowest lying part of the ventricular system. The hyperdensity has an upper horizontal boundary as a result of sedimentation (67).





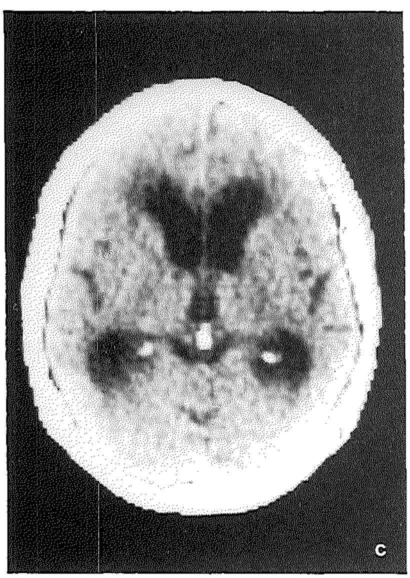


Fig. 16a. Female, aged 84 years. On admission comatose. Outcome: moderately disabled. Scan made on admission: acute subdural haematoma over left hemisphere. Slight midline shift to the right.

Fig. 16b. Same patient. Scan made 24 hours after admission: subdural haematoma disappeared spontaneously. Intraventricular blood. Small peripheral contusion in left hemisphere.

Fig. 16c. Same patient. Scan made 1 year after admission: no abnormalities. Ventricles probably too large.

Subependymal haemorrhage

Subependymal haemorrhage is revealed on the computer tomogram as mottled hyperdensity, situated on the walls of the ventricular system (69). This hyperdensity should be distinguishable from intraventricular blood which might be present at the same time.

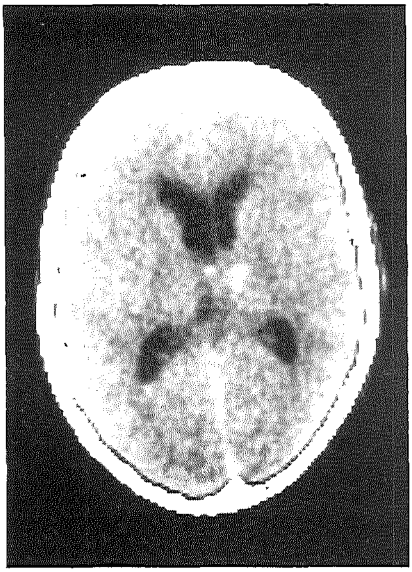


Fig. 17. Male, aged 14 years. On admission comatose. Outcome: recovery. Scan made on admission: small central contusion in right hemisphere. Subependymal blood near the foramen of Monro. Small quantity of intraventricular blood.

Herniation

The radiological signs of herniation used in this study are those described by Stovring, Osborn and Agnoli (1, 68, 81). The following can be distinguished:

Subfalcine herniation:

The cingulate gyrus, together with the anterior cerebral arteries or branches of these, becomes squeezed under the falx cerebri. This can ultimately result in an infarction in this territory. In this study, this form of herniation is only classified in terms of midline shift. The categories are: a shift of 0 - 5 mm, 6 - 10 mm and more than 10 mm.

Descending transtentorial herniation:

In addition to a midline shift, there is central and downward movement of the uncus and parahippocampal gyrus. The result is a re-shaping and shifting of the brainstem and surrounding CSF-spaces.
The ipsilateral ventricle is compressed, while the trigonum and temporal horn of the contralateral ventricle dilate (82). This situation may be complicated by infarction in the territory of the posterior cerebral artery.

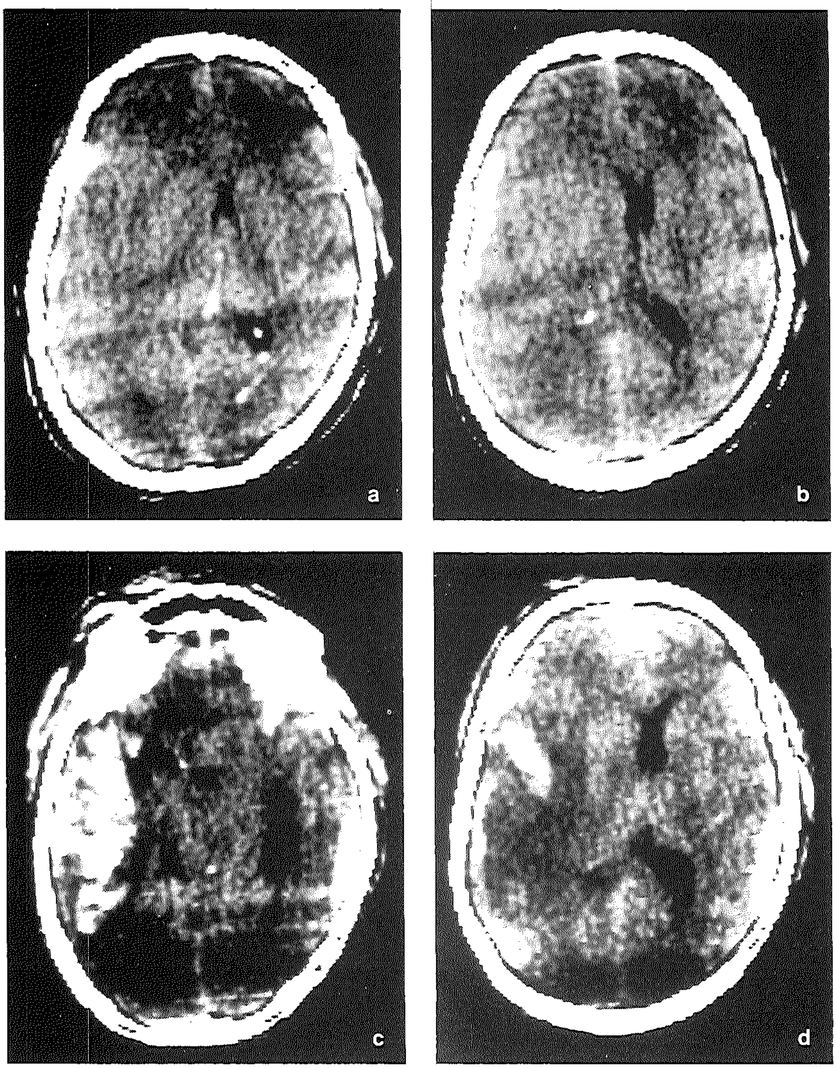
fig. 7a and b, p. 26.

Ascending transtentorial herniation (70, 16)

Radiological signs of this form of herniation (compression and/or shift of the fourth ventricle, obliteration of the pontocerebellar and supravermicular cisterns, possibly resulting in CSF-circulation disorder), are not sufficiently

reliable as yet for diagnosis with the help of CT.
The same is true for tonsillar herniation.
These forms of herniation were therefore excluded from this study.

Radiological delayed findings



See also fig. 16a and b, p. 35.

Fig. 18a. Male, aged 62 years. On admission comatose. Outcome: death. Scan made on admission: small subdural haematoma over left hemisphere. Midline shift to the right. Intraventricular blood.

Fig. 18b. Same patient. Scan made on admission: small subdural haematoma over left hemisphere. Compressed ventricles with midline shift to the right.

Fig. 18c. Same patient. Scan made 24 hours after admission: contusion of whole left temporal lobe. Small epidural haematoma on right side.

Fig. 18d. Same patient. Scan made 24 hours after admission: subdural haematoma over left hemisphere. Contusion in left temporal lobe. Epidural haematoma on right side. More pronounced midline shift to the right.

These are findings on a computer tomogram which were not present on preceding computer tomograms, and which would not have been expected on the basis of earlier scans.
Here it is not a matter of expansion of already visible lesions, but of newly developing lesions, or of an unexpected change in the appearance of a lesion. An example of this is the development of an intracerebral haematoma at the site of what was previously only a contusion.

LATE FINDINGS (LOCAL AND/OR DIFFUSE ATROPHY)

Local atrophy:
Local atrophy is shown on the computer tomogram as a hypodense area, with a density equal or similar to that of CSF (ca 0 - + 20 H. U.). Such a hypodense area is usually accompanied by local dilation of the ventricular system or of peripheral CSF spaces.

See fig. 2c and 4c, p. 21 and 23.

Diffuse atrophy:
With diffuse atrophy there is generalised dilation both of central and peripheral CSF spaces; as standards, normal sizes reported in the article of Meese et al (61) were used.
Local and diffuse atrophy can arise separately or in association. They may occur supra- and/or infratentorially, uni- or bilaterally.

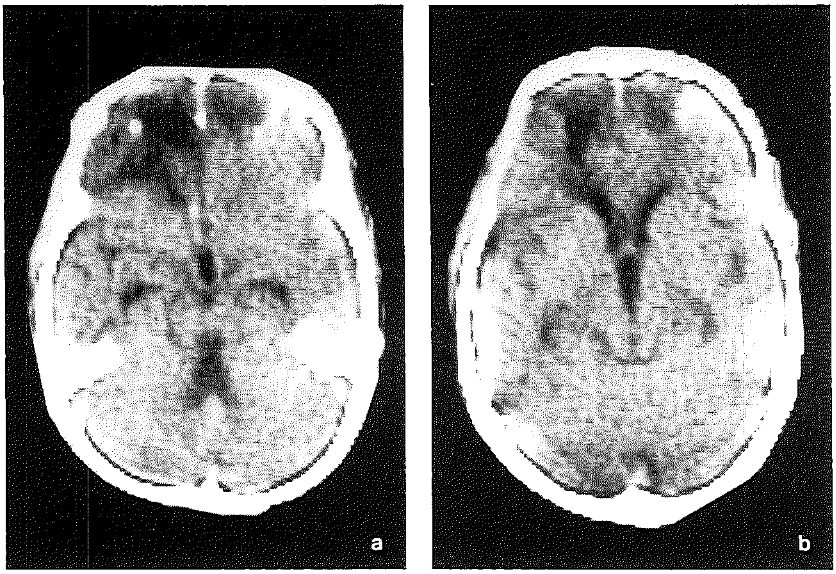


Fig. 19a. Female, aged 14 years. On admission comatose. Outcome: severely disabled. Scan made 1 year after admission: bilateral supratentorial and infratentorial atrophy.
Fig. 19b. Same patient. Scan made 1 year after admission: bilateral supratentorial atrophy.
See also fig. 5c and d, p. 24.

SERIAL COMPUTER TOMOGRAPHY

Serial CT is the making of a number of computer tomograms of the same patient over a period of a number of days or weeks. The number of scans and the intervals between them may vary.
The advantage of serial computer tomography is that it shows the changes and developments in findings over a period of time, as opposed to a single computer tomogram which only reflects the anatomical situation at that particular moment (77).

Materials and methods

In this study, the computer tomograms were made at the same time as the patients were undergoing a clinical examination for the multinational study. The intention was to compare the quality of probability statements based on computer-tomographic findings and related to a certain outcome of a patient, with the quality of the probability statements which were based on clinical findings alone. It was therefore obvious that the intervals at which both types of probability statements were to be made, should be the same as far as possible. This consideration gave rise to the following scan schedule: on admission, after 1 day, after 3 days, after 1 week, after 2 weeks, 1 month, 3 months and after 1 year.

PATIENTS

In the period from March 1977 to February 1979, 173 consecutive patients with severe traumatic brain damage were admitted to the neurosurgical and neurological departments of the "Dijkzigt" Academic Hospital of Erasmus University in Rotterdam. Of the 173 patients, 121 were comatose. Of these, 82% became comatose directly after the accident, the remaining 18% were lucid for a time prior to admission. Coma was defined according to the Glasgow Coma Scale as a state in which the patient does not open his eyes, does not utter any recognisable words and does not obey commands. Thirty-nine per cent of the comatose patients had both pupils dilated and nonreacting to light on admission, 12% had one pupil dilated and nonreacting and 48% had both pupils reacting to light. The distribution of the Glasgow Coma sum score on admission is given in table 4.

TABLE 4
Distribution of coma sum score on admission of 121 comatose patients.

Coma sum score (E + M + V)	On admission n	On admission %
unknown	5	4
3	13	11
4	23	19
5	13	11
6	34	28
7	26	21
8	7	6
9	–	–
total	121	100

The coma sum scores of 5 patients (4%) could not be assessed owing to intubation of the patient and/or swollen eyelids.

Table 5 shows the distribution of age and the outcome 1 year after onset of coma in these patients.

TABLE 5
Distribution of age and outcome after 1 year of 121 comatose patients.

Age	Death	PVS	Severe disability	Moderate disability	Recovery	Total n	Total %
0- 9 years	9	0	3	4	4	20	17
10-19 years	14	1	1	1	11	28	23
20-29 years	5	0	2	2	7	16	13
30-39 years	10	0	0	1	1	12	10
40-49 years	8	0	1	0	1	10	8
50-59 years	16	0	1	0	1	18	15
60-69 years	7	0	0	0	2	9	8
70-79 years	5	0	0	0	0	5	4
80-89 years	2	0	0	1	0	3	2
Total	76	1	8	9	27	121	100

Fifty-eight per cent of the patients were admitted one hour after the accident, and 90% within 6 hours.
Approximately two-thirds of the patients were transported directly from the site of the accident to our hospital. The remaining one-third were briefly admitted to another hospital before being redirected. In 74% of the patients, road accidents were the cause of the brain damage; 13% of the accidents occurred in and around the home.
Fifty-five per cent of the patients had a skull vault fracture. One in three patients had one other injury elsewhere in addition to the brain injury. One in five patients had more than one extracranial injury (multitraumatised).
Fifty-two of the 173 patients were not comatose according to the criteria of the Glasgow Coma Scale, but nonetheless showed symptoms of severe brain damage i.e. impaired consciousness and/or neurological deficit (see table 6).

TABLE 6
Signs in 52 non-comatose patients on admission.

	n
neurological deficit	5
impaired consciousness	19
neurological deficit and impaired consciousness	28
total	52

This group of patients is not as clearly defined as the group of comatose patients. Certainly the degree of impaired consciousness and the severity of the neurological deficit were reason enough for admission to our hospital.
Five patients had an open skull/brain injury.
The average age of this group was 37 years, with a range of 0 - 82 years, and the mortality rate in this group was 27% (n = 14).

The entire group of 173 patients formed the basis for the first part of this study, which examines the influence of CT on management. The group of 121 comatose patients forms the basis for the second part of the study, which deals with the prognostic value of computer tomography for comatose patients.

Patients with less serious brain injury were not included in this study. According to Merino de Villasante et al (62), computer tomography of patients without impaired consciousness or neurological deficit would only produce abnormal findings in a very small number of cases, and these findings would, moreover, have no neurosurgical implications.

COMPUTER TOMOGRAPHY AND PATIENTS

According to the protocol used in this study, each patient was to be scanned on admission, after 1, 3, 7, 14 and 30 days, after three months and after one year.
Occasionally, the transport of a patient to the scanning room was contra-indicated. Examples of such contra-indications were diffuse multiple injuries, the fact that the patient was being ventilated etc. Sometimes the EMI scanner was defective. It also happened that some patients were scanned an additional number of times because of unexpected deterioration during a period in which no scan was planned, or following an intracranial operation.

The number of scans which could have been obtained if all comatose patients had survived for at least one year after the accident, and had been investigated according to the protocol, was 121 x 8 = 968. Many patients however died, particularly in the first week following onset of coma (see table 7).

TABLE 7
Interval between onset of coma and moment of death of 76 comatose patients.

	n
< 24 hours	30
2-3 days	17
4-7 days	7
8-14 days	5
15-28 days	6
> 28 days	11
total	76

If all comatose patients had been scanned according to the protocol until the time of death or 1 year survival, the number of scans would amount to 546. However, in the group of 121 comatose patients, the number of scans actually made is 382, 70% of the total number of scans planned. In the 52 non-comatose patients who showed other signs of severe brain damage, the numbers are as follows: 180 scans made, 57% of the total possible according to the protocol. Thus the total number of scans which forms the basis of this study is 562. This is 65% of the maximum number obtainable according to the protocol.

STATISTICAL METHODS

PROGNOSTIC FEATURES

In the past few years it has been established that in patients with severe brain damage, certain clinical findings obtained at various times during the first weeks after the accident are closely correlated with a particular outcome (13, 31, 72). Such a correlation between clinical variables and outcome implies that in a new patient it is possible to make predictions about expected outcome, based on these clinical variables. Jennett et al (1979) (45) and Braakman et al (1980) (10) established that, from a predictive view point, the following were among the important clinical findings (variables) during the first weeks after the accident: age, the scores on the 3 features of the Glasgow Coma Scale and the scores which reflect brainstem dysfunction (pupil reactions, spontaneous or elicited eye movements, apnoea etc.).

PREDICTION OF OUTCOME

A prediction concerning the outcome of a particular patient will, in general, become more reliable when this is based on a combination of prognostically important variables, rather than on just one. Thus Price and Knill-Jones (75) established that combinations of nonreacting pupils and various levels of impaired consciousness at different times after the accident led to a good prediction concerning probability of death. It is, however, only in a limited number of cases that such combinations of variables with a high predictive value occur. This was sufficient reason for Braakman et al (10) to select sets of variables which together have the greatest possible prognostic weight. Such a selection was to be done systematically, based on discriminant analysis. This selection procedure was applied to the data on the 305 Dutch patients included in the multinational databank. The variables thus selected were used as the basis for a prognosis rule. A prognosis rule is a mathematical formula; the scores of certain features are substituted into this formula, and the result is a probability statement about the expected outcome.
The remainder of this section explains the formulation of prognosis rules. The scores of a patient in various tests are known as prognostic variables of that patient. One obvious method of predicting the outcome of a patient is to match his features with the features of a reference group. The probability of that patient surviving is then the same as the proportion of reference group patients who have those features and who survive.
For example in the following reference group:

FIG. 20
Distribution of age and outcome in the 305 Dutch reference patients.

	Outcome		
age	survive	die	total
< 30 years	118	59	177
⩾ 30 years	39	89	128
total	157	148	305

the survival probability of a patient who is under 30 is $\frac{118}{177}$.

This matching method cannot be used when there is an insufficient number of patients in the reference group with matching features. For example, if only two patients in the reference group are over 30 years old and one survives, then there is a very large variance on the 50% outcome prediction.
This situation is almost certain to arise if we wish to predict the outcome based on a large number of features. However, if we make the assumption that the features are statistically independent, then we can use the following statistical analysis to formulate the prediction.
Referring back to the previous reference group we can say:

- the probability of randomly selecting from the survivors a patient who is under 30 years of age is $\frac{118}{157}$;
- the probability of randomly selecting from the non-survivors a patient who is under 30 is $\frac{59}{148}$;
- the probability of randomly selecting a survivor is $\frac{157}{305}$, and of randomly selecting a non-survivor is $\frac{148}{305}$;
- then, the ratio of survivors to non-survivors in a randomly selected set of reference group patients who all happen to be under 30 years old is: $\left(\frac{118}{157} \times \frac{157}{305}\right) : \left(\frac{59}{148} \times \frac{148}{305}\right) = 118 : 59$, so that the survival probability is $\frac{118}{(118+59)} = \frac{118}{177} = 67\%$.

The result is, of course, the same as that obtained from the matching method. However, this same procedure can also be applied to combined scores when there are not sufficient patients in the reference group who exactly match features of the test patients.

As an example, we will use this second method to predict the outcome of a patient based on his scores in the previous "under 30 test" and the "pupil reaction test".

FIG. 21
Distribution of pupil reaction and outcome in the 305 Dutch reference patients.

	Outcome		
Pupil reactions	survive	die	total
Both pupils reacting	128	53	181
one pupil reacting	16	19	35
both pupils nonreacting	13	76	89
total	157	148	305

If we assume that the probability of randomly selecting a patient who is under 30 years old (P) is unrelated to the probability of randomly selecting a patient with two reacting pupils (Q), then we can say that the probability of randomly selecting a patient who is under 30 and who has two reacting pupils is P x Q. (Compare this to the matching method, where there must be a sufficiently large number of patients in the reference group who actually possess these two features).

Then:

- the probability of randomly selecting from the survivors a patient who has two reacting pupils is $\frac{128}{157}$;
- the probability of randomly selecting from the non-survivors a patient who has two reacting pupils is $\frac{53}{148}$;
- therefore, the probability of randomly selecting from the survivors a patient who is under 30 and who has two reacting pupils is $\frac{118}{157} \times \frac{128}{157}$;
- and, the probability of randomly selecting from the group of non-survivors a patient who is under 30 years and who has two reacting pupils is $\frac{59}{148} \times \frac{53}{148}$;
- the probability of selecting a survivor is $\frac{157}{305}$, and a non-survivor is $\frac{148}{305}$;
- therefore the ratio of survivors to non-survivors in a randomly selected set of patients who are under 30 and who have two reacting pupils, is:
  $\left(\frac{118}{157} \times \frac{128}{157} \times \frac{157}{305}\right) : \left(\frac{59}{148} \times \frac{53}{148} \times \frac{148}{305}\right) = 4.553 : 1$
  so that the survival probability is 82%.

In general, if:

- from the group of survivors alone:
  - a proportion S_i have feature F_i
  - (and so, a proportion $(1\text{-}S_i)$ do not have feature F_i)
- from the group of non-survivors alone:
  - a proportion N_i have feature F_i
  - (and so a proportion $(1\text{-}N_i)$ do not have feature F_i)
- the proportion of survivors from the total group is P

then the survival probability of an incoming patient with feature F_i is:

$$\frac{P \prod_{i=1}^{n} Si}{(1\text{-}P) \prod_{i=1}^{n} Ni \quad + \quad P \prod_{i=1}^{n} Si}$$

The probability for a particular outcome category can vary from 0% to 100%.

SELECTION OF VARIABLES

In the selection procedure a statistical model was used which assumed that the variables were independent of each other. Although in a strict sense this assumption is only partly correct, in a comparative study with other models this independence model seemed to produce good results in this series of patients with severe brain damage (92).

In order to select the variables which, when combined, have the greatest prognostic significance, the stepwise forward method of selection is used. The purpose of this method is to select a set of variables which is as small as possible and yet contains the maximum prognostic information

available. The first step in this method is to select out of all the possible variables that which has the greatest prognostic value; the second step is to choose from the remaining variables that which, when taken in conjunction with the variable selected in step one, has the greatest prognostic significance.
In step three, a third variable is added to the set on the same basis. This procedure is continued until the point where the addition of a further variable to the set would contribute virtually no improvement to the quality of prediction.

QUALITY OF PREDICTION

The quality of prediction can be established by comparing the probability statement with the actual outcome.
If the statement gives the chance of death or survival as more than 50% and this statement does not correspond with the true outcome, then this statement can be described as incorrect. The number of such incorrect predictions is expressed by what is known as the "error rate".
The error rate is literally that proportion of patients in which the actual outcome did not agree with the most likely outcome according to the probability statement. In this way only a rough indication of the quality of the probability statement is obtained. If it is calculated that for a certain patient the chance of death is greater than 90%, and yet this patient ultimately survives, the error is greater than if the patient's chance of dying had been calculated at 55%.

The quadratic penalty score is a measure which takes the size of error into account (28).
For example: the probability statement for an individual patient in the outcome categories of death, vegetative state, severe disability, moderate disability and recovery is 0.05, 0, 0.01, 0.03 and 0.91, respectively. In this patient, therefore, there is a high chance of recovery (91%).
For someone whose actual outcome is recovery, the ideal prediction is 0, 0, 0, 0, 1.0.
The quadratic penalty score for the probability statement is obtained by squaring and adding up the differences between the stated prediction and the ideal prediction. In our example, complete recovery, the correct prediction, has a penalty score of:
$0.05^2 + 0^2 + 0.01^2 + 0.03^2 + (1 - 0.91)^2 = 0.0116$.
By this method, the quadratic penalty score can assume any value between 0 and 2; 0 as the penalty score for an ideal prediction and 2 for a completely incorrect prediction.

By calculating the penalty score for a large number of patients and taking the average of these results, a mean penalty score is obtained which gives an impression of the quality of this prognosis rule.

A completely different method of determining the accuracy of predictions can be obtained by comparing the prediction and the actual outcome in particular groups of patients, e.g. in that group of patients in which the probability statement concerning outcome reached a high percentage, for example 90% or more. This type of probability statement is termed "sharp prediction". The total number of "sharp predictions" is of course

limited, and naturally depends – as with every probability statement – on the time when the prediction is made, on when the outcome is established and on the number of outcome categories.
For instance, it is more difficult to give a consistently accurate prediction on admission of the outcome after 6 months, than it is to give such a prediction when 4 weeks have already elapsed since the accident.
Moreover, it is easier to make a sharp prediction in two categories, for example death or survival, than to make a sharp prediction involving 4 survival categories.

SELECTED VARIABLES

Table 8 shows the combination of clinical variables selected, at various time intervals after the onset of coma, in the 305 Dutch patients in the multinational databank, using the stepwise forward method of selection.

TABLE 8

Selected prognostic variables at fixed time-points after onset of coma.

Moment	Selected variables
Admission	Age
	Pupil reation on admission
	E+M-score on admission
24 hours	Worst pupil reaction during first 24 hours
	Age
	Worst motor response during first 24 hours
Day 3	Worst E+M+V-score during days 2-3
	Age
	Worst eye indicant during days 2-3 *
	Motor response on admission
Day 7	Best E+M+V-score during days 4-7
	Age
	Presence of apnea periods during days 4-7
	Pupil reaction on admission
Day 14	Best E+M+V-score during days 4-7
	Age
	Presence of apnea periods during days 4-7
Day 28	Best verbal response during days 15-28
	Sex
	Best Motor response during days 15-28
	Age
	Worst pupil reaction during days 15-28

* the created eye indicant is a score which is composed of the spontaneous eye movement, oculocephalic and oculovestibular reaction scores.

from Braakman et al, 1980 (10).

These variables are used to determine outcome (5 categories) after 6 months.

Only clinical variables were selected. The possible prognostic significance of, for example, the E.E.G., cortical evoked responses, intracranial pressure and computer-tomographic findings were not included.

The particular aim of the current study is to investigate whether probability statements concerning outcome after 1 year can be made based on computer-tomographic findings alone or in combination with clinical variables. Furthermore, the quality of such predictions will be compared with that of predictions based only on clinical variables.

Computer tomography and management

PRINCIPLES OF MANAGEMENT

In the Dijkzigt Academic Hospital of Erasmus University in Rotterdam, the investigation and treatment of patients with severe brain damage is carried out in accordance with a protocol.
However, methods of investigation and treatment which differ from those suggested in the protocol may also be used. The following diagram represents the part of the protocol which is relevant to this study.

FIG. 22
Diagram of management principles.

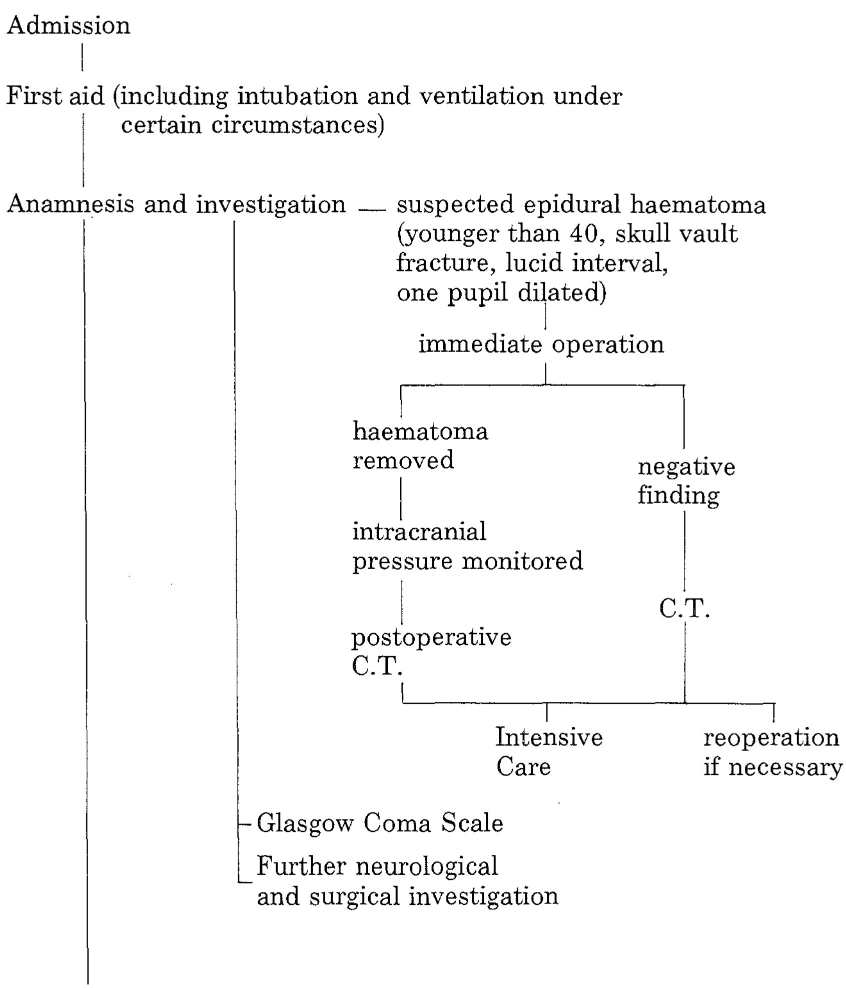


FIG. 22 CONTINUED
Diagram of management principles.

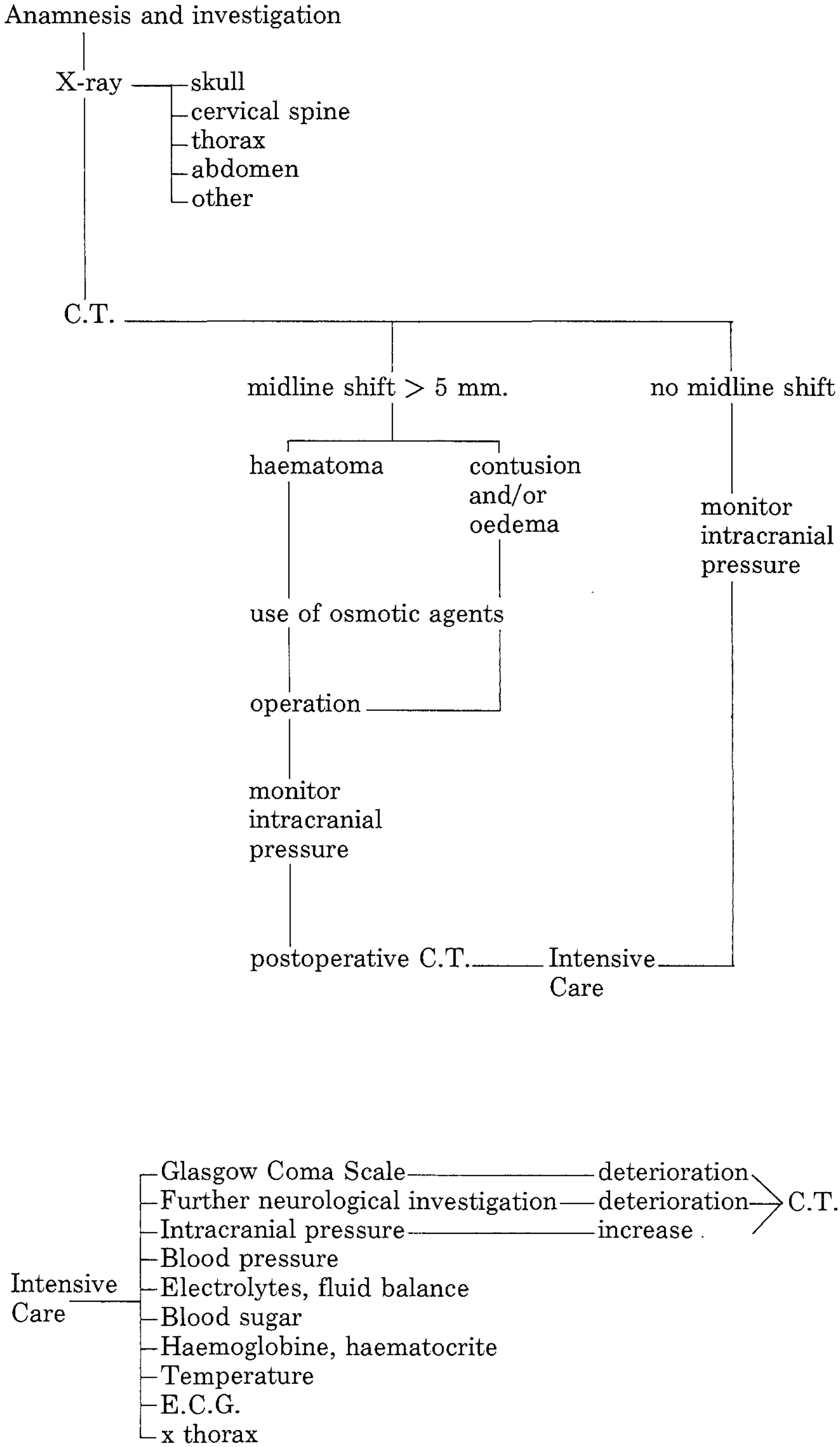
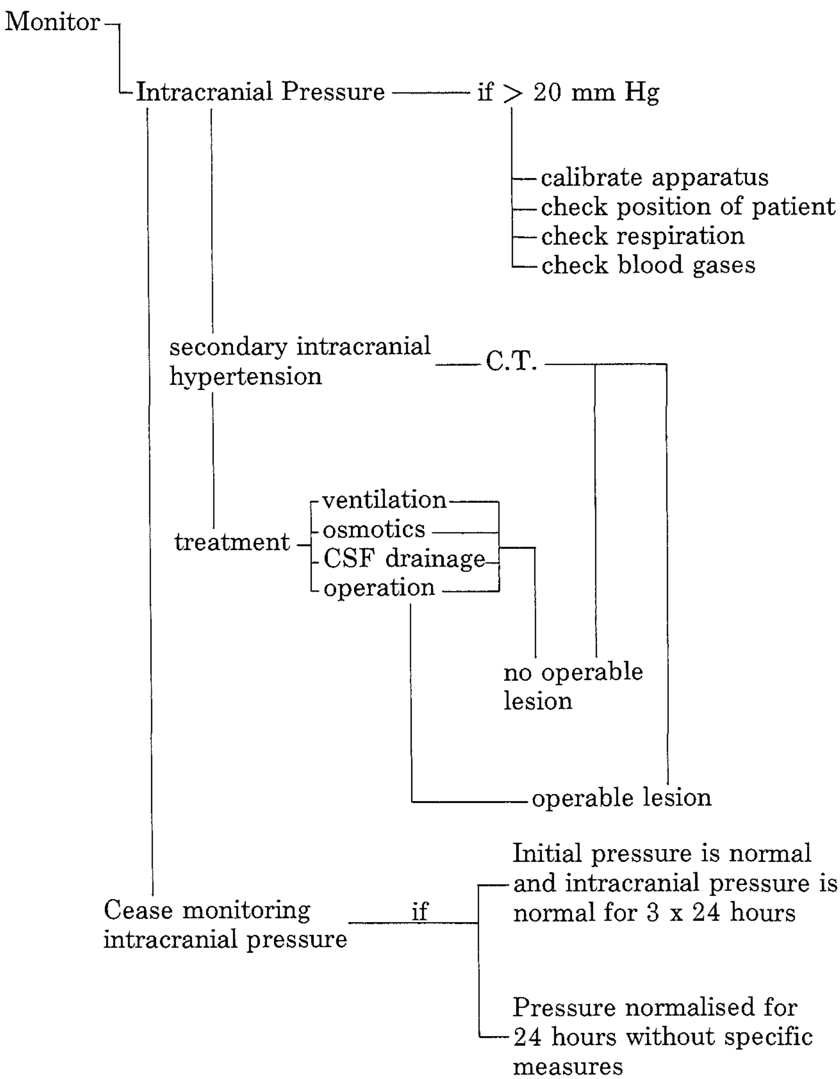


FIG. 22 CONTINUED
Diagram of management principles.



It can be seen from the diagram that computer tomograms are made:

- on admission
- within 24 hours after an operation
- after an exploratory operation which is unexpectedly negative
- in case of clinical deterioration
- in case of a rise in intracranial pressure to more than 20 mm Hg for at least 15 minutes.

One of the questions raised in this section of the study will be whether computer tomograms can also convey information at other times. An attempt will also be made to answer the following questions:

1. What is the distribution of computer tomographic findings at the various times when the patients were examined?
2. To what extent is a diagnosis which is based on a computer tomogram confirmed by operation or autopsy?
3. When should patients with severe brain damage be examined by means of computer tomography?
4. Which patients with brain damage should be examined by means of computer tomography?
5. What is the influence of computer tomography on the frequency with which other diagnostic techniques are used and on the treatment of patients with severe brain damage?

1) DISTRIBUTION OF COMPUTER TOMOGRAPHIC FINDINGS

What is the distribution of computer tomographic findings at the various times when the patients were examined?

One hundred and sixty seven out of the 173 patients were scanned on admission; 116 were comatose and 51 non-comatose.
In the case of 20 patients, no abnormalities were visible on the computer tomogram made on admission. The other 147 patients had computer tomograms on which abnormalities were detected; 41 (35 comatose, 6 non-comatose) showed a combination of intracerebral and extracerebral pathology. The distribution of findings is given in tables 9 and 10.

TABLE 9

Distribution of CT-findings in 121 comatose patients.

CT-finding	Scans on admission	24 hours	3 days	1 week	2 weeks	> 1 month
Parenchymatose lesions						
normal	39	15	11	9	14	
contusion type I	10	2	1	2	3	
contusion type II	16	7	8	5	4	1
contusion type III	16	12	10	10	11	
intracerebral haematoma	11	8	5	3	–	
central contusion	16	9	4	5	3	
brainstem lesion	8	4	2	3	–	
Extracerebral Pathology						
normal	60	34	32	28	25	
subdural haematoma	47	17	7	6	2	
epidural haematoma	9	6	2	3	–	
subdural effusion	–	–	–	–	8	6
Cisterns						
normal	33	21	23	27	31	
partially obliterated	25	14	11	8	3	
completely obliterated	56	20	6	2	1	
completely obliterated + infarction	2	2	1	–	–	
Ventricles and midline shift						
normal	17	9	10	13	20	
small ventricles, no shift	33	17	12	10	1	
ventricles compressed, shift 0-5 mm	27	16	8	10	12	
ventricles compressed, shift 6-10 mm	17	6	9	3	1	
ventricles compressed, shift > 10 mm	22	9	2	1	1	
Other findings						
intraventricular blood	15	8	2	1	1	
subependymal blood	15	10	2	2	–	
herniation	35	14	10	2	1	
radiological delayed findings	–	15	24	20	11	6
scans available	116	57	41	37	35	
no scans made	5	27	29	28	24	
patients dead since admission	–	37	51	56	62	

TABLE 9 CONTINUED

Distribution of late CT-findings in survivors out of 121 comatose patients.

CT-finding	Scans 1 month	3 months	1 year
Late findings			
normal	10	7	19
unilateral supratentorial atrophy	6	4	6
bilateral supratentorial atrophy	8	4	8
infratentorial atrophy	1	1	1
infratentorial + unilateral supratentorial atrophy	1	3	2
infratentorial + bilateral supratentorial atrophy	5	5	5
scans available	31	24	41
no scans made	24	23	4
patients dead since admission	66	74	76

TABLE 10

Distribution of CT-findings in 52 non-comatose patients.

	Scans on admission	24 hours	3 days	1 week	2 weeks	> 1 month
Parenchymatose lesions						
normal	21	9	10	13	10	
contusion type I	7	5	3	4	6	6
contusion type II	5	4	4	2	–	
contusion type III	6	2	2	1	–	
intracerebral haematoma	7	2	3	2	2	
central contusion	2	1	–	–	–	
brainstem lesion	3	2	2	–	1	
Extracerebral Pathology						
normal	33	17	18	18	13	
subdural haematoma	11	4	3	–	1	
epidural haematoma	7	3	2	1	1	
subdural haematoma	–	1	1	3	4	5
Cisterns						
normal	27	14	17	21	16	
partially obliterated	14	8	7	1	3	
completely obliterated	10	3	–	–	–	
completely obliterated + infarction	–	–	–	–	–	
Ventricles and midline shift						
normal	16	11	16	16	15	
small ventricles, no shift	11	7	2	1	1	
ventricles compressed, shift 0-5 mm	12	4	6	5	3	
ventricles compressed, shift 6-10 mm	8	2	–	–	–	
ventricles compressed, shift > 10 mm	4	1	–	–	–	
Other findings						
intraventricular blood	2	3	2	–	–	
subependymal blood	3	1	1	–	–	
herniation	10	2	–	–	–	
radiological delayed findings	–	7	6	8	4	5
scans available	51	25	24	22	19	
no scans made	1	21	19	20	21	
patients dead since admission	–	6	9	10	12	

TABLE 10 CONTINUED

Distribution of late CT-findings in survivors out of 52 non-comatose patients.

CT-finding	Scans 1 month	3 months	1 year
Late findings			
normal	8	3	17
unilateral supratentorial atrophy	6	4	12
bilateral supratentorial atrophy	1	1	3
infratentorial atrophy	–	–	–
infratentorial + unilateral supratentorial atrophy	–	–	1
infratentorial + bilateral supratentorial atrophy	1	2	1
scans available	16	10	34
scans not made	22	28	4
patients dead since admission	14	14	14

The tables show the large number of abnormal findings on the computer tomograms which were made within a few hours after the accident. A couple of hours after the accident, contusions and intracerebral and extracerebral haematomas were already visible, sometimes accompanied by perifocal oedema. Even massive midline shift and complete obliteration of the basal cisterns could be detected shortly after the accident (in 27 and 66 patients respectively). A large number of patients (45) already showed a radiological image of herniation. In the case of 2 patients, it was possible on admission to detect radiological signs of descending transtentorial herniation, in combination with an infarction in the territory of the posterior cerebral artery. In a substantial group (69%), little or no midline shift was visible on the computer tomogram. The most serious CT findings were observed in the group of comatose patients (83% of the central contusions and brainstem lesions and 85% of obliterated cisterns). This group also showed the largest degree of midline shift. A midline shift of 10 mm or more was found in 19% of the comatose patients and in 8% of the non-comatose patients.

As can be seen from the tables, subdural effusions generally appeared after the first week following the accident.

After one month had elapsed since the accident, there were usually no more changes in the computer tomograms. Exceptions to this were the 7 patients who still showed a contusion on the scan made 1 month after their admission, and the 11 patients who still had a subdural effusion at that point.
On the computer tomogram made 3 months after admission of one patient, there were signs of impairment of the CSF-circulation.

In table 11, column I, the numbers representing the distribution of CT findings are based on the definition of "intracerebral haematoma" which was given in the first part of this study. Column II shows how much a variation in the definition of a CT result can affect these figures.

TABLE 11

Distribution of CT findings on admission, based on two different definitions of "intracerebral haematoma".

	An intracerebral haematoma is a:	
	I. Homogeneous hyperdense lesion	**II. Mainly** hyperdense lesion
Contusion type II + III	61	27
Intracerebral haematoma	18	55
Brainstem contusion	11	8

If an intracerebral haematoma is defined on the computer tomogram as a **homogeneous**, hyperdense lesion then 18 cases can be said to have been observed. If, on the other hand, the following definition is used – "an intracerebral haematoma is a **mainly** hyperdense lesion" – then the number of cases becomes 55 and we find correspondingly fewer contusions and brainstem lesions.

2) CT DIAGNOSIS AND OPERATION OR AUTOPSY

To what extent is a diagnosis which is based on a computer tomogram confirmed by operation or autopsy?

Computer tomography is a pictorial method of diagnosis, with clear limitations. The quality of both contrast resolution and spatial resolution is restricted and furthermore dependent on the computer tomograph used. In this study the EMI CT-1010 scanner was used. The slice thickness was 13 mm. Abnormalities which are of less than half the slice thickness and which only show a slight difference in density with their surrounding are particularly difficult to detect. Because of the relatively long "exposure time", movement artefacts also affect the accuracy of this diagnostic method, especially in such areas as the infratentorial, temporo-basal and upper parietal regions (6). Small abnormalities situated just under the skull vault are often not visible on a CT scan. Consequently, not all traumatic abnormalities in the brain are shown on the computer tomogram.
Such considerations give rise to the following questions:

- which abnormalities are not visible on the computer tomogram?
- to what extent does this happen?
- are the abnormalities which are present on the computer tomograms correctly interpreted?

The CT findings of the 173 patients in this study could only be partially verified. This was the case with 43 patients whose CT findings were confirmed by operation, and with 18 by autopsy. Of the 43 patients who underwent surgery, in 41 patients (95%) the computer tomographic diagnosis was confirmed. In the case of 1 patient, it was difficult on the CT image to determine whether the intracranial haematoma was epidural or subdural. On operation, it appeared to be a small epidural haematoma. On the computer tomogram of the other patient a subdural haematoma appeared to be present, whereas on operation both subdural and epidural blood were found. A diagnosis based on the computer tomogram can therefore be confirmed, but may at the same time be shown to be incomplete. Hence 2 superficial contusions, which had not been visible on the computer tomogram, were subsequently observed during surgery. In the case of 4 patients, subcortically situated abnormalities were seen on the computer tomogram but were not subsequently observed during surgery. This could well be due to the fact that during an operation only a part of the intracranial contents is examined; moreover, it is often the case that only the surface of the brain is inspected.

More combinations of brain abnormalities were found during autopsy than were detected by computer tomography. Five cases involved a combination of extracerebral haematomas with contusions which were either superficial or located in the brainstem. Such contusions are difficult to detect by computer tomography for the reasons already given. In answer to the original question, all CT findings were confirmed by autopsy, although in some cases the CT results were found to be incomplete.

3) WHEN SHOULD PATIENTS BE EXAMINED?

When should patients with severe brain damage be examined by means of computer tomography?

The purpose of the computer tomographic investigation of patients with severe brain damage is two-fold, namely:

- to identify abnormalities which may explain the clinical picture of the patient concerned;
- to establish whether it is possible to operate on such abnormalities.

Furthermore, a computer tomogram may provide prognostic information.

Abnormalities were found in 86% of the computer tomograms made on admission. If all extracerebral and intracerebral haematomas are considered as potentially operable, then 92 operable abnormalities can be said to have been detected in this series on admission.
Type II and III contusions can also sometimes be removed by operation if their location is frontal or right temporal, and if they occupy much space. Such contusions were detected 43 times on admission. These figures show the importance of computer tomograms made on admission.

One of the aims of this study is to determine the possible influence on management of computer tomograms made at later stages. If a patient survives the accident, extracerebral haematomas which have not been operated on will usually disappear. Sometimes chronic subdural haematomas can occur. Parenchymatose lesions which have been detected by computer tomography usually change according to a certain pattern and within a certain period (8, 20, 52, 65). Hyperdense, space-occupying lesions decrease in volume and density. A local atrophy remains, unless the original abnormality was very small.
In the case of hypodense lesions, the difference in density as compared

with the surroundings gradually decreases in time, until again a local atrophy remains. In this series this "normal" pattern of changes was observed in 51 patients.

Exceptions to this pattern can occur.
A hypodense lesion may become partially or wholly hyperdense.
A partially hyperdense lesion may become homogeneously hyperdense.
Extracerebral fluid collections can arise in locations where these had previously not been seen. Such "unusual" changes, as observed on the computer tomograms, were described as "radiological delayed findings" (11, 18, 23). This category did not include findings which remained qualitatively the same but simply increased in volume or produced a greater degree of midline shift.

A "radiological delayed finding", as described above, was found in 44 out of the 173 patients (25%). In 23 cases such a finding appeared on the 24 hours scan; in 9 cases it appeared on the 3 days scan; in 10 cases it was observed between the first and second week after the accident; and in 2 cases it was seen in the period between 2 and 4 weeks after the accident. These data show that it is important to scan the patient not only on admission but also at other intervals after the accident.

The nature of the "radiological delayed findings" was:

– intracerebral haematoma	13 x
– type II or III contusion	16 x
– epidural haematoma	2 x
– subdural effusion	14 x
– impairment of CSF-circulation	1 x

It should be noted here that one patient showed both an intracerebral and an epidural haematoma as radiological delayed findings, following the evacuation of an epidural haematoma.
Another patient showed a type III contusion on his first computer tomogram, whereas the scan made 14 days after admission revealed a subdural effusion.

Intracerebral haematomas, type II or III contusions and epidural haematomas were all visible as radiological delayed findings on the scans made 24 hours or 3 days after admission. In 12 patients, a subdural effusion occurred within 14 days after admission. In the case of 2 patients, a subdural effusion was detected on the scan made 1 month after admission. All effusions disappeared spontaneously, without requiring operation, within 3 months of admission.

Thirty-two radiological delayed findings were observed on scans made 24 hours or 3 days after admission; 8 of the 32 occurred directly after an intracranial operation (what are known as "release haematomas"). In 18 cases, clinical deterioration of the patient gave an indication that such a change in the CT image was to be expected. Radiological delayed findings were not expected on the basis of the clinical symptoms of the other 6 patients in this group. Information on the intracranial pressure of these patients was not available.

In the case of nearly all the patients, the scan made 1 month after admission represented the final anatomical state on the computer tomogram. The only exceptions were the patients with a subdural effusion, the one patient with an impairment of the CSF-circulation and the 8 patients with a remaining contusion. The computer tomograms of these patients still showed changes at later stages.

The scan schedule given in fig. 23 shows one way of obtaining the maximum amount of information, including the final state of the brain, using a minimum number of computer tomograms.

FIG. 23
Suggested scan schedule for obtaining the maximum information from the computer tomograms of patients with severe brain damage.

- on admission
- after 1 day or 3 days
- after 14 days
- after 1 month
- in case of deterioration or after an operation.

4) WHICH PATIENTS SHOULD BE EXAMINED?

Which patients with brain damage should be investigated by means of computer tomography?

The admission scans of 86% of our patients were abnormal; this percentage is made up of 88% of the comatose patients and 81% of the patients who were not comatose but showed neurological deficit and/or signs of impaired consciousness. These data demonstrate the importance of computer tomography for both groups of patients on admission.

Twelve of the 44 radiological delayed findings were seen on the computer tomograms of non-comatose patients.
Subdural effusions were detected in 9 comatose patients and 5 non-comatose patients.

Forty-three patients underwent surgery.
Thirty-four of these were comatose on admission and 9 showed impaired consciousness and/or neurological deficit.

The value of computer tomography for both groups of patients can perhaps be shown more clearly if one considers how some computer tomographic results contribute to subsequent treatment of a patient. For example, 16 patients who were investigated by computer tomography were found to have an epidural haematoma. Nine of the 16 were comatose, and 6 of these died, in spite of rapid evacuation of the haematoma.
All 6 patients who died had both pupils nonreacting, so their outcome was no surprise; patients with both pupils nonreacting have a very poor prognosis. Seven patients out of the 16 were non-comatose, and all recovered after the operation. Such data show that early diagnosis of an

epidural haematoma, particularly in patients who are not yet comatose, is extremely important.

Computer tomography is an important diagnostic aid in the management of patients with severe brain injury.

Firstly, it can help to establish the existence of intracranial lesions which are responsible for the clinical state of the patient concerned. Secondly, computer tomography can help in determining whether such abnormalities are operable. It is also important, as far as management is concerned, to confirm the absence of intracranial lesions.

These considerations are valid for both groups of patients investigated in this study. In conclusion, the investigation by computer tomography of both the groups of patients in this study was proved to be worthwhile. It was not possible to make any statement about patients with less serious brain injury on the basis of the data in this study.

5) CONSEQUENCES OF COMPUTER TOMOGRAPHY

What is the influcence of computer tomography on the frequency with which other diagnostic techniques are used and on the treatment of patients with severe brain damage?

In the period before computer tomography, the most important forms of investigation in the early post-traumatic phase were angiography and ventriculography. Ventriculography was seldom practised in the early post-traumatic phase in our hospital. Angiography, on the other hand, was carried out on 38% of the patients who were comatose as the result of an accident. This method of investigation left a large degree of doubt in many cases as to the exact nature of a lesion detected. Consequently, 13% of these patients underwent an exploratory neurosurgical operation.

After the introduction of computer tomography, angiography was only carried out on 4 patients who were comatose following an accident. Ventriculography is now no longer practised on accident patients in our hospital. However, the intracranial pressure of every comatose patient is monitored, using a ventricle catheter or the Richmond screw.

It is considerably more difficult to determine whether the introduction of computer tomography has had an influence on the number and scope of intracranial operations. The percentage of intracranial operations carried out on patients with severe brain injury appears to be the same before and after the introduction of computer tomography.
However, the nature of the operations has changed. Before computer tomography, burr holes were made more often, whereas in the last few years, operations have tended to be relatively more extensive. This shift is partly due to the fall in the number of exploratory operations from 13% to 3%. The emphasis in recent operations has been on the removal of intra- and extra-cerebral haematomas which had been detected by means of computer tomography. Removal of contusions was only carried out under certain conditions.

CONCLUSIONS

Aims of computer tomography

Computer tomograms are made of patients with severe brain damage in order to ascertain which abnormalities are responsible for the clinical state of the patient concerned. When such abnormalities are detected, it must be established whether they are operable.

Serial computer tomography is carried out in order to:

- examine the natural course of existing abnormalities;
- check whether there are unexpected changes present on the computer tomogram;
- study the result of an operation;
- establish the extent of cerebral damage as observed on the final computer tomogram.

When should patients be scanned?

A possible scan schedule for the investigation by serial CT of patients with severe brain damage is as follows:

- on admission
- after 1 or 3 days
- after 14 days
- after 1 month
- in case of deterioration or after an operation.

Admission scans showed abnormalities in 88% of the patients. Although only 1 to 6 hours had elapsed since the accident, these scans already showed brain swelling, contusions and intracerebral haematomas with resultant midline shift, obliteration of basal cisterns and radiological signs of herniation.

Scans made 1 or 3 days after the accident showed unexpected findings – what are here described as radiological delayed findings – in a number of cases. Some of these findings were mass lesions which could be treated by surgery.

The purpose of the scan made 14 days after the accident is to detect whether subdural effusions are present.

The scan made more than 1 month after the accident is intended to establish the extent of cerebral damage, and to check whether the CSF-circulation is becoming impaired.

The objective of the scan made in the case of clinical deterioration of the patient, is to determine whether mass lesions exist which could be treated by surgery. Such lesions could have developed in the periods between the fixed points in time when the patient was scanned. The postoperative computer tomogram is made in order to check whether the operation has achieved its purpose.

Which patients should be scanned?

Serial scans should be made both of patients who are comatose as a result of an accident, and of patients who show impaired consciousness and/or neurological deficit.

The value of computer tomography to patients who "only" have a skull vault fracture or who have "only" been confused for a short period of time, cannot be discussed on the basis of the data in this study.

To what extent can a diagnosis based on CT findings be confirmed?
The diagnoses made with the aid of a computer tomogram were confirmed in the case of nearly all the patients who underwent an operation or autopsy.

A diagnosis based on computer tomographic findings is not always "complete". In a number of cases an operation and/or autopsy produced additional findings which were not visible on the computer tomogram.

DISCUSSION

Before the introduction of computer tomography, the choice of diagnostic techniques in the case of a patient with severe brain injury was as follows:

- angiography;
- ventriculography;
- echography;
- monitoring of intracranial pressure.

Angiography (via percutaneous puncture or by the Seldinger method) is a time-consuming procedure involving considerable risks (35). The most important diagnostic criteria on the angiogram are (57, 60):

- displacement of vessels;
- avascular extracerebral areas which are space-occupying;
- disturbance in circulation time;
- vascular wall lesions and/or traumatic vascular occlusions.

Little is known about the specific dangers of angiography as far as patients with severe brain damage are concerned. Nonetheless, because of the risks involved, angiography is only practised when absolutely necessary.

Ventriculography requires an intracranial operation.
However, this method of investigation also has its advantages.
It is possible, for example, to identify an extracerebral haematoma and then evacuate it at the same time. Moreover, if intracranial pressure is too high, the pressure can be lowered by CSF-drainage (7, 63, 64).
Intracranial pressure can also be measured over a longer period by placing an intraventricular drain (63, 64).

The diagnostic criteria of ventriculography are:

- the level of intracranial pressure;
- the size of the ventricular system;
- the distortion of the ventricular system;
- the degree of midline shift.

Echography is a technique which requires little time, no operation and is not expensive. In order to obtain a diagnosis which is as reliable as possible, echography must be carried out by trained and experienced staff. In these circumstances, it is usually possible to obtain an accurate idea of the degree of midline shift (48, 51). Moreover a "haematoma echo" can sometimes be detected; this indicates the presence of an extracerebral haematoma (96).

Intracranial pressure can be measured by using an intraventricular drain (5, 7), for instance, or by using subarachnoideal or extradural transducers (15, 97).
All these methods require a burr hole to be made. This form of investigation conveys a different kind of information than the three techniques described above. Angiography and echography give mainly anatomical information, whereas the measurement of intracranial pressure provide patho-physiological data.
This is the reason why the intracranial pressure of patients with severe brain injury is nowadays so frequently monitored in our hospital. Omission of this procedure could only be envisaged if the patient had a completely normal computer tomogram on admission (27, 77).

All four methods of investigation have one point in common: they are used to determine whether an intracranial abnormality is present. However, when an intracerebral abnormality is detected by one of these methods, a new dilemma has to be faced: is the abnormality a haematoma, a contusion, swelling or a combination of these?

Computer tomography has brought about significant changes in this area. With the introduction of this technique, it has become possible to distinguish between blood and oedema and/or necrosis.
Moreover it has become possible not only to detect the resultant effects of multiple space-occupying lesions, but also to give an image of the space-occupying lesions themselves.
This is very useful in cases such as that of two contusions of equal size, each located in opposite hemispheres and hence not necessarily accompanied by any resultant shift (84).

This capability of computer tomography can already be seen from the distribution of computer tomographic findings at the various intervals after the accident. It is possible to differentiate between type I, II and III contusions and intracerebral haematomas (tables 9 and 10). Moreover, the abnormalities present can be better localised in relation to neighbouring structures.

The question which must now be answered is this:
is a diagnosis which has been based on CT findings really accurate and complete? In 59 of the 61 cases of patients who underwent surgery or autopsy, the CT diagnosis was confirmed, although in a couple of cases the CT diagnosis was not complete.
This conclusion agrees with the data found in the literature (17, 22, 24, 37, 38).
In some cases doubt exists as to the exact location of an extracerebral haematoma (14, 76, 83). There are certain areas which, for diagnostic purposes, cannot be reached satisfactorily by computer tomography. Such areas are known to be the infratentorial space, the temporo – basal regions and the upper parietal region (38, 95).
Small abnormalities on the surface of the brain, situated directly under the skull vault, are also difficult to detect by computer tomography. The

extent and nature of these difficulties also depends, of course, on the type of computer tomograph, matrix and slice thickness used, and on possible restlessness of the patient (6, 17, 25, 101).

It is obviously very important to use computer tomography in the diagnosis of patients with severe brain damage (24); but is it really necessary to make a computer tomogram of a patient if, for example, it is more or less known for certain on clinical grounds that he has an epidural haematoma?
Various factors play a part here. If an epidural haematoma is present in a usual location, there is a delay in the start of appropriate surgical management.

On the other hand, more accurate information may be conveyed as to the extent and location of a haematoma at a less common site, and as to whether other, accompanying intracranial lesions are present. Moreover, it appears that suspicion of an epidural haematoma is by no means always confirmed.

Another quite different consideration is the amount of scantime available. If only one computer tomograph exists in a hospital, and if it can only be used during "normal working hours" and is then continually in operation, one would be less inclined to examine certain groups of brain injured patients than if more computer tomographs were available on a 24 hour basis. Fortunately, in our hospital, a computer tomograph is available on a 24 hour basis for patients with severe brain damage, and so in this study the problems associated with available scantime have not been discussed.

It is not only the computer tomogram made on admission which is important. It appears from the literature (53, 62, 73) that head injured patients who are in a bad neurological state following an accident, usually show extensive abnormalities on their computer tomogram made on admission. There are, however, exceptions: for instance, in our series 14 patients were comatose on admission and yet showed no abnormalities on their scans. Such patients may have been scanned too soon after their accident; if this were so, later scans would reveal abnormalities. This was the case in 4 comatose patients. Moreover, changes occur in the clinical state of patients with severe brain damage, from the time of admission onwards. These developments could well be accompanied by changes in the computer tomogram, in which case one scan made on admission would not be adequate.

It must then be decided at which intervals extra computer tomograms should be made. In this study, one possible scan schedule is suggested. In some cases, this schedule might be considered to be too extensive; it is intended to show a way of limiting the number of scans made, without sacrificing any significant diagnostic information. The purpose of the scans made on admission and on the second or third day, and of those made if the condition of a patient deteriorates, is to detect lesions which could be treated by surgery. The postoperative scan is made in order to establish whether the operation had achieved its purpose. Scans made 14 days after admission are intended to detect possible subdural effusions (12, 23, 37, 100, 102).
Given that all the subdural effusions observed in this series disappeared

spontaneously, it would appear that this finding is of no surgical significance; this computer tomogram could therefore be omitted. The same argument could be applied to the scan made 1 month after admission in order to ascertain the final state of the brain. However, it must be remembered that impairment of CSF – circulation can arise, albeit rarely, as a late result of the trauma (50).

Clearly, it is not necessary for every patient with a head injury to be examined by means of serial CT.
The scope of this study is restricted to 2 selected groups of patients: the group which was comatose as a result of brain injury and the group of patients which showed impairment of consciousness and/or neurological deficit. In the case of these two groups, computer tomography provides information which is important for the management of these patients. Computer tomography yields less information in the case of patients with less serious brain damage, according to Merino de Villasante and Taveras (62). These researchers detected slight abnormalities in a very small percentage of cases on the computer tomograms of such patients. The abnormalities consisted only of focal oedema, and were therefore of no therapeutic significance.

It has become evident since its introduction that computer tomography is a superior method of detecting intracranial abnormalities (21, 22, 24). Before CT was widely used, angiography was carried out on 38% of a similar group of comatose patients. Once computer tomography was made available, this proportion dropped to 3%. In all cases except 1, the grounds for using angiography were the serious condition of the patient, the strong suspicion of an operable lesion and the fact that the computer tomograph was not functioning. In the one exceptional case, the computer tomogram of this patient showed abnormalities which could not be clearly defined. Doubt existed as to the presence of an extracerebral haematoma, and hence angiography was used as a supplementary source of information.
The decline of angiography has one disadvantage as far as patients with severe brain damage are concerned, and that is that less attention is paid to traumatic damage of the large vessels leading to the brain and to damage of the intracranial vessels (22, 52, 99).

It is difficult to evaluate whether computer tomography has had an influence on the treatment of patients with severe brain damage. The only clear indication of such an influence is the fall in number of exploratory operations. Nadjmi and co-workers (65) have also pointed out that the fast, accurate CT investigation, which can be repeated whenever necessary, has made it possible for neurosurgical operations to be planned in advance and to be specifically oriented. According to these authors, exploratory neurosurgical operations can therefore almost always be avoided.

Computer tomography and prognosis

It is important to make an accurate prediction for a patient with severe injury for a number of reasons:

- the relatives of the patient concerned can be given more accurate information about the patients chances of survival.
- probability statements on the outcome of a patient may influence the choice of treatment for that patient. Decisions would be based on more accurate data than had been the case in the past.
- accurate predictions of outcome, made on admission or in the early post-traumatic period can have important implications as far as comparisons between series of patients are concerned. For instance, alternative regimens of treatment of identical groups of patients can be better evaluated (10).

The aim of the first part of this section is to establish whether a relationship exists between individual CT findings at various predetermined intervals after admission, and the mortality rate within one year of the accident.
In the second part, the relationship between combinations of CT findings and the mortality rate is considered.
A description follows of the statistical selection of variables with prognostic significance, using the stepwise – forward selection method. The variables were chosen from the following categories:

- CT variables alone
- clinical variables alone
- a combination of CT and clinical variables.

Probability statements about a certain outcome were made, using the variables selected; in the final part of this study, the quality of these statements is examined.

INDIVIDUAL CT FINDINGS AND OUTCOME

PARENCHYMATOSE LESIONS

A computer tomogram was made on admission of 116 out of the 121 comatose patients (see table 12).

Thirty-nine patients showed no parenchymatose lesions on their admission CT, and yet 46% of these patients died. One possible explanation for this is that although no intracerebral abnormalities were found, extracerebral abnormalities, such as epidural haematomas, were present. Certain

lesions may not have been detected on a computer tomogram because of their density, dimension or location.
Moreover, although the first scan of a patient seemed normal, abnormalities could have been present on later scans (radiological delayed findings). This was the case in 4 out of the 121 comatose patients.

Seventy-seven patients showed parenchymatose lesions on admission. Forty-two contusions were observed.
The mortality rate was higher with type III contusions (75%), than with type II contusions (69%) ant type I contusions (50%); the differences between mortality rates were not significant ($X^2 = 1.6$). The highest death rate was noted in 11 patients with an intracerebral haematoma (81%) and in 8 patients with a brainstem lesion (88%).

The distribution of parenchymatose findings was approximately the same in the scans made 24 hours after admission, as in the admission scans. However, the mortality rate varied between 12% in the case of patients who had no intracerebral abnormalities, and 88% in the case of patients with brainstem lesions (see table 13).

The number of scans made at the other predetermined intervals was fairly small, owing to the fact that many patients had died in the meantime (see table 7).
Abnormalities in the brain structure were found in 17% both of the scans made 3 days after admission and of the scans made 1 week after admission.

TABLE 12

Parenchymatose lesions on admission and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Parenchymatose lesions.				
normal	18	4	17	39
contusion type I	5	1	4	10
contusion type II	11	1	4	16
contusion type III	12	0	4	16
intracerebral haematoma	9	0	2	11
central contusion	12	3	1	16
brainstem lesion	7	0	1	8
total	74	9	33	116

Five patients could not be scanned on admission.

TABLE 13

Parenchymatose lesions on 24 hour scans and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Parenchymatose lesions.				
normal	2	3	10	15
contusion type I	0	1	1	2
contusion type II	3	1	3	7
contusion type III	8	0	4	12
intracerebral haematoma	7	0	1	8
central contusion	6	1	2	9
brainstem lesion	3	0	1	4
total	29	6	22	57

Thirty-seven patients out of the 121 comatose patients died within 24 hours.
Scans were not made 24 hours after admission of 27 of the patients.

EXTRACEREBRAL PATHOLOGY

Extracerebral abnormalities were observed in 56 out of 116 scans made on admission. In 47 cases the abnormality was a subdural haematoma; 25 of these patients had a haematoma which was thicker than 8 mm and 22 had a haematoma which was 8 mm thick or less. Nine patients had an epidural haematoma.
The mortality rate in the group of patients who showed no extracerebral abnormalities was 42%; in the group which had a subdural haematoma less than 8 mm thick, it was 73%; in the patients who had a subdural haematoma which was more than 8 mm thick, it was 96%. Six of the 9 patients with an epidural haematoma died. The relatively high mortality rate in patients with epidural haematomas will be discussed later.

In 23 out of the scans made 24 hours after admission, extracerebral haematomas were found; 17 of these were subdural haematomas, 4 of which were post-operative remains. In the 13 cases of subdural haematomas which had not been removed, the haematoma itself appeared to be relatively small, but was accompanied by other extensive intracranial lesions. Seven scans showed post-operative remains of epidural haematomas. One patient had both an epidural and a subdural haematoma.

Remains of extracerebral blood were still visible on later scans: in some cases, up to and including 2 weeks after admission. No extracerebral blood was detected on later computer tomograms.

CISTERNS

Thirty-three patients had normal cisterns on admission. Partial obliteration was observed in 25 cases, complete obliteration in 56 cases and complete obliteration in combination with an infarction in the territory of the posterior cerebral artery was seen in 2 cases. The mortality rate in the group of patients with normal cisterns was 27%, and in the group with partially obliterated cisterns it was 48%. Of the patients who showed completely obliterated cisterns on their CT scans, 91% died.

On the scans made after 24 hours, in 21 cases the cisterns were normal, in 14 cases they were partially obliterated and in 20 cases completely obliterated. Complete obliteration with an infarction in the territory of the posterior cerebral artery was seen in 2 patients. Out of the group of patients with normal cisterns, 19% died. The mortality rate in patients with partially and totally obliterated cisterns came to 36% and 90% respectively (see table 14 and 15).

TABLE 14

Basal cisterns on admission and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Cisterns				
normal	9	5	19	33
partially obliterated	12	2	11	25
completely obliterated	51	2	3	56
complete obliteration + infarction	2	0	0	2
total	74	9	33	116

Five patients could not be scanned on admission.

TABLE 15

Basal cisterns on 24 hour scans and the outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Cisterns				
normal	4	3	14	21
partially obliterated	5	2	7	14
completely obliterated	18	1	1	20
complete obliteration + infarction	2	0	0	2
total	29	6	22	57

Thirty-seven patients out of the 121 comatose patients died within 24 hours.
Scans were not made 24 hours after admission of 27 of the patients.

VENTRICLES AND MIDLINE SHIFT

Out of the computer tomograms made on admission, 17 showed a normal ventricular system without any midline shift. The death rate in this group was 47%.
Ventricles which were too small, but not accompanied by any midline shift, were observed in 33 cases; this group had the lowest mortality rate, i.e. 33%. If the ventricular system was compressed and median structures were displaced, the mortality rate increased in proportion to the degree of midline shift. In the group of patients with compressed ventricles and a midline shift greater than 10 mm, as many as 95% of these patients died (see table 16).

TABLE 16

Ventricles and midline shift on admission and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Ventricles and midline shift				
ventricles normal, no shift	8	1	8	17
ventricles small, no shift	11	7	15	33
ventricles compressed, shift ⩽ 5 mm	18	1	8	27
ventricles compressed, shift > 5 mm, ⩽ 10 mm	16	0	1	17
ventricles compressed, shift > 10 mm	21	0	1	22
total	74	9	33	116

Five patients could not be scanned on admission.

Midline shift remained visible for quite some time on the scans made 24 hours after admission and later.
In 2 patients, displacement of median structures could still be detected on the scans made 1 month after the accident.
A relationship between the degree of midline shift and the mortality rate could also be clearly deduced from the computer tomograms made 3, 7 and 14 days after admission.
In every case where a shift of more than 5 mm was visible on the scan made 1 week after the accident, the patient died.

OTHER COMPUTER TOMOGRAPHIC FINDINGS

A contusion in the corpus callosum was detected in 7 patients during the early post-traumatic period: Four of these patients died.
Central contusions were observed in 26 patients; 12 of these died. Fifteen patients showed subependymal blood, and out of this group 11 died. Thirty-nine patients died out of the 45 who showed radiological signs of descending transtentorial herniation. Intraventricular blood was present on the scans of 15 patients; 10 of these died.

COMBINATIONS OF CT FINDINGS AND OUTCOME

On admission:
It seems probable that the prognosis will be better if a patient only has, for instance, a contusion, than if he has both a contusion and a subdural haematoma.
On the basis of this assumption, the mortality rate was studied of the patients who showed more than one abnormality on their computer tomogram. To this end, every possible combination of intra- and extracerebral abnormalities, the state of the basal cisterns and the state and position of the ventricles was considered. The following are the combinations of radiological findings which were frequently observed on admission scans:

- no abnormalities (14 patients)
- intra- **or** extracerebral abnormalities + normal cisterns (17 patients)
- intra- **or** extracerebral abnormalities + partially obliterated cisterns (21 patients)
- intra- **or** extracerebral abnormalities + completely obliterated cisterns (33 patients)
- intra- **and** extracerebral abnormalities + completely obliterated cisterns (26 patients).

The mortality rate varied from 7% in the group of patients with no abnormalities, to 96% in the group with a combination of intra- and extracerebral abnormalities and obliterated cisterns (see table 17).

TABLE 17

Combinations of CT findings on admission and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
Combinations of CT findings				
normal	1	2	11	14
intra- **or** extracerebral abnormalities + cisterns normal	6	3	8	17
intra- **or** extracerebral abnormalities + cisterns partially obliterated	8	2	11	21
intra- **or** extracerebral abnormalities + cisterns completely obliterated	30	2	1	33
intra- **and** extracerebral abnormalities + cisterns completely obliterated	25	0	1	26
total	70	9	32	111

Five patients were not scanned on admission, and a further 5 out of the group of 116 patients who were scanned could not be placed in the categories above.

Of the 5 patients who could not be placed in the categories in table 17, 2 had a combination of intra- **and** extracerebral abnormalities with normal cisterns; both these patients died.
The remaining 3 patients showed intra- **and** extracerebral abnormalities with partially obliterated cisterns, and 2 of these patients died.

The following cases are worth considering individually in relation to table 17.

A1 : the patient who had a normal admission scan but still died.

B1, 2 : the two patients who had normal admission scans and yet remained disabled.

C1-6 : the 6 patients with intra- or extracerebral abnormalities and normal cisterns on their admission scans, who died.

D1 : the patient with extracerebral abnormalities on his admission CT and totally obliterated cisterns, who recovered completely.

E1 : the patient with intra- and extracerebral abnormalities with totally obliterated cisterns on the admission scan, who recovered completely.

The following short descriptions of these patients include the "predicted probability of death"; this refers to the patient's chance of dying within 6 months after the accident.
The probability of death is calculated on the basis of the patient's age and the E+M score and pupil reactions as assessed on admission (10, 28).

A1

sex	: male
age	: 24 years
E+M score	: 5
pupils	: 1 pupil reacting
predicted probability of death	: 30%
admission scan	: subarachnoideal and intraventricular blood
other scans	: subarachnoideal blood disappearing
last scan	: 2 weeks after admission. No abnormalities
clinical state 3 weeks after admission	: still confused and hemiparesis on right side
outcome	: death
time of death	: 1 month after admission
cause of death	: sepsis

B1

sex	: female
age	: 53 years
E+M score	: 6
pupils	: 1 pupil reacting
predicted probability of death	: 44%
admission scan	: status after negative exploratory operation. No further abnormalities. Normal cisterns
other scans	: no abnormalities
last scan	: 1 year after admission. No abnormalities
outcome	: severely disabled

B2

sex	: female
age	: 18 years
E+M score	: 5
pupils	: both reacting
predicted probability of death	: 19%
admission scan	: small ventricles, normal cisterns, further no abnormalities
other scans	: bilateral frontal contusions, disappearing later. Normal cisterns
last scan	: 1 year after admission. Bilateral supratentorial atrophy
outcome	: persistent vegetative state

C1

sex	: female
age	: 8 years
E+M score	: 5
pupils	: both non-reacting
predicted probability of death	: 56%
admission scan	: type III contusion including location in brainstem. Normal cisterns. No midline shift
other scans	: contusion visible for a long time. Later extension to intracerebral haematoma. Totally obliterated cisterns
last scan	: 14 days after admission. Remains of intracerebral haematoma and contusions. Normal cisterns
outcome	: death
time of death	: approximately 1 month after admission
cause of death	: extensive brain damage

C2

sex	: male
age	: 32 years
E+M score	: 5
pupils	: both reacting
predicted probability of death	: 28%
admission scan	: small ventricles. Intraventricular blood. Normal cisterns
other scans	: central contusion 3 days after admission
last scan	: 1 month after admission. No abnormalities
clinical state 1½ month after admission	: spontaneous eye opening. Spontaneous movement of both arms. No verbal response (tracheostoma)
outcome	: death
time of death	: 2 months after admission
cause of death	: infection of respiratory and urinary tracts, extensive brain damage. No autopsy

C3

sex	: male
age	: 72 years
E+M score	: 6
pupils	: both reacting
predicted probability of death	: 78%
admission scan	: small ventricles. Type II contusion, right temporal. Normal cisterns
other scans	: subdural effusion. Local atrophy
last scan	: 1 month after admission. Remains of contusion. Local atrophy. Remains of subdural effusion
clinical state 1 month after admission	: spontaneous eye opening, commands obeyed. Verbal response: orientated. Left hemiparesis improving
outcome	: death
time of death	: 2½ months after admission
cause of death	: sudden death. Reason unknown. No autopsy

C4

sex	: male
age	: 31 years
E+M score	: 5
pupils	: both reacting
predicted probability of death	: 28%
admission scan	: type I contusion right hemisphere. Incomplete CT. No information of infratentorial region
last scan	: admission scan
outcome	: death
time of death	: 2 days after admission
cause of death	: extensive brain damage

C5

sex	: male
age	: 59 years
E+M score	: 5
pupils	: unequal, both reacting
predicted probability of death	: 55%
admission scan	: type II contusion, intracerebral haematoma in right hemisphere. Normal cisterns. No statement possible about infratentorial region
last scan	: 3 days after admission. Same as admission scan
clinical state 1 week after admission	: spontaneous eye opening spontaneous movement of right arm incomprehensible sounds
outcome	: death
time of death	: 1 week after admission
cause of death	: pulmonary embolism

C6

sex	: male
age	: 9 years
E+M score	: 4
pupils	: 1 pupil reacting
predicted probability of death	: 30%
admission scan	: multiple contusions and intracerebral haematoma. Abnormalities in brainstem. Normal cisterns
other scans	: same as admission CT
last scan	: 1 week after admission. Same as admission CT
clinical state 1 week after admission	: no change since admission
outcome	: death
time of death	: 1½ weeks after admission
cause of death	: extensive brain damage

D1

sex	: male
age	: 5 years
E+M score	: 6
pupils	: unequal, both reacting
predicted probability of death	: 6%
admission scan	: large frontal, epidural haematoma. Cisterns obliterated
other scans	: obliterated cisterns. No further abnormalities. Later no abnormalities
last scan	: 1 year after admission. No abnormalities
outcome	: recovery

E1

sex	: male
age	: 28 years
E+M score	: 4
pupils	: 1 pupil reacting
predicted probability of death	: 36%
scan admission	: small left temporal epidural haematoma. Contusion in right hemisphere. Cisterns obliterated
other scans	: no epidural haematoma. Release haematoma. Cisterns partially obliterated
last scan	: 1 year after admission. Unilateral and infratentorial atrophy
outcome	: recovery

These patients will be discussed on pages 94 and 97.

Combinations of CT findings after 24 hours, and outcome

The correlation between CT findings made on admission and outcome, and the correlation between CT findings after 24 hours and outcome, were approximately the same (see tables 17 and 18).

TABLE 18

Combinations of CT findings on 24 hours scans and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
combinations of CT findings				
normal	0	2	4	6
intra- **or** extracerebral abnormalities + cisterns normal	4	2	9	15
intra- **or** extracerebral abnormalities + cisterns partially obliterated	4	2	5	11
intra- **or** extracerebral abnormalities + cisterns completely obliterated	12	0	1	13
intra- **and** extracerebral abnormalities + cisterns completely obliterated	10	1	0	11
total	30	7	19	56

Thirty-seven patients had already died and 27 patients were not scanned; 1 patient could not be placed in the categories above.

On the whole, normal cisterns were observed more often on the CT scans made 24 hours after admission. It can be seen from table 18, that a patient has a good chance of returning to an independent life if the scan made after 24 hours shows one of the following:

- no abnormalities (4 patients out of 6)
- intra- **or** extracerebral abnormalities with normal cisterns (9 patients out of 15)
- partially obliterated cisterns (5 patients out of 11).

The chance of returning to an independent life is very slight if the cisterns are completely obliterated; such an outcome was only seen in the 2 patients whose obliterated cisterns resulted from the presence of an epidural haematoma (see patient D1 and E1).

The number of computer tomograms made 3 days after admission or later was relatively small; this was due to the fact that many patients had already died 24 hours after admission, and in other cases scanning was contra-indicated because transportation to the computer tomograph was considered to be too dangerous. In view of the limited number of CT scans, more general categories were used (see table 19).

TABLE 19

Combinations of CT findings on scans made after 2 weeks and outcome after 1 year in 121 comatose patients.

Outcome	Died	Dependent (PVS, SD)	Independent (MD, GR)	Total number of patients
combinations of CT findings				
normal	2	3	8	13
intra- **or** extracerebral abnormalities + cisterns normal	4	2	6	12
intra- **or** extracerebral abnormalities + cisterns abnormal	1	0	0	1
intra- **and** extracerebral abnormalities + cisterns abnormal	1	1	2	4
total	8	6	16	30

Sixty-two patients had already died and 24 patients were not scanned. Five patients could not be placed in the categories above.

There are only 5 patients in this group with abnormal cisterns, i.e. 1 patient with totally obliterated and 4 patients with partially obliterated cisterns. The following cases are worth studying individually in relation to table 19.

F1, 2 : the patient with a normal scan 14 days after admission, who died.

G1-4 : the patients with intra- or extracerebral abnormalities and normal cisterns, who died.

H1-3 : the patients with normal scans, who remained disabled.

F1

sex	: male
age	: 66 years
E+M score	: 3
pupils	: 1 pupil reacting
predicted probability of death	: 83%
admission scan	: subdural haematoma, 5 mm thick. Partially obliterated cisterns. Compressed ventricles and midline shift of 5 mm
last scan	: 14 days after admission. No abnormalities
clinical state 2 weeks after admission	: slight improvement. Spontaneous eye movement. Unable to obey commands. No verbal response
outcome	: death
time of death	: 3 weeks after admission
cause of death	: sepsis

F2 (= patient A1)

sex	: male
age	: 24 years
E+M score	: 5
pupils	: 1 pupil reacting
predicted probability of death	: 30%
admission scan	: subarachnoideal and intraventricular blood
other scans	: subarachnoideal blood disappearing
last scan	: 14 days after admission. No abnormalities
clinical state 3 weeks after admission	: still confused, hemiparesis on right side
outcome	: death
time of death	: 1 month after admission
cause of death	: sepsis

G1

sex	: female
age	: 57 years
E+M score	: 3
pupils	: unequal, both reacting
predicted probability of death	: 70%
admission scan	: small ventricles, subependymal blood. Type I contusion. Normal cisterns. No midline shift
scan 14 days after admission	: type III contusion. No midline shift. Normal cisterns
last scan	: 1 month after admission. Bilateral supratentorial atrophy
clinical state 1½ months after admission	: vegetative state
outcome	: death
time of death	: 2 months after admission
cause of death	: pneumonia

G2

sex	: female
age	: 53 years
E+M score	: 5
pupils	: unequal, both reacting
predicted probability of death	: 55%
admission scan	: subdural haematoma, 10 mm thick. Partially obliterated cisterns. Compressed ventricles. Midline shift 10 mm
scan 14 days after admission	: type III contusion. Normal cisterns
last scan	: 1 month after admission. Bilateral supratentorial atrophy
clinical state 3 weeks after admission	: slight improvement. Spontaneous eye movement. Localisation, unable to obey commands. Incomprehensible sounds
outcome	: death
time of death	: 1 month after admission
cause of death	: Sudden death. Reason unknown. No autopsy

G3

sex	: male
age	: 33 years
E+M score	: 3
pupils	: both non-reacting
predicted probability of death	: 81%
admission scan	: type III contusion, including brainstem lesion. Partially obliterated cisterns. Compressed ventricles, no midline shift
scan made 14 days after admission	: contusion remained visible for a long time. Cisterns normal
last scan	: one month after admission. Bilateral supratentorial and infratentorial atrophy
clinical state 1 month after admission	: spontaneous eye opening. Flexion on both sides. No verbal response (tracheostoma)
outcome	: death
time of death	: 1½ months after admission
cause of death	: unknown. Patient died during period of unexplained high temperatures. No autopsy

G4 (= patient C1)

sex	: female
age	: 8 years
E+M score	: 5
pupils	: both non-reacting
predicted probability of death	: 56%
admission scan	: type III contusion, including location in brainstem. Normal cisterns. No midline shift
other scans	: contusion visible for long time. Later extension to intracerebral haematoma. Totally obliterated cisterns
last scan	: 14 days after admission. Remains of intracerebral haematoma and contusions. Normal cisterns
outcome	: death
time of death	: approximately 1 month after admission
cause of death	: extensive brain damage

H1 (= patient B1)

sex	: female
age	: 53 years
E+M score	: 6
pupils	: 1 pupil reacting
predicted probability of death	: 44%
admission scan	: status after negative exploratory operation. No further abnormalities. Normal cisterns
scan made 14 days after admission	: no abnormalities
last scan	: 1 year after admission. No abnormalities
outcome	: severely disabled

H2 (= patient B2)

sex	: female
age	: 18 years
E+M score	: 5
pupils	: both reacting
predicted probability of death	: 19%
admission scan	: small ventricles. Normal cisterns. Further no abnormalities
scan made 14 days after admission	: no abnormalities
last scan	: 1 year after admission. Bilateral supratentorial atrophy
outcome	: persistent vegetative state

H3

sex	: male
age	: 4 years
E+M score	: 4
pupils	: unequal, both reacting
predicted probability of death	: 19%
admission scan	: intraventricular and subependymal blood. Obliterated cisterns. Compressed ventricles. No midline shift. Contusion type II
scan made 14 days after admission	: no abnormalities
last scan	: 1 year after admission. Extensive supra- and infratentorial atrophy
outcome	: severely disabled

These patients will be discussed on page 98.

SYSTEMATIC SELECTION OF PROGNOSTIC VARIABLES

The procedure was as follows:

- prognostic variables were selected from sets of CT variables alone, clinical variables alone, and a combination of CT and clinical variables;
- probability statements were made for individual patients, using the variables selected;
- the quality of probability statements thus obtained was examined.

CT VARIABLES:

The variables were selected from the following categories:

- parenchymatose lesions
- extracerebral pathology
- cisterns
- ventricles and midline shift.

In the first step, "cisterns" was selected as the variable with the greatest prognostic significance. In the second step "parenchymatose lesions" was selected. The addition of a further variable (e.g. "extracerebral pathology") made no further improvement in the quality of the probability statement. The quality of the probability statements was assessed using the quadratic penalty score (28) (see p. 47).

When probability statements are made using the two variables selected, a sharp prediction was possible in 35 cases (30%).
The term "sharp prediction" is used to describe a probability statement where the calculated chance of a certain outcome is more than 90%.
The sharp predictions in these 35 cases were all related to the probability of death within 1 year after the accident.
Thirty-two (91%) of the predictions were correct. It was not possible to make a sharp prediction for the remaining 81 patients (70%).
These patients, who had a less than 90% chance of a certain outcome, were placed in the "doubt" category.

Table 20 gives the prediction based only on CT findings on admission, and the actual outcome 1 year after the accident. The data for this section of the study were taken from the 116 patients who were scanned on admission. Five patients were not scanned on admission, owing to a fault in the computer tomograph.
On the basis of clinical findings, 3 of these patients were predicted to die and 2 were predicted to survive.

TABLE 20

Sharp predictions of outcome after 1 year, based on CT variables on admission, compared with actual outcome.

	Actual outcome		
sharp predictions of outcome	death (n)	survival (n)	total (n)
death (n)	32	3	35
survival (n)	0	0	0
doubt (n)	42	39	81
total (n)	74	42	116

Five patients could not be scanned on admission.

CLINICAL VARIABLES

The following were selected consecutively from a set of clinical variables assessed on admission: pupils, motor response and age. The addition of another variable made no further improvement in the quality of the probability statement.
Using these variables, sharp predictions were possible in the case of 56 patients (48%). Nearly all these sharp predictions, i.e. 51 (91%), were related to the category "Death".
It is clear from these data that it is easier to make a sharp prediction of death than of survival. When sharp predictions were made on the basis of clinical variables alone, 93% of the predictions were correct, i.e. 48 out of the 51 sharp predictions of death (94%) and 4 out of the 5 sharp predictions of survival (80%). In the case of 60 patients, the probability statements were such that they were placed in the category "doubt". Twenty-five (58%) of these patients died (see table 21).

TABLE 21

Sharp predictions of outcome after 1 year, based on clinical variables on admission, compared with actual outcome.

	Actual outcome		
sharp predictions of outcome	death (n)	survival (n)	total (n)
death (n)	48	3	51
survival (n)	1	4	5
doubt (n)	25	35	60
total (n)	74	42	116

Five patients could not be scanned on admission.

COMBINED CLINICAL AND CT VARIABLES

In this part of the study, both clinical and computer-tomographic variables were selected. The variables were selected consecutively, until no further improvement in the quality of the probability statement could be obtained. The variables chosen were: pupils, motor response, ventricles and midline shift, parenchymatose lesions and the age of the patients. Sharp predictions were made in 72 cases (62%) (see table 22).

TABLE 22

Sharp predictions of outcome after 1 year, based on clinical **and** CT variables on admission, compared with actual outcome.

	Actual outcome		
sharp predictions of outcome	death (n)	survival (n)	total (n)
death (n)	51	2	53
survival (n)	1	18	19
doubt (n)	22	22	44
total (n)	74	42	116

Five patients could not be scanned on admission.

This number is higher than when only CT findings or when only clinical variables were used. Moreover, it was possible to make 19 sharp predictions of survival. Out of the total of 72, 69 sharp predictions were correct (96%).

It can be seen from table 22, that for 2 patients sharp predictions of death were made, whereas in fact they survived the accident. In another case, a sharp prediction of survival was made, but the patient died 1 month after admission.

These sharp predictions were made on the basis of a combination of clinical and CT variables. The predictions of death based on clinical variables alone in these 3 cases were 83%, 90% and 30%, as can be seen from the short descriptions of these patients (J1, J2, K1).

J1

sex	: male
age	: 58 years
E+M score	: 5
pupils	: both non-reacting
predicted probability of death (based on clinical variables)	: 83%
admission scan	: type III contusion. Compressed ventricles. Normal cisterns
other scans	: temporary subdural effusions and frontal intracerebral haematoma, subsequently removed
last scan	: 1 year after admission. Bilateral supratentorial atrophy
outcome	: recovery

J2

sex	: female
age	: 84 years
E+M score	: 6
pupils	: both reacting
predicted probability of death (based on clinical variables)	: 90%
admission scan	: acute subdural haematoma 12 mm thick. Small ventricles. Normal cisterns
other scans	: 24 hours after admission the subdural haematoma disappeared spontaneously. Intraventricular blood and type II contusion
last scan	: 1 year after admission. No abnormalities
outcome	: moderately disabled

K1 (= patient A1)

sex	: male
age	: 24 years
E+M score	: 5
pupils	: 1 pupil reacting
predicted probability of death (based on clinical variables)	: 30%
admission scan	: subarachnoideal and intraventricular blood
other scans	: subarachnoideal blood disappearing
last scan	: 2 weeks after admission. No abnormalities
clinical state 3 weeks after admission	: still confused. Hemiparesis on right side
outcome	: death
time of death	: 1 month after admission
cause of death	: sepsis

These patients will be discussed on page 97.

CONCLUSIONS

A. MORTALITY RATE AND COMPUTER TOMOGRAPHY

1. The death rate was highest when the following findings were present on the computer tomogram made on admission:
   - brainstem lesion, 88% (n = 8);
   - acute subdural haematoma thicker than 8 mm, 96% (n = 25);
   - completely obliterated cisterns, 95% (n = 58);
   - compressed ventricles with midline shift of more than 10 mm, 95% (n = 22);
   - intra- + extracerebral abnormalities combined with completely obliterated cisterns, 96% (n = 26).

2. The death rate was highest when the following findings were present on the computer tomogram made 24 hours after admission:
   - intracerebral haematoma, 88% (n = 8);
   - subdural haematoma thicker than 8 mm, 77% (n = 6);
   - completely obliterated cisterns, 98% (n = 22);
   - compressed ventricles with midline shift of more than 10 mm, 87% (n = 9);
   - intra- + extracerebral abnormalities in combination with completely obliterated cisterns, 92% (n = 11).

3. The death rate was lowest when the following findings were present on the computer tomogram made on admission:
   - normal computer tomogram (intra- and extracerebral structures, ventricles and cisterns), 7% (n = 14);
   - no parenchymatose lesions, 46% (n = 39);
   - no extracerebral abnormalities, 42% (n = 60);
   - normal cisterns, 27% (n = 33);
   - small ventricles, without midline shift, 33% (n = 33).

4. The death rate was lowest when the following findings were present on the computer tomogram 24 hours after admission:
   - normal computer tomogram (intra- and extracerebral structures, ventricles and cisterns), 0% (n = 6);
   - no parenchymatose lesions, 13% (n = 15);
   - no extracerebral abnormalities, 44% (n = 34);
   - normal cisterns, 19% (n = 21);
   - small ventricles, without midline shift, 29% (n = 17).

B. PERSISTING NEUROLOGICAL SIGNS AND COMPUTER TOMOGRAPHY

1. It was not possible to make statements about persisting neurological signs on the basis of certain CT findings.
   This was because many patients died within 24 hours after admission, and the survivors with these particular CT findings were too few to be placed in the large number of survival categories.
2. Most of the patients whose outcome was moderate disability or good recovery had a normal computer tomogram on admission (79%).
3. Patients who showed intra- or extracerebral abnormalities combined with completely obliterated cisterns on admission CT scans, hardly ever came into the outcome categories of moderate disability or good recovery. Exceptions to this were the two patients whose admission scans showed completely obliterated cisterns which were due to the presence of a large epidural haematoma.
4. In this series, the presence of extensive abnormalities on CT scans made on admission and after 24 hours did not result in a large number of patients who were severely disabled or in a persistent vegetative state. The total number of patients with these outcome categories was very small (9 patients).

C. SYSTEMATIC SELECTION OF VARIABLES

1. The CT variables with the most prognostic significance on admission were, in order of importance:
   - cisterns;
   - parenchymatose lesions.
2. The clinical variables with the most prognostic significance on admission, were in order of importance:
   - pupils;
   - motor response;
   - age.
3. The variables with the most prognostic significance out of the set of combined CT and clinical variables on admission, were, in order of importance:
   - pupils;
   - motor response;
   - ventricles and midline shift;
   - parenchymatose lesions;
   - age.
4. Using the variables selected, it was possible to make sharp predictions on admission:
   - on the basis of CT findings alone, in 35 of the 116 patients: 91% of the predictions were correct;

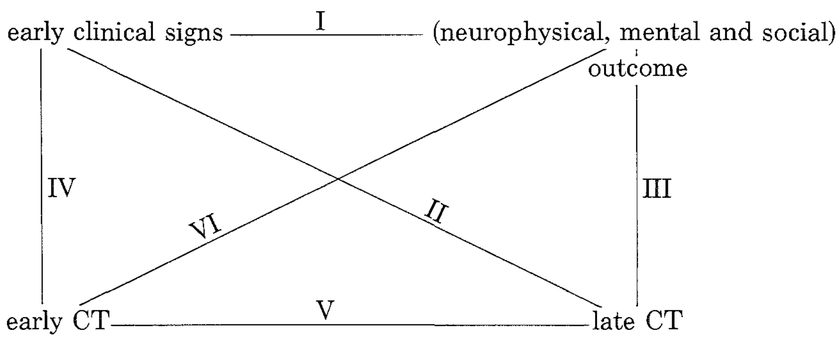
- on the basis of clinical variables alone, in 56 of the 116 patients: 93% were correct;
- on the basis of CT and clinical findings, in 72 of the 116 patients: 96% were correct.

DISCUSSION

A computer tomogram made in the early post-traumatic phase does not only provide data which are important for the management of the patient; it is also a potential source of prognostic information.

In order to determine the relationship between CT findings and the prognosis of patients with severe brain damage, the correlations II - VI inclusive, as shown in fig. 24, must be examined:

FIG. 24
The six correlations between early clinical signs, outcome and CT.



All six correlations will be discussed; special attention will be paid to correlation VI i.e. the correlation between early CT findings and outcome.

THE CORRELATION BETWEEN EARLY CLINICAL SYMPTOMS AND OUTCOME (CORRELATION I)

Over the last 10 years, various authors have published results of studies on the correlation between early clinical symptoms and the outcome in patients with severe brain injury. These studies have shown the prognostic significance of age, E+M+V sum score and pupil reactions. Carlsson (13) found that the mortality rate was higher in patients over 40 years old. Heiskanen and Overgaard et al (31, 71) also described the higher death rate in older patients. Pazzaglia and co-workers stated that the prognosis was worse when the lesion was located more caudally in the brainstem; location was assessed on clinical grounds (72).
They also found that age influenced the clinical course and the death rate. Jennett et al wrote that prognostically unfavourable signs were absence of eye movement, absence of pupil reaction and the depth and duration of the coma (45).

The importance of intracranial pressure in determining a prognosis was stressed by Miller et al (63). Braakman et al (10) stated that only a limited number of features determined prognosis, and that it is feasible in the first few days after injury to make correct probability statements about outcome in a surprisingly large number of cases. Some of these prognostically significant features were age, E+M+V sum score, best motor response of the arms, eye movements and pupil reactions (see table 8).

It can also be seen from this study that variables such as the age of the patient, the best motor response of the arms and the pupil reactions on admission have important prognostic value as far as the outcome after 1 year is concerned. When probability statements about outcome were made using these three variables, it was possible to make sharp predictions for 56 out of 116 patients (48%). Fifty-two out of the 56 predictions were of death. When only clinical data are used, it is clearly easier to make a sharp prediction of death than of survival.

In a case of severe brain damage, the presence of certain signs and symptoms means that a sharp prediction of death can be made. A less serious brain injury does not imply, however, that the patient will survive the accident. Even a patient with a relatively mild brain injury may later retain serious symptoms or even die from an intra- or extracranial complication. Not all such complications can be predicted. It is unsatisfactory that sharp predictions of survival based on clinical variables could only be made for 4% of our comatose patients (5 out of the 116 patients).

THE CORRELATION BETWEEN EARLY CLINICAL SYMPTOMS AND THE COMPUTER TOMOGRAMS AFTER 1 YEAR (CORRELATION II) AND THE CORRELATION BETWEEN THESE LATE CT FINDINGS AND OUTCOME (CORRELATION III).

We have already written about these two correlations (19). The conclusions in that study were as follows:

- on the scans made 1 year after admission, the patients with the most serious abnormalities (infratentorial atrophy with or without supratentorial atrophy) were, on average, younger than the patients with less serious abnormalities. This was probably because older patients with serious brain damage died within 1 year of the accident.
- patients with a best coma sum score of less than 8 on admission showed more serious abnormalities more often on their CT scans after 1 year than patients whose best coma sum score amounted to more than 8 on admission.
- the more severe the abnormalities present on a "late" CT scan, the longer the patient took to achieve a coma sum score of 15 in the post-traumatic phase. Patients who showed the most serious abnormalities (infratentorial atrophy + bilateral supratentorial atrophy) on their "late" computer tomograms, only achieved a coma sum score of 15 after an average of 194 days after the onset of coma. The patients with a normal computer tomogram after 1 year took an average of 14 days to reach this score.

- six of the 8 patients whose best motor score in the first 24 hours after the onset of coma was "abnormal flexion" or "extension", showed a combination of intra- and supratentorial atrophy on their CT scans made after 1 year. The quality of motor response in the first 24 hours was related to the percentage of normal late computer tomograms: the better the motor response, the higher the percentage of normal CT scans.
- all the patients who were dependent (PVS or SD) 1 year or more after the accident showed serious abnormalities (infratentorial atrophy with or without supratentorial atrophy) on their "late" computer tomograms. The outcome of the patients who had a normal "late" computer tomogram was classified as "good recovery" 1 year or more after the accident; however, patients who had completely recovered 1 year after the accident could still show an abnormality on their "late" CT scan.
- patients with a normal "late" computer tomogram usually showed no persisting neurological deficit. Forty per cent of the patients with supratentorial atrophy on their "late" computer tomograms showed neurological abnormalities. Ninety-six per cent of the patients with infratentorial atrophy, possibly combined with supratentorial atrophy, showed neurological deficit. There was a particularly high correlation between the presence of ataxia in a patient and infratentorial atrophy as seen on the "late" computer tomogram.

It can be seen from the above data that there are correlations between early clinical symptoms and "late" CT findings, and between "late" CT findings and the outcome after 1 year.

THE CORRELATION BETWEEN EARLY CT FINDINGS AND EARLY CLINICAL SYMPTOMS (CORRELATION IV)

Lanksch and Kazner (1978) (53, 54, 55) stated that there was a clear correlation between the extent of brain damage as detected on the computer tomogram, and neurological deficit. At the same time they noted that the computer tomogram did not always show the particular pathological abnormalities which were expected on the grounds of the clinical state of the patient. Twenty-four per cent of the patients in their series who had a serious brain injury, in some cases with unequal pupils and symptoms of bilateral neurological deficit, showed no abnormalities on their computer tomograms. On the CT scans of 55 of their patients with mild brain injuries, no abnormalities were detected. These authors did not make a systematic series of computer tomograms. Huk and Schieffer (37), Merino de Villasante (62) and Weisberg (99) all found that there were few or no abnormalities present on the CT scans of patients with only mild brain injury. From this literature, a relationship can be seen to exist between the degree of severity of the clinical state on admission and the extent of abnormalities as observed on the admission scan.

For the part of this study concerning the relationship between computer tomography and prognosis, all patients examined were comatose on admission. Their EMV sum score on admission varied between 3 and 8.

The CT findings on admission ranged from completely normal to a combination of intra- and extracerebral abnormalities with compressed ventricles, midline shift, completely obliterated cisterns and an infarction in the territory of the posterior cerebral artery.
The aim of this part of the study was to find out whether patients with less serious brain injuries, as assessed on clinical grounds, showed less extensive abnormalities on their computer tomograms.
To this end, the CT scans of the 52 patients who were not comatose but showed neurological deficit and/or impaired consciousness, were compared with the scans of the 121 comatose patients (see table 23).

TABLE 23

Percentage of normal findings on admission in four categories for comatose and non-comatose patients.

percentage of normal findings	comatose patients	non-comatose patients
parenchymatose lesions	34% (39 patients)	41% (21 patients)
extracerebral abnormalities	52% (60 patients)	65% (33 patients)
cisterns	28% (33 patients)	53% (27 patients)
ventricles and midline shift	15% (17 patients)	31% (16 patients)

In the categories "cisterns" and "ventricles and midline shift"; the percentage of normal findings on the scans made on admission of non-comatose patients was significantly higher ($p < 0.01$ and $p < 0.05$ respectively). In the other two categories the percentage of normal findings was again higher in the group of non-comatose patients, but not significantly so.

It is not necessarily always the case that comatose patients, and the patients with neurological deficit and/or impaired consciousness, show abnormalities on their admission scans. There are three possible explanations for this:

1. The clinical symptoms could be caused by a functional disorder rather than a structural abnormality in the brain. Patients with such a disorder would then recover relatively quickly, and their later scans would be normal.
   Ten out of the 121 comatose patients included in this study had a completely normal computer tomogram in the early post-traumatic period; these patients also showed no abnormalities on the scan made 1 year after the accident. The outcome of all 12 patients was classified as "good recovery".
2. The admission scan may have been made too soon to show a structural abnormality.
   In the case of 4 of the comatose patients in this study, the first scan after admission showed no structural lesions, whereas subsequent computer tomograms revealed a contusion or an intracerebral haematoma.
3. The spatial resolution of the computer tomograph may have been insufficient in some cases, and hence important parenchymatose lesions would not have been shown.

In the case of 4 of the survivors out of the group of comatose patients, the CT scans made in the early post-traumatic period showed no abnormalities; however, late scans revealed local or diffuse atrophy as a late sign of brain injury.

THE CORRELATION BETWEEN EARLY AND LATE CT FINDINGS (CORRELATION V)

In comparing the CT scans made on admission with those made 1 year after the accident, only intracerebral abnormalities were considered in comatose patients. Scans were made on admission of 116 comatose patients; of the remaining 5 patients, computer tomograms were made within 24 hours of admission. Forty-five out of the total of 121 patients survived the accident. Scans were made of 43 survivors 1 year after the accident; the last scans of the other 2 survivors were made 3 months after admission.

In 16 out of the 45 patients, no intracerebral abnormalities were present on their "late" computer tomograms; their admission scans were also normal. Seventeen of the 45 survivors showed abnormalities both on their first and on their "late" scans.
On the basis of the location of the abnormality, it was assumed that the late finding resulted from the abnormalities which had been observed on admission (see fig. 4). However, when multiple abnormalities had been seen on the first computer tomogram, it was not possible to detect all the locations again in the form of atrophy on the late scan. Ten out of the 45 patients showed no abnormalities on their admission scans, and yet local and/or diffuse atrophy could be seen on their late scans. The scans made within 14 days after admission showed abnormalities in 6 out of these 10 patients.
Two patients had abnormalities on their first CT scans, whereas their late scans were normal.

It can happen that a computer tomogram is made so soon after the accident that structural lesions are not yet visible.
Abnormalities in the brain or brainstem may not be detected on scans made soon after the accident, owing to technical reasons; such abnormalities may later give rise to persisting symptoms and may be seen as atrophy on the late computer tomogram. The use of new generations of scanners will bring about changes in this field.
Faster scan times, thinner slices and finer matrices will all improve the diagnosis of abnormalities, especially in the regions which have hitherto been difficult to reach. Such an improvement was observed when the 160 × 160 matrix was introduced to replace the 80 × 80 matrix (62).

THE CORRELATION BETWEEN EARLY COMPUTER TOMOGRAPHIC FINDINGS AND THE OUTCOME AFTER 1 YEAR (CORRELATION VI)

This correlation can be subdivided as follows:

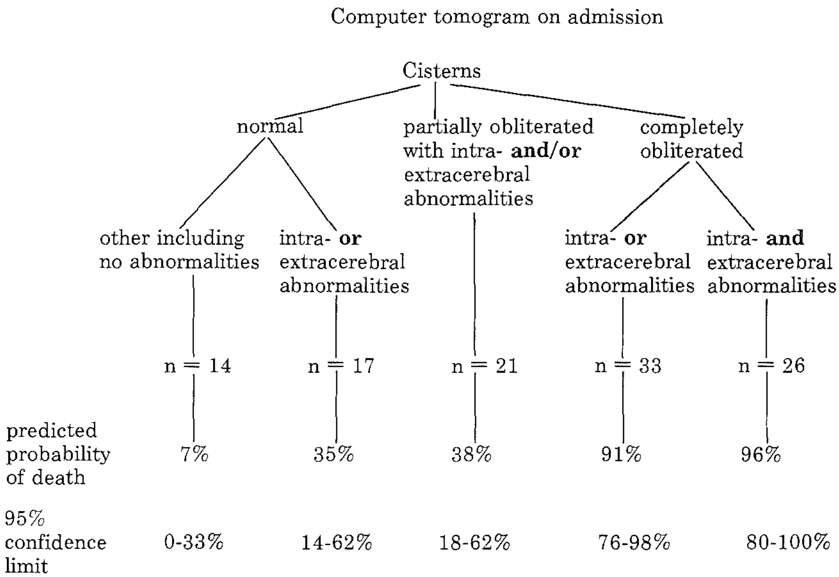
a. early CT findings and the death rate;

b. early CT findings and the quality of survival.

It can be seen from the results of this study that statements can be made on the basis of CT findings alone about a patient's chance of dying (see tables 12-18 inclusive).
A "prognosis tree" can be made from the results in table 17 (fig. 25).

FIG. 25

Prognosis tree based on computer tomographic findings.



For patients with a normal computer tomogram on admission, the prognosis was favourable. In the group of patients who showed intra- or extracerebral abnormalities and normal cisterns on their CT scans, the death rate was 35%. Is there an explanation for the deaths of the patients whose admission scans were either normal or "only" showed slight abnormalities (patients A1, C1-C6 inclusive)? On studying the data of these patients a number of important factors emerge. Two patients died as the results of a brainstem lesion, which was visible on the computer tomogram (C1 and C6). The cause of death of 2 patients was not known (C3 and C4).
The scan of patient C4 was incomplete, and hence no statement was possible about the brainstem area. It appears that a "minor" lesion detected on a computer tomogram can still imply a poor prognosis, especially when such a lesion is located in the brainstem (38, 93, 95, 103). The time of death of patient C3 indicates that the cause of death was probably extracranial. For the other patients (A1, C2 and C5), the cause of death was extracranial.

Hence, if no correlation can be found between the CT findings on admission and the outcome (death or survival) of a given patient this could be due to one or more of the following:

- an incomplete computer tomogram;
- technical problems (artefacts, insufficient spatial and contrast resolution);

- extracranial causes;
- radiological delayed findings.

More sharp predictions could be made based on the clinical variables selected than when only computer tomographic variables were used. However, the number of sharp predictions increased when a combination of clinical and computer tomographic findings was used. The most important change which resulted from this combination of variables was the clear increase in the number of patients for whom a sharp prediction of survival could be made.

Out of the set of CT variables alone, the following were selected in order of importance:

- cisterns;
- parenchymatose lesions.

The addition of another variable made no improvement in the probability statements. Out of the combined set of clinical and CT variables, the following were selected in order of importance:

- pupils;
- motor response;
- ventricles and midline shift;
- parenchymatose lesions;
- age.

The variable with the most prognostic significance in the set of CT variables, i.e. cisterns, does not appear in the set selected from both computer tomographic and clinical variables. The reason for this becomes clear when one looks at the selection procedure as a whole. The variables are graded according to the quality of the probability statements thus obtained. In the first step in the selection from the combined set of CT and clinical findings, the order is as follows:

1. pupils;
2. cisterns;
3. created eye indicant;
4. ventricles and midline shift;

   etc.

The variable "pupils" is hence selected first.

In the second step a variable is selected from those remaining in the set; this variable must have the greatest predictive power when taken together with the variable "pupils" which has already been selected. When the remaining variables are placed in order according to their prognostic value, the following picture emerges:

1. motor response;
2. EMV sum score;
3. ventricles and midline shift;
4. created eye indicant;
5. E+M score;
6. cisterns;

   etc.

Thus, in step two "motor response" and not "cisterns" is selected. The variable "cisterns" falls back to sixth place. The variables "pupils" and "cisterns" clearly overlap in terms of the information they provide. By selecting the variable "pupils" the information from that overlap is chosen; any remaining information does not have so much prognostic significance as to justify the selection of the variable "cisterns" at this stage.

The overlap in information between the variables "pupils" and "cisterns" can be seen from the following table 24.

TABLE 24

Correlation between the variables "pupils" and "cisterns" on admission.

On admission	Pupils bilaterally reacting	One or both pupils non-reacting
cisterns partially or completely open	40	17
cisterns completely obliterated	14	44

n = 115
$P < 0.001$

One-hundred and sixteen patients were scanned on admission. In the case of one of these patients, the pupil reaction was not assessed on admission.

Is it possible to improve the accuracy of probability statements based on a set of CT variables by placing more emphasis on the state of the basal cisterns? This question arises because the variable "cisterns" has already been seen to have the greatest predictive value of all the CT variables; this was why the following CT categories were chosen:

- normal;
- normal cisterns with intra- or extracerebral pathology;
- partially obliterated cisterns with intra- and/or extracerebral pathology;
- completely obliterated cisterns with intra- or extracerebral pathology;
- completely obliterated cisterns with intra- and extracerebral pathology;

The number of sharp predictions based on these variables was larger than when clinical variables or a set of clinical and CT variables were used (see table 25).

TABLE 25

Sharp predictions of outcome after 1 year based on combined CT findings, compared with actual outcome.

	Actual outcome		
sharp predictions of outcome	Death (n)	Survival (n)	Total (n)
Death (n)	55	4	59
Survival (n)	1	13	14
Doubt (n)	14	24	38
Total (n)	70	41	111*

* One hundred and eleven patients could be placed in the 5 CT categories (see pages 74 and 75).

The total number of sharp predictions was 73 (66%); 68 (93%) of these were correct. The number of patients for whom sharp predictions of survival were made was 14 (10%); this was a somewhat smaller number than when probability statements were made based on a set of clinical and CT variables.

When a combination of clinical and CT variables was used as the basis for probability statements, the number of sharp predictions increased. However, there were three incorrect predictions, concerning patients J1, J2 and K1. For patient J1 a sharp prediction of death was made, and yet this patient recovered completely. The computer tomogram on admission showed a type III contusion and compressed ventricles without midline shift. The basal cisterns were normal. For patient J2 there was also a sharp prediction of death, but she survived, albeit moderately disabled (see fig. 16). Her cisterns were also normal on the admission scan. For patient K1 a sharp prediction of survival was made, but this patient died as a result of sepsis 3 weeks after admission. The computer tomogram on admission showed intraventricular and subependymal blood, with normal cisterns. If the state of the cisterns had been selected as a variable with prognostic significance, the predictions for patients J1 and J2 would not have been incorrect. The predicted probability of death as calculated on the basis of CT findings alone would have been about 35% instead of more than 90%.

CT AND QUALITY OF SURVIVAL

Lanksch and Kazner and others have already demonstrated that a correlation exists between the degree of severity of a brain injury and the CT findings in the early post-traumatic period. Patients with mild brain injury but without neurological deficit showed no abnormalities on their computer tomograms. On the scans of patients with more serious brain injuries, structural abnormalities were often detected; the location of these abnormalities was correlated to the clinical symptoms. The question is whether in the case of patients with severe brain injury, a correlation exists between the degree of brain damage as shown on the computer tomogram, and the quality of survival.

In this study, a high death rate was observed in patients with serious abnormalities on their admission scan.
There was a good chance of complete recovery when no abnormalities could be seen on the computer tomogram made on admission.
However, there were exceptions (patients B1 and B2). In the case of patient B1, no reason could be found even on later computer tomograms for her final state; perhaps the CT scan failed to show small abnormalities present in the brain or brainstem.
With patient B2 however, there were no abnormalities visible on her admission scan. However, she must have had parenchymatose lesions on admission; the presence of these lesions is indicated by her clinical state on admission, the multiple contusions seen on her later scans, her final outcome and the findings on her last scan.

The apparently normal scan on admission must have been due to technical problems.

The number of patients who remained disabled was larger in the group of patients who showed abnormalities on their admission scans than in the group who had a normal computer tomogram. However, the number of survivors was small, particularly in relation to the relatively large number of outcome categories; hence it was not possible to make reliable predictions about the quality of survival on the basis of the computer tomograms made on admission. In spite of the small percentage of survivors, however, an attempt was still made to formulate statements about the quality of survival, based on information obtained from scans made at slightly later intervals, in the early post-traumatic period; this proved to be too difficult.
It was not even possible to make statements about the probability of death or survival based on these findings. A variety of complicated factors all play a part in this post-traumatic phase (2 weeks after the accident); this can be seen from the following cases.
Patients F1, F2, G1: these patients all died from extracranial complications, which for obvious reasons could not be detected by means of cranial computer tomography.
Patients G2, G3: the time of death of these patients suggests that the cause of death was extracranial, although this could not be proved.
Patients H1, H2, H3: these patients showed no abnormalities on their CT scans made 14 days after admission; however their outcome was classified as "dependent" (S.D. or P.V.S). Patient H1 also had normal scans on admission and after 1 year. The apparent absence of abnormalities on these scans must have been due to technical problems.

This study has shown that accurate predictions of death could be made for a number of patients with severe brain damage. Accurate predictions of survival were also made, albeit for a much smaller number of patients. The formulation of probability statements about the quality of survival proved to be impossible, because of the relatively small number of survivors and because of the technical limitations of the scanner used.

The use of later generations of scanners will undoubtedly lead to improvements in the detection and localisation of small lesions, even when these are situated in the brainstem.
Hence in the future it may become possible to make accurate predictions of death and survival in a larger number of cases; it may even become possible to make probability statements about the quality of survival.

Summary

– The purpose of this study has been:

- to examine the influence of computer tomography on the diagnosis and treatment of patients with severe brain damage, and
- to investigate whether it is possible to make predictions on the outcome of these patients, based on CT findings.

– To this end, a series of computer tomograms was made of 173 consecutive patients with severe brain damage. One hundred and twenty-one of the 173 patients were comatose on admission. The other 52 patients were non-comatose, but showed impaired consciousness and/or neurological deficit. The computer tomograms were made, as far as possible, at predetermined intervals after the accident. The number of scans thus obtained was 562.

– There was a high percentage of abnormal findings on the computer tomograms made on admission. However, 20 patients (12%) with clinical symptoms of serious brain damage showed no abnormalities on their admission scan. The most serious abnormalities were generally observed on the computer tomograms of the comatose patients.

– In 61 patients, the abnormalities detected on the CT scans could be checked by operation or autopsy. In all cases the CT diagnosis was confirmed.
Occasionally, an operation or autopsy revealed other abnormalities in addition to those which had been observed on the patient's scan: such findings were small, peripheral or basal contusions and infratentorial abnormalities.

– A radiological delayed finding in the form of a contusion, an intra- or extracerebral haematoma or a subdural effusion was seen in 25% of the patients.
Most of these findings were observed on the computer tomograms made 24 hours or 3 days after admission. Subdural effusions were often seen around the 14th day after admission. Radiological delayed findings were detected in comatose and non-comatose patients.

– The following scan schedule shows one possible way of restricting the number of computer tomograms made of each patient, without sacrificing any diagnostic information: a scan on admission, after 24 hours or 3 days, after 14 days, after 1 month, after operation and in case of clinical deterioration.

– This scan schedule should be used both with comatose and non-comatose patients. No statement can be made in this study about the value of computer tomography in the case of patients with less serious forms of brain injury.

– The introduction of computer tomography has resulted in a noticeable decrease in the percentage of angiographies carried out on patients with severe traumatic brain injury.
Exploratory intracranial operations are rarely required nowadays, whereas the number of specifically oriented intracranial operations has increased.

– A computer tomogram does not only convey diagnostic information; it also has prognostic significance. This can be seen from the fact that the death rate in patients with a normal computer tomogram on admission was low, i.e. 7%.
In comatose patients who showed intra- and extracranial abnormalities combined with totally obliterated cisterns on their admission CT, the death rate was 96%. Out of a set of combined CT findings, the feature with the most prognostic value was the state of the basal cisterns. The probability statements on outcome made on the basis of these combined CT findings were more accurate than those based on clinical variables alone.
However, the best predictions on outcome, including the largest number of accurate sharp predictions, were made on the basis of a combination of clinical and CT variables.
For a number of patients, it was also possible to make sharp predictions of survival, using this combined set of variables. Unfortunately, the formulation of probability statements on the quality of survival, based on these data, proved to be too difficult.

– This study could be continued in the future, using a later generation scanner: it may then become possible to produce a larger number and a higher standard of probability statements on the quality of survival.

Samenvatting

– In deze studie wordt de invloed van de computer-tomografie op de diagnostiek en de behandeling van patiënten met ernstig traumatisch hersenletsel nagegaan.
Bovendien werd bestudeerd of op basis van computer-tomografische bevindingen, voorspellingen konden worden gedaan betreffende de afloop van dergelijke patiënten.

– Hiertoe werd bij 173 opéénvolgende patiënten met ernstig traumatisch hersenletsel een serie computer-tomogrammen vervaardigd. Honderd-een-en-twintig van de 173 patiënten waren bij opname comateus. De overige 52 patiënten waren niet comateus, doch toonden bewustzijnsdaling en/of neurologische uitvalsverschijnselen. De computer-tomogrammen werden zoveel mogelijk op van tevoren vastgestelde tijdstippen na het ongeval vervaardigd. Het aantal computer-tomogrammen aldus verkregen bedroeg 562.

– Het percentage afwijkende bevindingen op de computer-tomogrammen bij opname was groot. Toch waren er 20 patiënten (12%) die ondanks klinische verschijnselen van ernstige hersenbeschadiging, geen afwijkingen op het computer-tomogram bij opname vertoonden. In het algemeen waren op de computer-tomogrammen van de comateuze patiënten de ernstigste afwijkingen zichtbaar.

– De op de computer-tomogrammen geconstateerde afwijkingen konden 61 maal door middel van operatie of obductie worden nagegaan. Bij alle gevallen kon de geconstateerde afwijking worden bevestigd.
Een enkel maal bleken naast de geconstateerde afwijking, kleine, perifeer en basaal gelokaliseerde contusiehaarden en infratentoriële afwijkingen bij operatie of obductie aanwezig te zijn, zonder dat zij op het computer-tomogram te zien waren.

– Bij 25% van de patiënten bleek er sprake te zijn van een zogenaamd "radiological delayed finding", in de vorm van contusiehaard, intra- of extracerebraal haematoom of subdurale effusie. De meeste van deze bevindingen kwamen voor op de computer-tomogrammen, die 24 uur of 3 dagen na opname gemaakt waren. De subdurale effusies bleken vooral rondom de 14e dag na opname te ontstaan.
Deze afwijkingen, kwamen zowel bij de comateuze patiënten als bij de niet comateuze patiënten voor.

– Wanneer men zonder aan diagnostische informatie in te boeten, het aantal computer-tomogrammen per patiënt zou willen beperken, kan als scantijd schema worden gehanteerd: een scan bij opname, na 24 uur of 3 dagen, na 14 dagen, na 1 maand en bij verslechtering of na operatie.

– Dit scantijdschema zou zowel bij de comateuze als bij de niet comateuze patiënten toegepast moeten worden.
Over de zin van de computer-tomografie bij patiënten met een lichtere vorm van schedel-hersenletsel kan op grond van deze studie geen uitspraak worden gedaan.

– De introductie van de computer-tomografie had tot gevolg dat het percentage angiografieën bij patiënten met ernstig traumatisch hersenletsel aanmerkelijk daalde. De exploratieve neurochirurgische ingreep werd nagenoeg niet meer verricht, terwijl het aantal gerichte neurochirurgische ingrepen toenam.

– Naast diagnostische informatie blijkt een computer-tomogram ook prognostische betekenis te hebben.
Zo blijkt de mortaliteit bij de groep comateuze patiënten met een normaal computer-tomogram "slechts" 7% te bedragen.
De mortaliteit bij comateuze patiënten met een computer-tomogram waarop bij opname intra- en extracerebrale afwijkingen in combinatie met geoblitereerde cisternen zichtbaar zijn, bedraagt daarentegen 96%.
Bij bestudering van het computer-tomogram alleen blijkt de toestand van de basale cisternen het belangrijkste prognostische criterium te zijn.
De beste voorspelling wat betreft de afloop van een patiënt kan echter op basis van een combinatie van klinische en computer-tomografische variabelen worden gedaan. Het aantal juiste "scherpe" voorspellingen is dan het grootst. Ook blijkt het daarmee mogelijk om in een aantal gevallen "scherp" te voorspellen of een patiënt het ongeval zal overleven.
Het bleek echter niet goed mogelijk om op basis van de bestaande gegevens kansuitspraken te doen omtrent de kwaliteit van overleven.

– Het lijkt waarschijnlijk dat een voortzetting van deze studie met behulp van een nieuwere generatie computer-tomograaf, betere kansuitspraken over de kwaliteit van overleven mogelijk zal maken.

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Curriculum vitae

Schrijver van dit proefschrift werd op 23 september 1942 te Broek onder Akkerwoude (Friesland) geboren. In 1961 behaalde hij het diploma H.B.S.-B te Rotterdam. Hierna volgde de medische studie aan de Rijksuniversiteit te Leiden, waar in 1966 het doctoraal examen werd afgelegd. De studie werd voortgezet bij de Stichting Klinisch Hoger Onderwijs te Rotterdam. Deze stichting ging later op in de Medische Faculteit Rotterdam.
Het artsexamen werd in 1969 verkregen.
Na vervulling van de dienstplicht bij de sectie geestelijke gezondheidszorg van de Koninklijke Luchtmacht, werd een aanvang genomen met de opleiding tot neuroloog op de afdeling Neurologie van het Academisch Ziekenhuis Dijkzigt te Rotterdam (Hoofd: Prof. Dr. A. Staal).
Tijdens deze opleiding, welke op 1-2-1974 eindigde, groeide de belangstelling voor de Neuroradiologie.
In februari 1974 begon hij aan de opleiding tot Radioloog op de afdeling Radiologie van het Academisch Ziekenhuis Dijkzigt te Rotterdam (Hoofd: Prof. K. Hoornstra).
Tijdens deze opleiding werden stages gevolgd op de afdeling Neuroradiologie van het Wilhelmina-Gasthuis te Amsterdam (Hoofd: Prof. Dr. F. L. M. Peeters); op de afdeling Neuroradiologie van het Academisch Ziekenhuis te Leiden (toenmalig Hoofd: Dr. R. E. M. Hekster); en op de afdeling Neuroradiologie van de Universitätskliniken te Mainz (Hoofd: Prof. S. Wende).
Vanaf maart 1978 is hij stafmedewerker van de afdeling Radiologie van het Academisch Ziekenhuis Dijkzigt te Rotterdam met als speciale opdracht, de uitoefening van de Neuroradiologie.