Child's Nerv Syst (2000) 16:755–759

ORIGINAL PAPER

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Imaging after head trauma: why, when and which

Received: 3 January 2000

Paper presented at the World Conference on Pediatric Neurosurgery, 2000 A.D.: State of the Art and Perspectives for the Third Millennium, Martinique, 27 November to 4 December 1999

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Abstract CT scanning is the current first imaging technique to be used after head injury, in those settings where a CT scan is available. The first scan is usually done without contrast enhancement. The value of CT is the demonstration of scalp, bone, extra-axial hematomas and parenchymal injury. It is rapid and easily done in the presence of the multiple monitors that many trauma patients have in place. It can be used to demonstrate the bony anatomy of the spine and is good for evaluation of abdominal and chest trauma also. MRI is more sensitive for all post-traumatic lesions other than skull fracture and subarachnoid hemorrhage, and can demonstrate parenchymal spinal cord injury. The cons are a longer scanning time, interference of the imaging by certain ICP monitors and problems with the positions of the monitoring equipment and ventilators outside the MRI magnetic field. MRI will be used increasingly to study early head injury because of its ability to measure cerebral blood flow, cerebral blood volume and the location and extent of cerebral edema. If the CT does not demonstrate pathology adequate to account for the clinical state, MRI is warranted. Follow up is best done with MRI as it is more sensitive to parenchymal change than is CT.

Keywords Head trauma · Children · CT scan · MRI scan · Follow-up

Why

There are several requirements for the ideal imaging system of the brain post-trauma. Any system that can also image other areas of the body has some advantage over one that cannot. The time requirement of the test compared with the usefulness of the information produced is an important aspect of any test. Any possible detrimental affects on the patient have to be weighed against the benefits. The cost of both the actual test and the equipment required to perform it are important, and this is especially so in the poorer countries where the ability to perform large numbers of studies may be more important than certain details per study.

The imaging has to demonstrate the bone such that fractures of all sorts can be identified. In addition, the test must be sensitive to fresh bleeding in extradural, subdural, subarachnoid, intraventricular and intracerebral locations. The imaging should also demonstrate all the various pathologies that can result from trauma: diffuse axonal injury; cerebral swelling; contusion; intracerebral hemorrhage; brain edema; ischemia; and infarction, in both the brain stem and the cerebrum. Information such as that of cerebral blood flow, CBF; cerebral blood volume, CBV; location of swelling or edema, intra- or extracellular, are likely to be required in the future for ideal management and therefore need to be considered, even though they are essentially research measurements at the moment.

Any imaging test that is valuable in trauma must be immediately available and able to accommodate very sick patients and all the resuscitation equipment they may have. The results must also be immediately available for viewing. The test should be readily repeatable

and comparable with the last examination. The site of the imaging equipment must be convenient to the ER and ICU to avoid long transfer times for unstable patients. Taking into consideration all the above requirements, the CAT scan is currently assumed to be the most valuable neuroimaging test for the acute clinical diagnosis of post-traumatic brain pathology.

Additional considerations when deciding the "best" imaging study after trauma are: what accumulated knowledge is there on the reliability and predictability of the clinical course related to the test findings; how well studied is the imaging modality in head injury; is there a diagnostic grading system that compares the imaging findings to the clinical injury? Obviously the CT scan is the only imaging modality that fulfills these requirements at present [8, 9, 17, 18, 19]. One further question that refers to the timing of the studies is: is the information delivered by the primary imaging test the same information that is required from any later tests? Long term outcome has been well correlated to delayed MRI scanning in children [4, 5, 6, 11]. In adults correlation studies have been examined with reference to CT scan.

When

The most common cause of death after head injury is as a result of elevated intracranial pressure, and in most studies that have examined 'talk and die 'patients, missed intracranial mass lesions are the most frequent finding in adults, whereas diffuse swelling, hyponatremia and multiple contusion are the more common reasons in children [10, 14, 15]. There are clues to the risk of delayed deterioration, based on the type of injury, the severity of the trauma, the results of the initial CT scan, and abnormal clotting studies. Thus an imaging study of the brain should be obtained, if possible, as soon as the patient is stabilized. A study done too early may miss the development of an epidural hematoma or a delayed intracerebral hematoma. Most other lesions are already present at the time of the initial scan in children. However in those studies where serial scans have been compared, the rate of change of the CT scan is 50% or more, within the first 48 h [7, 16]. Mostly, the scans indicate a worsening of the condition, but a percentage also show improvement. An early imaging study in patients with a GCS of ≤8 is necessary as soon as the patient is stabilized.

All children who have surgery for removal of a mass lesions should be scanned within 24 h for evaluation of the extent of removal of the mass, and for assessment of any recurrent hemorrhage. As noted, a large percentage, 50% or more, of CT scans in adults after head injury show a change. The impression is that this is less common in children but the study of Stein and Spettell [16] suggests a similar incidence of worsening in children. Thus a second scan is usually required within the first 48 h. The timing is dependent on the findings from the first scan. Children with multiple contusions, extra-axial, or intracerebral hematomas all require a second scan within 24 h to have identified the possible need for surgical evacuation of a lesion. Children in whom the ICP is high in the face of a rather normal first scan require a repeat scan within the first 24–48 h for the identification of the pathological cause of the raised pressure: mass lesion, diffuse swelling, ventricular dilatation. If the ICP is stable for several days and then rises, whether or not there is a clinical change, a repeat scan is required to investigate the cause of the delayed rise in pressure: brain edema, brain swelling, infarction or evidence of increased CSF. In general, any change in clinical examination, or monitored parameters that is unexpected is an indication that a repeat scan should be considered, since the pathology of head injury changes with time.

A scan is usually performed prior to the removal of the ICP monitor in children who have been unconscious for more than 3 days. Later scans are done, based on the clinical progress and the findings on previous scans. The frequency with which delayed follow-up scans are obtained will vary with the ability to obtain such scans. Usually a scan is carried out approximately 3 months after trauma, then one at 6 months and one at 1 year after trauma. These scans are used to predict the risk of long term dysfunction and to rule out late problems such as hydrocephalus and chronic subdurals.

Which

In the few papers that have compared CT and MRI scans after trauma, the MRI scan has proven superior for every pathology other than skull fracture and subarachnoid hemorrhage [1, 2, 3, 13, 20]. The ability to identify even epidural and subdural hematomas appears to be approximately 30% better for MRI. These studies do not demonstrate a clinical care deficit related to the lower sensitivity of CT scanning, but the sensitivity and specificity for extracerebral lesions appears better for MRI. In addition MRI is much more sensitive to the presence of intraparenchymal injury; edema, diffuse axonal injury, contusions and hematomas (Figs. 1, 2). Based on the small amount of comparative information available from children, the most sensitive neuro-imaging study following a head injury appears to be the MRI scan.

Despite the greater sensitivity of the MRI scan, the CT scan remains the most common imaging test after head trauma. The reasons are: the ease of obtaining the study; the speed of the study; and the ability to easily image the spine for bony injury and the abdomen or chest for traumatic injury, at the same sitting as for the head scan. The subtle findings that are less well seen on CT scan than on MRI scan do not appear to be clinically significant. The newer CT scans that will be even faster,

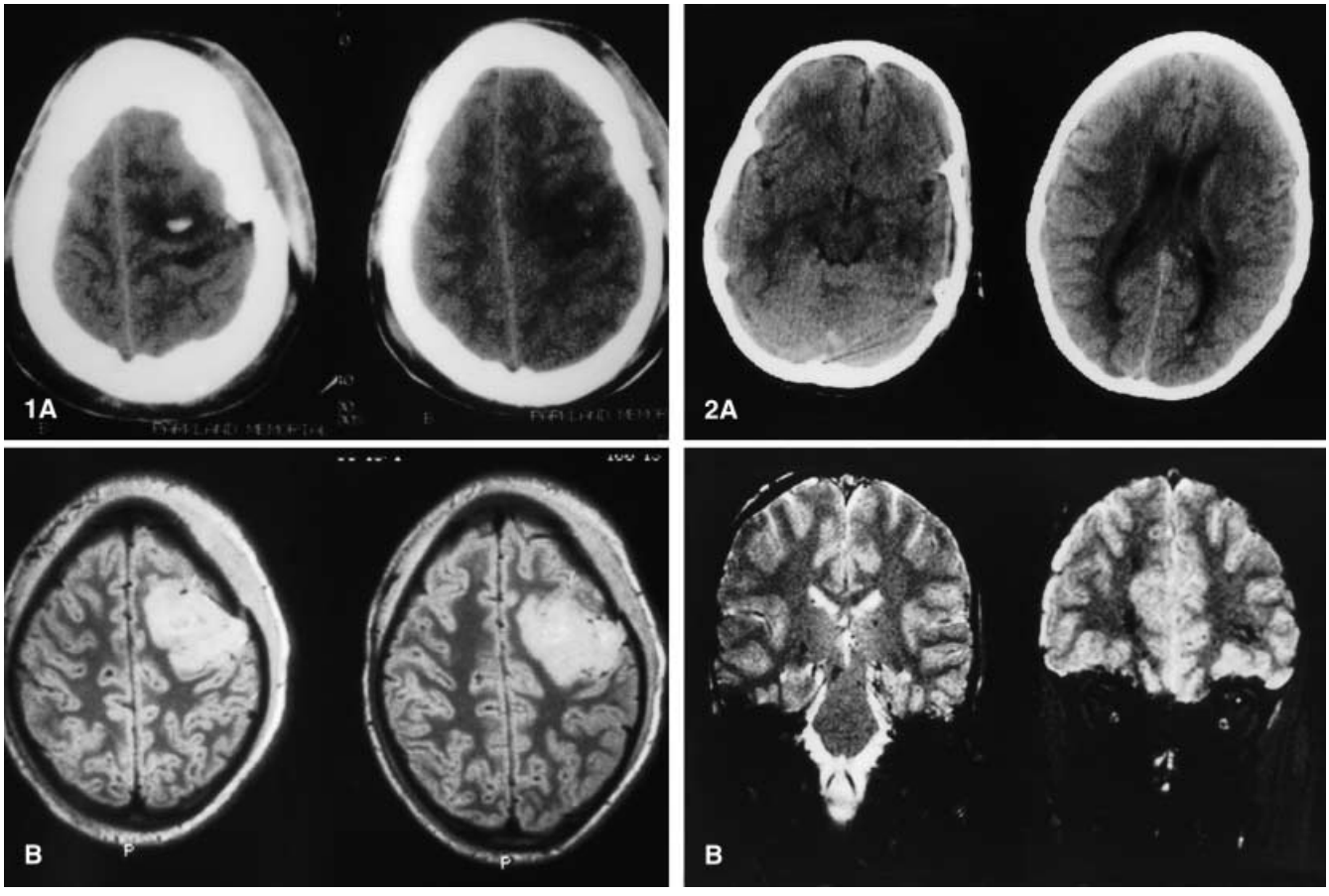

Fig. 1A, B CT and MRI scans within the first 48 h of trauma. CT demonstrates the diffuse axonal injury much less well than does the MRI scan. The superior two images are CT scans, the inferior two are MRI scans

Fig. 2A, B CT and MRI scans of early cortical contusion. MRI demonstrates the lesion much better than CT

with better resolution, will further support the selection of the CT scan as the primary neuro-imaging study after head trauma.

Selective use of the MRI scan in the early stages of traumatic injury will increase in the next few years. The ability to measure CBF, CBV and to identify the location of edema fluid, intra- or extracellularly, is now possible. It is hoped that this information, with the addition of MRI spectroscopy, will allow the clinician to subdivide further the types of head trauma, and to define better, certain aspects of pathology. These will be the location of ongoing ischemia, if it exists; the frequency of vasogenic edema and its contribution to elevated intracranial pressure; and the presence and distribution of intracellular edema and its potential role in elevated ICP. The value of early MRI scanning will be defined dependent on the effects of these findings on the therapy, and ultimately the outcome, of head injured children. Even if a better definition of the pathology of head injury can be obtained with the use of MRI scanning, and that information can be used either to develop new therapies or to better select the currently available therapies, it seems unlikely that MRI will replace CT as the primary diagnostic procedure. It is more likely that the information gained by the MRI studies will be converted into clinical treatments based on CT comparison and clinical data such as the type of trauma, presence of hypoxia or hypotension and presence of other injuries. In this manner, advances in therapy can be available to all head injured children even if a MRI scanner is not available.

Factors favoring CT scan

The CT scan has a long track record of use in head injured children. The study is readily available in most centers and can easily be repeated. Patients with all their resuscitation equipment can be accommodated in the CT scan without difficulty. The scanning time is short, 5 min. All major pathologies can be identified and surgical lesions diagnosed. The bony spine can be imaged at the same time as the brain. The abdomen and chest can be scanned with relatively little additional time – 30 min.

CBF and CBV [12] can be measured but this requires the addition of stable xenon for the first study and a contrast bolus for the second, adding considerably to the time required for the study. Xenon is not available in most imaging departments. While these investigations have been applied to research groups of patients they have not become part of the standard trauma imaging.

Factors against CT as the best study

The most serious deficiency is the lack of ability to discern small extracerebral lesions especially in the posterior fossa. This deficiency is also true for the extent of DAI, early contusions, the ability to diagnose early ischemia, current ischemic areas and the location and extent of increased tissue water. However none of these minor lacks of sensitivity seem to be of any clinical significance. In addition the CT is limited in value for follow-up compared with the MRI. The latter has been shown to correlate better with clinical and cognitive recovery.

Factors favoring the MRI scan

The extreme sensitivity and specificity in the diagnosis of all the lesions associated with intracranial trauma. The ability of the scan to measure blood flow, and blood volume, and to identify the location of any increased brain water. Its ability to image the blood vessels in the cranium. The sensitivity to soft tissue injury of the spine. The potential to identify areas of post-ischemic injury and possibly on going ischemia with the use of spectroscopy. Also there are many studies correlating clinical and cognitive recovery with findings, or the lack of them, on MRI scans making them potentially better predictors of ultimate recovery. If an early MRI scan can be shown to accurately predict outcome, it would be another reason for considering early MRI scanning after trauma.

Factors against MRI as the best study

The lack of immediate availability in most centers is the single most limiting factor in the application of MRI as the primary study following trauma. The length of the study is a problem if the patient is unstable. Also, because of the limitations of the equipment that can be accommodated in the MRI scanning suite, it is not a user-friendly environment for the multiple trauma patient to be in. The information on other organ system scanning is not as complete as it is for the CT scan. In addition, the lack of good bone definition is a deficit as is the ability to identify and quantitate the amount of subarachnoid hemorrhage. Finally there is the cost of the equipment and the need to have technicians constantly on call. Also, to maximize the value of the MRI it really requires a neuroradiologist to decide on the best sequencing for each patient. This necessitates having a radiologist with MRI experience on call and in-house.

Conclusions

The current recommendation for children with severe head injury is for a neuroimaging study to be done as soon as the patient is stabilized. This will usually be a CT scan without contrast. In the next few years, a host of new information on the use of the MRI scan as the primary study is likely to be forthcoming. It seems certain that these studies will add to our knowledge of the early and developing pathology of head injury, and hopefully will lead to more rational protocols for therapy. Whether the MRI scan will replace the CT scan as the primary study following trauma will depend on improvements in the speed of imaging, improved environment in the MRI scanning suite for the multiple pieces of equipment that accompany the trauma patient and on whether the early MRI scan is shown to be of clinically more value than the CT scan. At present it seems more likely that the primary study will be a CT scan and, depending on the pathology shown on the first study, the follow-up studies may be MRI. This will be especially true in patients with diffuse swelling, diffuse axonal injury or a normal CT scan.

Repeat imaging studies will be performed depending on the patient's condition. Alterations in clinical examination or ICP are reasons for repeat imaging. Patients who have a mass lesion evacuated will usually be re-imaged within24 h. Most other patients will have a repeat

Table 1 Proposed schema for post-trauma imaging

Study	Timing	Plain/contrast
Timing of CT imaging studies after head trauma		
Initial study	As soon as the patient is stable	Plain
Second study	Within 24 h of surgery	Plain
	24–48 h post-trauma	
	Any change in clinical state or unexpected change in ICP	Plain
Further studies	Before removing ICP monitor	Plain
	Any deterioration in clinical state	
	1–3 months post-trauma	Plain
	6–12 months post-trauma	Plain
Current use of MRI		
Initial scan	At time of second CT (depending on clinical state)	
Follow up	1–3 months	
	12 months	

imaging study within 48 h, based on the high incidence of changes on the second CT scan. An imaging study is usually performed in patients who have had ICP monitoring and therapy for its control for more than 3 days.

Follow up scans, which are probably best to be MRI if available, are performed depending on the clinical course. Routine scans are usually obtained at 3 months and 1 year post-trauma (Table 1).

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