Introduction

Craniocerebral trauma is not uncommon in young children who are physically abused [1–3]. In a study of 100 consecutively hospitalised patients below 2 years of age, approximately 54% had a head injury which was presumed to have been nonaccidental [4]. Other series have estimated the incidence of abuse in infants with head injuries under one year of age to be much lower, more on the order of 7 to 10% [5]. As morbidity and mortality are usually the result of injuries to the central nervous system (CNS), the focus has continued to be on the heads of abused infants. There is general agreement that severe accidental trauma is relatively uncommon in children less than 2 years of age [5], in whom nonaccidental injuries account for 80% or more of deaths from head trauma [5]. In the United States, it is estimated that there are 3,000 deaths per year from nonaccidental injury and at least 10% of children with mental retardation and cerebral palsy are presumed to have been damaged by child abuse [6].

There is often a combination of cranial and skeletal injury in young children without a history of overt trauma, or with a history of trivial trauma, inconsistent with the degree of the CNS injuries. Unless there is a high index of suspicion, diagnosis of abuse may be missed since most battered infants present to the casualty departments with nonspecific findings, such as seizures and encephalopathy, without external evidence of head trauma. Investigation of these infants is often time-consuming and misleading, resulting in a delay in treatment. The radiologist may be the first to suggest the possibility of child abuse upon identification of skull fractures, intracranial haemorrhages, etc. [7].

Just as the cause of trauma changes with the age of the patient, so do the capacity of the brain to respond to trauma and the protective mechanisms that guard against injury. The infant, especially the young infant, has a large head, which represents 10% of body mass; in the adolescent or adult the head represents a much smaller proportion. The young infant has weak neck muscles that do not function effectively in supporting and holding the head erect. The infant’s skull is thin and easily deformed by a direct blow, which bends the skull inwards, sometimes even without fracturing it. Because of this relative thinness, however, fractures are quite common following blows to the calvarium. The sutures are not fused in infancy, giving the cranium a greater degree of overall flexibility. These unfused sutures also provide for a greater degree of expansion of the cranial contents, such as can occur with an extracerebral haematoma, cerebral swelling or hydrocephalus. Usually the calvarium expands outwards and the fontanelle bulges, but the brain in the supratentorial compartment does not usually herniate infratentorially. The perimesencephalic cisterns can be obliterated, however, and the brain stem compressed by the supratentorial mass effect. The lack of myelination in the cerebral hemispheres renders them relatively soft and compressible. As a force bends the calvarium inwards, the hemi-
spheres can absorb some of the impact and, consequently, relatively less damage occurs than in someone older. The same unmyelinated white matter, however, is vulnerable to shearing stresses that accompany rapid acceleration-deceleration movements, so white-matter tears can occur with violent shaking.

In the young infant, the subarachnoid space is frequently generous. Veins which drain the cerebral hemispheres cross this space to enter the dura venous sinuses, such as the superior sagittal sinus. The sinuses are embedded in the periosteum (dura mater) of the inner table of the skull, and its dural projections, the falk cerebri, tentorium and falx cerebelli are therefore firmly fixed to the calvarium. With rapid to-and-fro motion, such as in acceleration-deceleration, the brain moves, along with the bridging veins, at a different speed from the calvarium and its attached dural venous sinuses. This stresses the veins, leading to tears and bleeding into the potential subdural space between the arachnoid and dura mater.

Cerebral vasomotor reactivity appears to be different in young infants from that in older children and adolescents. The way the brain responds to traumatic stimuli and hypoxia with the release of excitatory amines, such as glutamate and glutamine, may be different in infants, children, adolescents, and adults. Other factors, such as the use of a car-seat or seat-belt, the thickness of the hair and skull, the position of the patient at the time of the injury, and the force and its vector, all play a role.

In accidents in young children, the most common mechanism of head injury involves falls from short distances which impart linear force to the head. These forces produce focal skull deformation, which may be sufficient to cause simple fractures, but is usually not of clinical consequence [8–10]. Falls from greater heights lead to impact forces which produce depressed or comminuted fractures and focal brain contusion and subarachnoid haemorrhage [11–15]. Global neurological function is usually not impaired, but if it is, recovers rapidly.

In contrast to linear or translational forces, angular or rotational forces lead to greater brain deformation and shear strain. This leads to concussion, subdural haematoma and diffuse axonal injury [8, 9, 16, 17]. The exact mechanisms of intracranial injuries in physically abused infants may remain unclear in some cases, because most of these events are not witnessed. However, certain specific patterns of assault can be postulated by a constellation of the clinical history and physical findings and the features of the intracranial pathology, as determined by neuroimaging and/or necropsy [18–21]. The radiological findings in nonaccidental cranio-cerebral trauma vary and depend mainly on whether the injury was caused by blunt impact(s) alone, shaking with or without impact, strangling, smothering, stabbing, drowning or poisoning. We review imaging of common and uncommon patterns of CNS injury under the categories of different traumatic mechanisms in child abuse.

Blunt impact

Mechanisms of blunt injury

Young children subjected to blunt impact, either accelerated or decelerated, usually have soft-tissue bruises with or without fractures of the skull or other bones. Subgaleal haematomas are often seen in association with a skull fracture (Fig. 1). The impact forces will vary, depending on the type and degree of the assault, such as being hit by a hard object, thrown out of a window and hitting the ground or being struck against the wall [22, 23]. The history given by the carer is often not consistent with the degree of physical insult (Fig. 1).

Skull findings

The skull of an infant is elastic and partially ossified and, on impact, tends to bend and recoil but not to fracture; however, this may increase the likelihood of injury to the underlying brain [24]. Falls from a bed onto a carpet, often claimed as causing what proves to be non-accidental injury, rarely causes fractures of the elastic infant skull or leads to significant brain injury [4]. Non-accidental skull fractures may be linear or depressed and are often parietal or occipital. They may be stellate, bilateral or multiple and can cross suture lines. Even though, overall, linear skull fractures are most frequent, the depressed, diastatic and comminuted fractures are more frequent in victims of child abuse than in accidental injury.

Skull fractures are found in approximately half of children with nonaccidental intracranial injury [25, 26]. However, half of children with intracranial injury do not have fractures. Fractures are more frequent in long bones than in the skull in victims of child abuse [27]. Thus, examination of long bones and ribs to search for recent or older fractures, and careful physical examination for stigmata of prior beatings are indicated.

Conventional skull films, while still the gold standard for calvarial fractures, may be of limited value, because a fracture line in the less well-mineralised calvarium of infants may be difficult to see. Fractures more than 5 mm wide on presentation have the potential to expand subsequently as a “growing fracture,” (Fig. 2) [13, 27–29].

Growing fractures are rarely seen after the age of 3 years [30]. The majority have been reported in infants under the age of 1 year, the typical age for non-accidental injury. The parietal bone is affected more often than the frontal bone. Three-dimensional (3D) CT using a bone algorithm is particularly useful in delineating the extent of a growing fracture and its relation to the sutures (Fig. 2).