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Abstract Evaluation of the child with suspected spinal injury can be a difficult task for the radiologist. Added to the problems posed by lack of familiarity with the normal appearances of the paediatric spine is anxiety about missing a potentially significant injury resulting in neurological damage. Due to differences in anatomy and function, the pattern of injury in the paediatric spine is different from that in the adolescent or adult. Lack of appreciation of these differences may lead to overinvestigation and inappropriate treatment. This review attempts to clarify some of the problems frequently encountered. It is based on a review of the literature as well as personal experience. The normal appearances and variants of the spine in children, the mechanisms and patterns of injury are reviewed highlighting the differences between children and adults. Specific fractures, a practical scheme for the assessment of spinal radiographs in children, and the role of cross sectional imaging are discussed.

Introduction

Spinal injury in children, both minor and serious, is fortunately rarer than in adults. Children account for 1–10% of all spinal injuries [1–5]. The mortality among spine-injured children is higher than in adults and is estimated at 25–32% [5–8]. Death is most often due to associated injuries to other organs, including the brain.

Reports of associated neurological damage vary, depending on the reporting centres, being higher in tertiary referral centres. The quoted incidence is between 25 and 50% [5, 9–14], which is similar to adult studies [3, 15, 16]. Practical experience in a hospital such as ours, which serves a population of about 400,000 for primary trauma, suggests that serious neurological sequelae occur in less than 1% of all children admitted with a history of spinal injury. In neurologically impaired survivors the trauma is at the C1–2 level or in the lower cervical or thoracic spine. Fractures below L1 may be associated with nerve root damage but as the cord normally ends at L1 level, cord damage does not occur. Fifty percent of children with neurological damage have complete sensory and motor loss below the level of the cord injury with a poor prognosis for recovery [5, 8, 10, 11, 13, 17].

Children with ‘incomplete’ neurological lesions fare better than adults [5, 8, 10, 11, 18] with up to 90% showing significant and 60% showing full recovery [5, 14].

Spinal injury in children less than 8 years old is mainly in the upper cervical spine [5, 10, 12, 14, 18, 19] and is associated with a high risk of neurological damage [5, 6, 14, 19, 20], as much of the serious trauma is at atlanto-occipital level. Neurological injury resulting from trauma at C1–2 is dependent on the degree of subluxation sustained at the time of injury. The cervical canal is at its widest at this level, providing a measure of protection, and subluxation may take place without impinging on the cord. Injury at a lower level, where the canal is smaller, carries a greater risk of cord damage. After the age of 8 years, the fulcrum of movement changes from C2–3 to C5–6, the adult fulcrum. The types and patterns of spinal injury in those over 8 years of age reflect this.

Children with spinal injuries have associated head injury in 25–50% of cases [7, 13, 21, 22], extremity fractures in 30% [13] and chest and abdominal injuries in...
Abdominal injuries, particularly of the small bowel, are associated with 'seatbelt' fractures of the thoracolumbar spine [13]. Neurological status is impossible to assess in the unconscious patient and victims of severe trauma are considered to have spinal injuries until proven otherwise. The initial trauma series includes a lateral view of the cervical spine. The cervical collar remains in situ until the clinical examination and spinal X rays have been deemed normal. The incidence of cervical spine fracture in blunt trauma victims requiring admission is estimated at 1–2% for both paediatric and adult populations [7, 23].

Spinal injury often occurs at more than one level [5, 13, 14, 19, 24]. While most injuries occur at contiguous levels, 16% occur at different levels in the spine [13, 14]. It is therefore recommended that if spinal injury is identified at one level, the entire spine should be imaged, especially in high-risk situations, and is best achieved by sagittal T1-weighted (T1W) and T2-weighted (T2W) MRI of the whole spine. MRI is mandatory when there is neurological deficit. In reported series with multiple levels of injury, the other fractures are mainly compression fractures that do not alter acute management. Long-term sequelae of compression fractures include kyphosis, especially if the injury involves the growth plates.

**Aetiology**

Road traffic accidents (RTAs) account for 36–54% of spinal injury in children, [5, 7, 10, 13, 21, 25], followed by falls and sports injuries. In children under 12 years the majority of incidents are motor vehicle/pedestrian/cycle accidents. With increasing age, injury sustained as car passengers increases. Above the age of 8 years, boys are affected more than twice as often as girls [5, 7, 10, 12, 13, 17, 26, 27]; below this the sex incidence is equal. In the USA, gunshot injuries are a frequent cause, accounting for 22% of injuries in one study of 277 patients with spinal trauma [4].

Birth trauma is a rare, but well recognised cause of cervical spine injury [3, 18–20, 28–30] with up to 75% occurring with breech deliveries [28]. Cadaver studies show that the spinal column can be longitudinally stretched to about 2 inches without disruption in a neonate, whereas the cervical cord will rupture if stretched beyond 1/4 inch [31, 32]. Many cases are ‘without radiographic abnormality’ but have profound neurological damage.

NAI is a rare cause of spinal trauma [6, 13, 29, 33–36] and occurs mainly at the thoracolumbar junction and lumbar spine, though Hangman’s fractures are recorded. The mechanism is hyperflexion. Compression fractures are commonest, but vertebral dislocation also occurs.

Congenital anomalies of the cervical spine, such as ‘os odontoideum’, block vertebrae, Klippel-Feil syndrome and Down’s syndrome increase the risk of cervical spinal trauma [12]. Atlanto-axial instability is reported to occur in 10–20% of individuals with Down’s syndrome [36, 37], but is symptomatic in about 3%. There are 31 reported cases of atlanto-axial dislocation in Down’s syndrome up to 1987. Most of these had a minimum of a 1-month history of neurological signs before major difficulties ensued [36].

**Differences between adult and paediatric spinal injury**

The patterns of spinal injury in children, especially in the cervical region, relate to changing anatomy [1]. Other factors include the child’s resilience to trauma and potential for growth and recovery, which allows for restoration of vertebral body height after anterior wedging, but may rarely result in progressive spinal deformity if end plate injury or paralysis has occurred [1]. In the child less than 8 years old, cervical spine fractures tend to occur from the occiput to C2 [5, 10, 13, 14, 17, 19, 37]. Possible reasons for this include:

- Fulcrum of movement located at C2–3 in the child, C5–6 in the adult.
- Relatively large head and weak neck muscles
- Ligamentous and joint capsule laxity
- Horizontal orientation of the facet joints in younger children
- Underdeveloped uncinate processes
- Mild physiological anterior ‘wedging’ of vertebral bodies
- Incomplete ossification of the odontoid process [1, 31]

Late spinal deformity after spinal injury may occur in children and often appears at times of growth spurts [1]. In general, children who injure their spines do not sustain occult injury [1]. Neurological trauma is usually apparent at the time of presentation.

**SCIWORA**

The term ‘SCIWORA’ was coined in 1982 by Pang and Wilberger [29] and is defined as “spinal cord injury without evidence of vertebral fracture or malalignment on plain radiographs and computed tomography” [29, 38–40]. Though radiographs are normal, MRI has shown significant pathology in many of these patients [39, 41] (Fig. 1).

The overall reported incidence of SCIWORA amongst spinal cord-injured children varies from 5 to 65% [6, 8, 17, 20, 29, 38]. SCIWORA is commoner in