# Chapter 32
# Spine Trauma

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## 32.1 Introduction

Paediatric spinal trauma is relatively rare, accounting for 2–5% of all spinal trauma [1, 2]. Nonetheless, these injuries are a significant cause of morbidity and mortality in this population and pose special challenges for clinicians involved in their care. Gathering an accurate account of the neurological symptoms may be difficult and clinical examination is frequently challenging. This is compounded by the variation in the extent and type of injury dependent on the child's age and thus the level of activity interacting with the anatomical and functional developmental changes of the maturing spine.

In this chapter, we review the epidemiology, mechanisms and characteristics of traumatic spinal injury (TSI) in children and discuss general management principles including the role of surgery in this population. It is not possible, in one chapter, to provide a comprehensive review of the entire subject, but we hope to provide a broad overview with particular focus on the most common spinal injuries the reader may face in clinical practice.

## 32.2 Epidemiology

Paediatric spine fractures represent 1–2% of all paediatric fractures, with the vast majority (80%) occurring in the cervical spine [3, 4]. Thoracic and lumbar fractures represent only 0.6–0.9% of all spinal trauma cases, with their proportion increasing with age [1]. The incidence of TSI has two peaks, in children under 5 years and in

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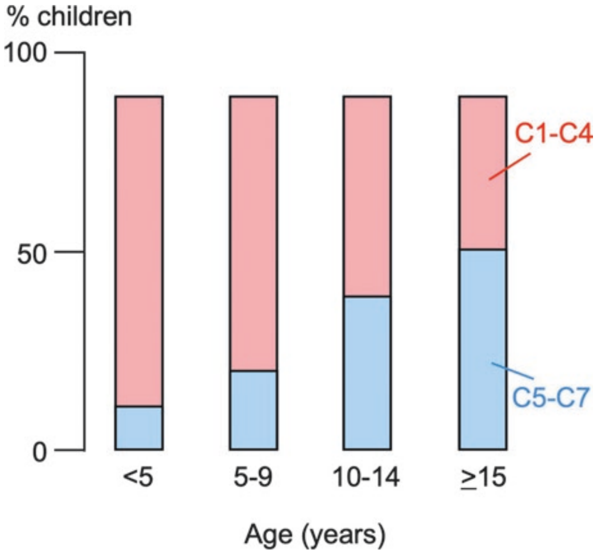

**Fig. 32.1** Injury level (C1–4, C5–7) versus age. Data from the US National Pediatric Trauma Registry (n = 75,172) over a 10-year period, 1988–1998 [6]

those over 10 years old [5]. It is common to have seasonal peaks relating to school holidays [5].

One of the largest epidemiological studies from the US National Pediatric Trauma Registry over a consecutive 10-year period found that 1.5% of the 75,172 children registered in the database had cervical injury, with a male:female ratio 1.6:1 [6]. Upper cervical injury (C1–4) was prevalent across all age groups and almost double that of lower cervical (C5–7) injuries (52%, C1–4; 28%, C5–7). Lower cervical injuries became increasingly more prevalent in older children (85% occurring in children >8 years) (Fig. 32.1) [6, 7]. An overwhelming majority of cervical injuries were due to blunt trauma (95% of cases), of which road traffic accidents represented the largest proportion (61%). Of these, 42% were passengers, 14% pedestrians and 5% cyclists [6]. Passengers of motor vehicles were found to be unrestrained in 61% of cases. Falls, as a mechanism of injury, was more prevalent in the younger age group (18% in children ≤8 years vs. 11% in those >8 years), and sports-related injuries more common in older children (3 vs. 20%). Non-accidental injury should be recognised by the clinician, especially in younger children. Shaken young babies develop cranio-cervical junction injuries, whereas beaten children sustain injuries related to where the direct force was applied.

## 32.3 Children Are Not Small Adults

Children sustain distinct types of spinal injuries, not commonly seen in adults, related to their evolving spinal anatomy, the age-specific biomechanical properties of the spine and its supporting ligamentous and muscular structures [6].

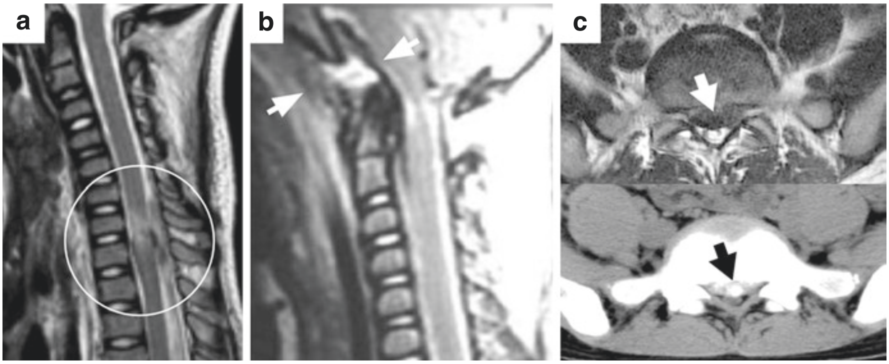

**Fig. 32.2** Radiologic examples SCIs in children. (**a**) MRI of SCIWORA (circled). (**b**) MRI of atlanto occipital dislocation (arrows). (**c**) Top (MRI) and bottom (CT) of vertebral apophyseal fracture at L5/S1 (arrow)

In contrast to the adult spine, the paediatric spine exhibits intrinsic ligamentous laxity and elasticity, along with smaller and more horizontally orientated facet joints [1, 7]. These features, in addition to a markedly changing large head to torso ratio, along with the less developed paravertebral muscles, predispose infants and younger children to flexion-extension spinal injuries [5]. Such unique biomechanical characteristics explain why younger children (<8 years) suffer fewer fractures and higher rates of spinal cord injury without radiographic abnormality (SCIWORA) (Fig. 32.2a). Exposure of the hypermobile paediatric spine to hyperextension forces can lead to transient dislocation followed by self-reduction, resulting in spinal cord injury (SCI) even with normal bony alignment and no fracture on X-ray or CT [5, 7]. Patel et al.'s epidemiological study of the US National Pediatric Trauma Registry found that cervical spine dislocations were twice as likely in younger children than older ones (31% at age ≤ 8 years; 17% at age > 8 years) [6]. SCI occurred in 35% of children with almost half having SCIWORA. The changing head to torso ratio results in a fulcrum at C2–3 in infants, gradually descending with maturity to the adult position at C5–6 [8].

## 32.4 Initial Management of Paediatric Trauma

The early management of children involved in trauma follows the standardised approach of the Advanced Trauma Life Support (ATLS) protocols. The spine should be immobilised in a neutral position at the scene and throughout transfer to a Major Trauma Centre to avoid the risk of progression of neurological deficit through instability that has been overlooked.

Cervical injury should be suspected in high velocity injuries, in children with torticollis, neck pain or spasm, impaired consciousness and those with permanent or transient neurological deficit (including radiculopathies). It is common to face difficulty fitting a rigid collar due to poor collar sizing or agitation. The UK National Institute of Clinical Excellence (NICE) guidelines and Advanced Paediatric Life Support (APLS) courses support a pragmatic approach whereby the spine is maintained in a neutral or comfortable position using blocks or rolled-up towels on either side of the head secured with tape [5, 9, 10]. In young children, the comparatively larger head may be forced into slight flexion when lying flat on a spinal board and, therefore, a degree of thoracic elevation may be required to accommodate this [7]. Rigid cervical collars can potentially exacerbate atlanto-axial distraction injuries; in suspected cases, sandbags placed on either side and secured with tape may be more appropriate than collars.

The primary SCI, sustained at the time of the insult, is generally irreversible. Secondary SCI, thought to be due in part to cord oedema, ischaemia and complex inflammatory processes, should be aggressively managed to reduce progression of neurological deficit. Cord hypoperfusion is a significant contributor to this, hence treatment of systemic hypotension is an important goal. Appropriate organ support including the use of vasopressors necessitate transfer to an Intensive Care Unit (ICU). Despite much research on neuroprotective therapies to reduce secondary SCI, currently, there are no drug treatments in clinical use. The controversy around corticosteroids in SCI persists. The National Acute Spinal Cord Injury Studies (NASCIS II and III) showed beneficial effect for methylprednisolone if given within 8 h of SCI for children aged >13 years, but others have found the benefits to be outweighed by the significant adverse effects of steroids including respiratory infection and sepsis [11–13]. In adults, the available evidence supporting the use of corticosteroids is unclear, and specific evidence in the paediatric population is even more sparse [13].

### 32.4.1 Recent Developments in Early Management of Acute SCI

Recently, techniques have been developed to monitor from the injury site by inserting a pressure probe under the dura to record intraspinal pressure (ISP) (Fig. 32.3) [14]. This allows the spinal cord perfusion pressure (SCPP) to be computed as mean arterial pressure minus ISP. The concepts of ISP and SCPP for SCI are analogous to the concepts of intracranial pressure (ICP) and cerebral perfusion pressure (CPP) for brain injury. The optimum SCPP ($\mathrm{SCPP}_{\mathrm{opt}}$) can then be computed as the SCPP that optimises autoregulation (quantified using the spinal pressure reactivity index, sPRx) [14, 15]. $\mathrm{SCPP}_{\mathrm{opt}}$ varies between patients and temporally in each patient thus supporting individualised management. Multi-modality monitoring from the injury site has also been described using microdialysis to assess spinal cord metabolism [16]. Evidence from these monitoring studies [17] and from serial MR scans of SCI patients [18] suggests that the dura is a major cause of cord compression after SCI and a randomised controlled trial, termed DISCUS, is being set up to evaluate the

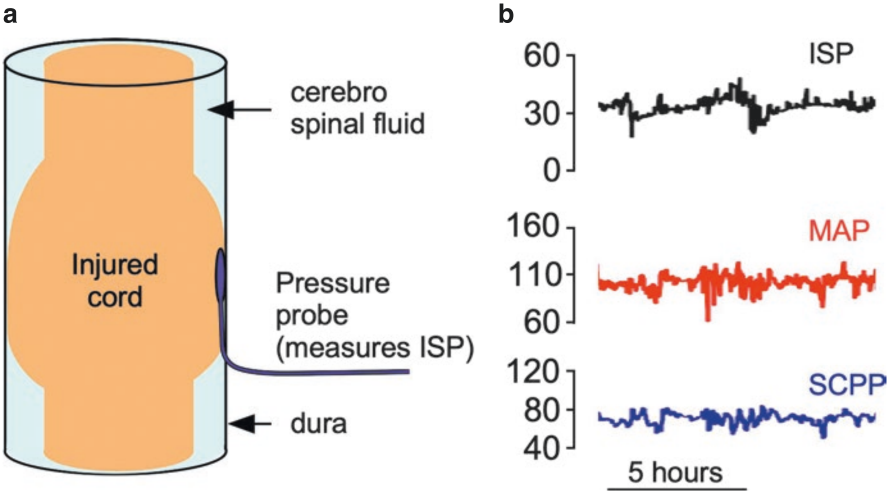

**Fig. 32.3** Monitoring from injury site after severe SCI. (**a**) Schematic showing position of pressure probe between dura and swollen cord. (**b**) Monitoring of ISP, MAP (mean arterial pressure from radial artery) and SCPP (computed as MAP minus ISP)

role of expansion duroplasty in acute, severe SCI. The concepts presented here of ISP, SCPP, sPRx, $SCPP_{opt}$ and duroplasty have been developed in adult patients with SCI. Whether these concepts also apply to children remains to be shown.

## 32.5 Cervical Radiology

Consultation with a specialist Paediatric Radiologist is vital when interpreting paediatric spinal imaging, because it is easy to confuse normal anatomical variants for pathology. It is beyond the scope of this chapter to provide a thorough review of this subject, but some key points to consider are listed:

1. Prevertebral soft tissue swelling may be a normal finding in a crying child or during flexion. Such x-rays are best repeated when the child settles [19].
2. Radiological measurements differ in children compared to adults, for example the atlanto-dental interval is >5 mm in children compared to >3 mm in adults.
3. Pseudo-subluxation (commonly C2 on C3) may be evident due to cervical spine elasticity. Such subluxation is usually <2 mm and the spino-laminar line is not disrupted [9].
4. Epiphyseal growth plates (synchondroses) may be misinterpreted for fractures – theses tend to be symmetrical, and it may be useful to compare images of a patient of a similar age.

## 32.6 Specific Cervical Spine Injuries

### 32.6.1 Atlanto Occipital Dislocations (AOD)

AODs (Fig. 32.2b) are rare and sustained through high velocity injuries such as road traffic accidents. They occur three times more commonly in children than adults due to the higher head-to-torso ratio amongst other anatomical differences [20]. Most (~80%) patients have neurological symptoms at presentation, often associated with severe brain damage. A missed diagnosis in such patients often results in high mortality and morbidity. Early stabilisation is required to prevent this. CT is the initial modality of choice in high velocity injuries to identify the bony injury, followed by MRI to identify ligamentous injury. Horn et al. used CT and MRI to stratify patients into two groups (Table 32.1) [21]. Grade 1 injuries may be trialled with a halo brace for 12 weeks followed by flexion-extension X-rays to confirm stability. If the halo brace is unsuccessful, then occipital cervical fusion is required. Grade 2 injuries have gross disruption of ligamentous structures thus necessitating occipital cervical fixation upfront [21].

### 32.6.2 Atlas and Axis Fractures

Jefferson fractures, caused by axial loading of the head on the lateral masses of the atlas, is rare in children. Unlike the anterior and posterior arch fracture seen in adults, children may just have a single break with a hinge on the synchondrosis [3]. CT may suggest injury to the transverse ligament if there is fracture at the insertion sites on the medial lateral masses. MRI is useful to determine the integrity of the transverse ligament. If the transverse ligament is torn, C1–2 fusion is necessary. More commonly, if the lateral mass is fractured and the transverse ligament disrupted, a halo brace achieves healing in 74% of injuries, negating the need for surgical fixation [22].

Odontoid fractures are relatively common, and usually not associated with neurological deficits. The developing C2 vertebra has five ossification centres and six synchondroses, which close by 13.5 years [3]. In young children odontoid fractures usually propagate through the dento-central synchondrosis and are classed as Salter Harris type I (Fig. 32.4). The dens is usually angulated posteriorly, evident on a lateral X-ray. It is important not to confuse the mild angulation of the dens for a dens

**Table 32.1** Atlanto axial dislocation according to Horn et al. [21]

| Grade | CT | MRI |
|---|---|---|
| Horn grade I | Normal | Moderately abnormal |
| Horn grade II | Abnormal | Grossly abnormal |

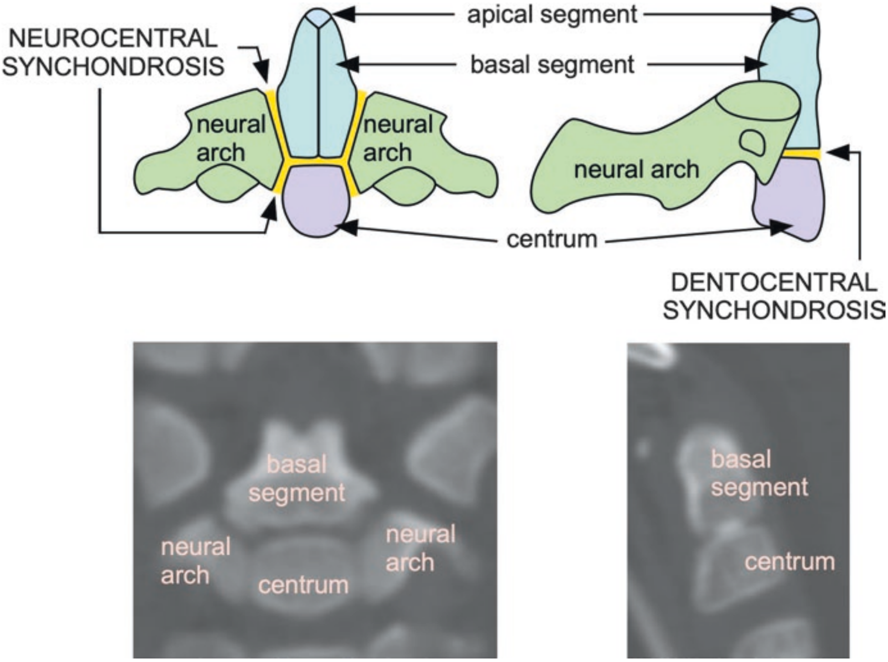

**Fig. 32.4** Development of the C2 vertebra. Schemtacics and CT of the synchondroses and ossification centres of the C2 vertebra

fracture; dynamic imaging may be required to evaluate stability [3]. Displaced odontoid fractures may be reduced without traction using mild extension and posterior translation and placed in a Minerva collar for 6–10 weeks. Dynamic X-rays will help confirm stability and union.

Once dens synchondroses have closed, odontoid fractures may be classified as per the Anderson and D'Alonzo classification. Type I and III fractures are generally stable and managed with external orthoses, as are minimally displaced (<5 mm) type II fractures. Type II fractures with more significant displacement may require surgical intervention either odontoid screw or atlanto-axial fusion.

### 32.6.3 Subaxial Fractures and Ligamentous Injuries

These injuries are more common in older children and have adult fracture morphologies. Beyond the age of 8 years, the subaxial spine is well developed and bears close resemblance to that of an adult spine [23]. Typical fractures include compression vertebral body fractures, facet fractures with subluxation/dislocation, and spinous process fractures. The management is generally similar to that of an adult. Younger patients with subaxial fractures, can be managed in a hard, cervical collar depending on the injury type, stability and presence of neurological deficit [23]. Although numerous calssification systems have been proposed to guide management of adult cervical fractures, none have been widely accepted or validated in the paediatric population. Nevertheless, the Subaxial Cervical Spine Injury Classification (SLIC) is a useful framework to manage these fractures [23].

## 32.7 Lumbar Spine Injuries

Knowledge of patient age and the various stages of development are crucial for accurate radiological diagnosis. Three ossification centres develop in each vertebra: the centrum plus right and left neural arches; these centres fuse between 2 and 6 years. There are five secondary ossification centres that fuse with the primary ossification centres in teenagers except the endplate ossification centres that fuse by the age of 25 years (Fig. 32.5) [5]. The spinal canal reaches near-adult volume by 6 years and the spine reaches near adult state by 10 years [1]. Due to a combination of ligamentous elasticity, shallow facet joint orientation, incomplete ossification and underdeveloped paravertebral musculature, the paediatric spine maintains its flexible state into early adolescence.

These normal developmental findings may be misinterpreted as pathological on imaging: the neurocentral synchondrosis can appear as a groove on either side of the vertebral body, and incomplete fusions of the endplates may be misconstrued as fractures [5]. Patients without injury may have anterior-to-posterior vertebral body height ratio as low as 0.89; this 'physiological wedging' of the vertebral bodies may be confused for compression fractures.

### *32.7.1 Compression Fractures*

These commonly occur at the thoracolumbar junction and are the most common fracture. Children are more susceptible to these types of fractures owing to the physiological wedging and kyphosis of their spine during maturation. Axial loading due to falls or sports injuries are commonly associated with this fracture. Higher energy injuries may cause multiple compression fractures and one should have a low threshold for investigating for intra-abdominal injuries [24]. Though most such fractures have <30% loss of vertebral height, loss of >50% vertebral height makes it likely that the posterior ligamental complex is disrupted. Most of these fractures may be managed in a thoraco-lumbo-sacral orthosis (TLSO) for 8 weeks with good outcome. Evidence of end plate damage and an associated kyphosis of >30%, even in the context of stable injuries, make progressive deformity likely [1, 5].

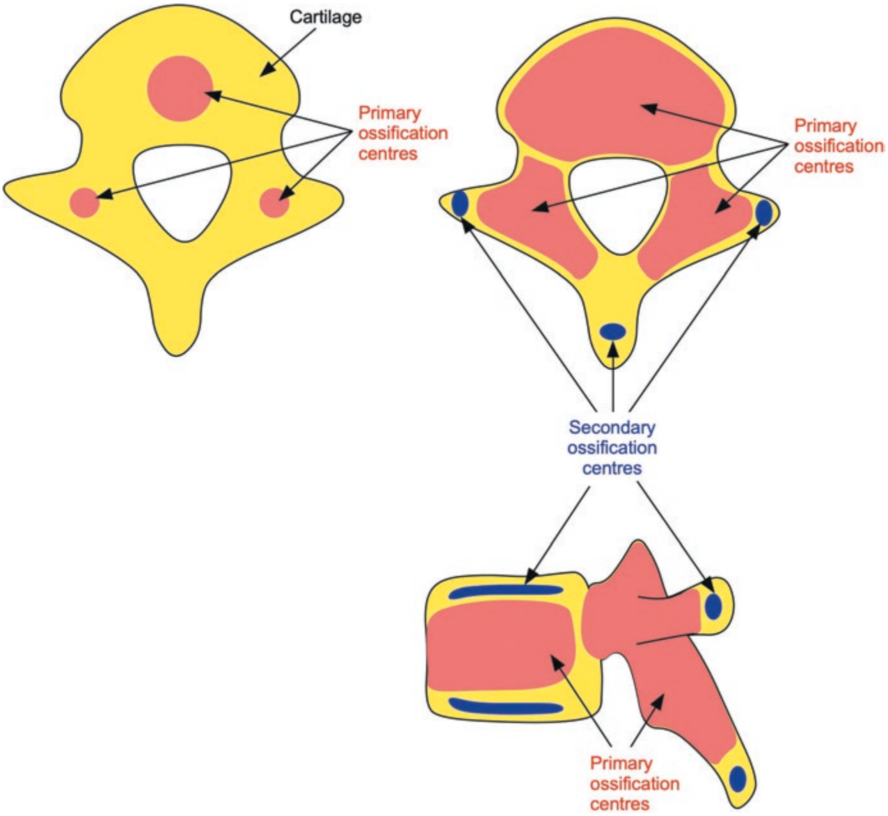

**Fig. 32.5** Ossification centres of a vertebra. Primary (red) and secondary (blue) centres. Three primary (centrum, right, left) and five secondary (tip of spinous process, tip of left and right transverse processes, upper and lower ring epiphyses) centres

### *32.7.2 Burst Fractures*

These fractures account for up to 20% of all vertebral body fractures and occur with axial loading without flexion. They are associated with higher energy injuries, are characterised by disruption of the posterior wall, and may be complete or incomplete. Retropulsed fragments into the spinal canal are commonly seen. Premature epiphyseal fusion may occur in younger children when the germinal layer is damaged [24]. CT is the usual initial imaging of choice then MRI to visualise neural structures and the posterior ligamental complex. Surgical management ranges from decompression with fixation to isolated fixation depending on the presence of neurological deficit and the degree of canal compromise. Whereas it is common to instrument two vertebral levels above and two below in adults, such fusions may lead to stunted truncal growth in children and crankshaft deformity, whereby the posterior spinal fusion causes progressive rotational and angular spinal deformity due to continued growth of the anterior elements.

### *32.7.3 Vertebral Apophysis Fracture*

The apophyseal ring ossifies by the age of 6 years and fuses by 18 years. It is attached to the annulus fibrosus. An osteo-cartilaginous portion lies between the vertebral body and apophyseal ring and is susceptible to repeated stresses. Patients classically describe a 'pop' at the time of injury with radicular leg pain, akin to disc herniation in adults [1, 5]. These distinct fractures are typically seen in adolescents and young adults from activities such as lifting heavy objects, falls or twisting injuries. CT may reveal a detached end plate fragment and MRI an associated disc herniation (Fig. 32.2c). If conservative measures are ineffective, surgical intervention such as microdiscectomy or posterior decompression often have good outcome [1, 5].

## 32.8 Spinal Orthoses and Surgical Considerations

In general, stable fractures are managed conservatively in a brace and unstable fractures require surgical stabilisation. In the absence of validated paediatric spinal trauma classification systems, the authors find it useful to use the frameworks used for adult spine to guide management.

Of the numerous braces available for thoracic and lumbar immobilisation, the authors have found that the TLSO brace is easily accessible (in the UK) and provides satisfactory outcome. For upper thoracic fractures, a Sterno-Occipito-Mandibular Immobiliser (SOMI) may be used in conjunction with a TLSO. Whatever the brace, interval review and imaging with X-rays provide a good safety net for patients whose fracture may progress. Typically, bracing therapy is applied for 10–12 weeks, but the duration depends on the type of injury and surgeon preference.

The decision to surgically intervene is determined by considering local fracture-related factors (need to decompress neural structures, stability of fracture, long-term healing potential) and systemic factors (haemodynamic status of patient, safety of general anaesthetic, need for haemodynamic management first). The authors find the Thoracolumbar Injury Classification and Severity (TLICS) score, which has been validated in children, a useful framework to guide management, but this needs to be placed in the context of the overall fitness of the patient and systemic injuries (Table 32.2) [23, 25]. Surgical stabilisation can generally be performed via posterior approach using adult-type instrumentation in children above 9 years of age. Younger children have smaller pedicles and smaller spinal canals which may make pedicle screw placement challenging; and sublaminar hooks unsafe. Computer navigation

**Table 32.2** Summary of the Thoracolumbar Injury Classification and Severity scoring system (TLICS) [1, 23]

| Feature | Score |
|---|---|
| Morphology | |
| Compression | 1 |
| Burst | 2 |
| Translation/rotation | 3 |
| Distraction | 4 |
| Neurology | |
| Intact | 0 |
| Nerve root | 2 |
| Cord (incomplete injury + 1) | 2 |
| Cauda equina | 3 |
| Posterior longitudinal ligament | |
| Intact | 0 |
| Indeterminate | 2 |
| Injured | 3 |
| **Recommended treatment** | |
| **Non-surgical** | **0–3** |
| **Surgeon’s choice** | **4** |
| **Surgical** | **>4** |

and robot assisted surgery may prove useful in such cases, though the latter is in the early stages of clinical practice [5].

## 32.9 Conclusions

The morphology of spinal fractures, their diagnosis and their management substantially differ in children compard with adults. In this chapter we highlighted several key differences to enable the treating clinician to make a common-sense approach to such injuries.

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