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REVIEW ARTICLE

Spinal clearance in unconscious children following traumatic brain injury

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Summary

Spinal clearance in unconscious children following traumatic brain injury is an area of controversy. The risk of significant injury in this high-risk group needs to be balanced against that of prolonged spinal immobilization and all its implications. No national or international guideline exists to aid clinicians faced with such a scenario. This article reviews traumatic spinal injury in children looking at prevalence, risk factors, anatomical considerations, and radiological investigation. Spinal immobilization is discussed along with the use of appropriate and targeted radiological investigations to aid clearance.

Introduction

Spinal injury in children is a rare event (1–3). Following trauma, children sustaining a spinal injury especially at the cervical level are likely to have an associated head injury (4,5). Much has been written on spinal clearance in conscious children (2). The issue of spinal clearance in unconscious children however remains controversial. The huge implications of missing a clinically significant injury must be balanced against the potential for morbidity and mortality with prolonged spinal immobilization. Clinical examination is unreliable adding emphasis to mechanism of injury and the utilization of appropriate radiological examinations. All units caring for children following severe traumatic head injury face this clinical dilemma. No international guideline exists on how best to manage this situation. Moreover, a recent UK-based study pointed up a lack of consensus among pediatric intensive care units in the United Kingdom and Ireland when tasked with such a clinical scenario (6). This clinical review aims to explore these issues and inform clinicians looking after critically injured children.

Prevalence

The risk of spinal injury following trauma in children is low. Injury at the cervical level accounts for only 1–2% of all trauma (7). Due to anatomical factors, risk of injury at the thoracolumbar levels is even lower. Coexisting head trauma has traditionally been highlighted as a risk factor for cervical spine injury (CSI) (4,5). With decreasing age, this association becomes less significant. CSI is extremely rare following mild or moderate impact head trauma (8). Out of any population, it is those children, unconscious and ventilated in PICU who may be at highest risk of having sustained a serious injury to their spinal column. Figures from the Pediatric Intensive Care Network (PICANet, personal communication, 1st Dec 2010) show that between May 2008 and November 2010 out of 47 862 children admitted to 27 PICUs in the United Kingdom and Ireland, 1127 (1% incidence rate) had a primary diagnosis of traumatic brain injury. Of note 911 (0.8% incidence rate) of these children had a period of sedation and ventilation. Ninety-five (0.08% incidence rate) subsequently died from their injuries. It is appreciated that such a scenario, an unconscious child with a traumatic brain injury (TBI) in which spinal precautions remain *in situ* is extremely rare. Depending on the size of the PICU clinicians can only expect one or two cases per year.

Injury patterns

When assessing the potential for spinal injury in children following trauma, mechanism is paramount. Isolated

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major head trauma raises the index of suspicion of injury to the cervical spine. Injury may occur in up to 9% of those with traumatic brain injury (5). The majority of spinal injuries occur at the cervical spine level (3,9). NICE guidelines describe dangerous mechanisms risking the cervical spine as falls from height greater than one meter or five stairs, axial load to the head, high-speed motor vehicle collisions, rollover motor accidents, ejection from a motor vehicle, accidents involving motorized recreational vehicles and bicycle collisions (10). Major polytrauma, including chest, abdomen, or pelvis, also puts the entirety of the axial skeleton at risk of injury.

It must be appreciated that the anatomical and biomechanical characteristics of the spine, especially the cervical spine, markedly change over the course of time in a child. This in turn leads to certain patterns of injury depending on age. Children less than 8 years of age have a propensity for high cervical injuries. Those 12 years and above have injury patterns similar to adults with low cervical injury more common (3,4). The period between eight and 12 years of age is often described as the transitional period (2,4,11). Clinicians should not assume specific injury patterns in this age group. Rather they must be alert to the potential for cervical injury at any level while always taking into account the mechanism.

Primary mechanism of injury also differs depending on the age of the child. In younger children, it is motor vehicle crashes that tend to prevail. Nonaccidental injury has been highlighted as an important cause in infants (8). Older children especially those in the early teen years tend to sustain injury due to sporting activities (12).

Thoracolumbar injuries (osseous, soft tissue, and cord) are very rare in children (13). Excluding soft tissue and cord injury, however, incidence of fractures involving the thoracic spine may be as common as cervical fractures (14,15). Common injury patterns include compression, burst-type injury, flexion-distraction and fracture dislocation. It is recognized that information pertaining to injury patterns of the thoracolumbar vertebral column and spinal cord are lacking in current literature (16).

The 6% rate of noncontiguous second spinal fracture in children is similar to adults (17). The implications of this are huge potentially strengthening the case of those advocating imaging the entire spinal column in major traumatic head injured children. As stated previously, the optimum imaging modalities both to pick up a clinically significant injury and to aid in potentially clearing the spine in this scenario are unknown.

SCIWORA

Spinal cord injury without radiological abnormality (SCIWORA) was an acronym coined by Pang and Wilberger in 1982 describing an acute spinal cord injury that results in sensory and/or motor deficits without radiographic evidence of vertebral fractures or bony misalignment on plain radiographs or CT (18). SCIWORA, although overall extremely rare as an entity, appears to be more prevalent in children than adults (19). Various studies have reported the incidence anywhere as high as 35% in children with spinal injuries (20,21). The incidence of SCIWORA in adults is unknown though small studies report incidence levels around 10–15% of all spinal injuries (22,23). The average age of children sustaining SCIWORA is 7–8 years (24). Up to 75% of SCIWORA occurs at the cervical level due to increased mobility and malleability of the osseous, cartilaginous, and ligamentous components in childhood. A time lag in demonstrable clinical onset of SCIWORA has been reported in conscious children (25). This may be due to evolving edema and inflammation of the cord. Such a finding could have implications for the optimum timing of MRI in the patient group under discussion.

The small but increased risk of SCIWORA in children following serious traumatic brain injury is one of the main reasons that spinal clearance cannot be achieved in the same manner as adults. One practice in adults with prolonged periods of unconsciousness is to remove all spinal precautions if absence of injury is demonstrated on CT scanning (26,27). This approach has been recently called into question (28). The risk of missing an injury, especially one that is clinically significant or unstable, is felt to be outweighed by the potential for morbidity and even mortality of prolonged inappropriate immobilization (27).

Anatomic considerations

The developing pediatric spine demonstrates numerous anatomical and biomechanical differences in comparison with the adult spine. Those physicians tasked with diagnosing injuries and clearing the pediatric spine should understand these differences. The pediatric spine is more malleable compared with the adult. It will tolerate loading and deformity thus increasing the risk of spinal cord injury while reducing the risk of fracture hence increased SCIWORA cases in children. This malleability is the result of facet joints being more horizontal than that of the adult spine, relative ligamentous laxity, incomplete ossification of the vertebral bodies, and incomplete development of the spinous processes

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(11). The increased incidence of CSI in children is due to the above anatomic factors coupled with the relative increased mass/volume ratio of the infant head.

Thoracolumbar injuries although rare can be extremely serious. The elasticity of the neural elements and the intervertebral disks act to transmit forces like a wave through multiple levels resulting in multi-level injury in children.

Pediatric spinal clearance

Traditionally, spinal clearance in conscious children has been based on history and examination with the aid of plain x-rays if deemed necessary. The subsequent introduction of the NEXUS guideline and its validation in children has rationalized imaging of the cervical spine as well as permitting clearance in those considered low risk (2). No such rule exists for the thoracolumbar spine and diagnosis and clearance are still based around the original pillars of history, mechanism of injury, clinical examination and targeted imaging if necessary. The unconscious, ventilated child in intensive care is more challenging. While less if any significance can be placed on clinical examination, much more will be attached to mechanism of injury and radiological examination.

Risks of immobilization

Advanced Trauma Life Support teaching instructs that an appropriate immobilization device should be instituted during the primary survey and left in place until spinal injury has been excluded (19). Diagnosis and clearance of spinal injury becomes a priority only when reversible life threatening injuries have been dealt with. Until then, patients are nursed supine on an appropriate mattress with semi-rigid collar, lateral restraints, and tape. Other instruction manuals recognize that immobilization in small children is not quite so straightforward (29). Strong emphasis, rather, is placed on manual immobilization and the issue of rigid collars and their limitations in small children in recognized. The clinical effectiveness of spinal immobilization in children following trauma is beyond the scope of this article; however, it is clear that controversy does exist (30–32).

Following major traumatic head injury spinal immobilization is logical if the patient is able to be examined clinically in a timely fashion and an informed decision taken in conjunction with appropriately targeted radiological investigations. Unfortunately, in the case of children with severe head injury who are sedated, intubated and ventilated such an approach will not work. To persevere with the attitude that clearance can only be permitted if examination is normal, an approach adopted by many clinicians despite normal radiological investigations puts the pediatric patient at a number of risks.

Pressure ulceration from immobilization in semi-rigid collars is well described in the literature (33,34). The exact risk is unknown and is likely to vary in different populations. Studies quote incidences between 7% and 24% of immobilized patients (34,35). After 48–72 h, the risk increases significantly (36). In the setting of trauma, peripheral circulation and nutrition may be compromised, further increasing the risk of ulceration and infection. Softer collars such as the Aspen or Philadelphia although designed to reduce, do not completely negate this risk. Everyday spent adhering to full spinal precautions in this set of patients, in the absence of definitive diagnosis or clearance, essentially means deeper levels of sedation, increased likelihood of muscle relaxation, increased staff numbers for patient interventions, restricted physiotherapy regimes, increased tendency to intracranial hypertension (37,38), gastrostasis, reflux and aspiration (39), and increased complexity with regards to intubation and central venous access.

The application of current guidelines

No international standard currently exists to aid clinicians when faced with this specific patient scenario. Within guidance from specialist bodies, there are some recommendations that have much relevance to this situation; however, none is written with the aim of answering this specific dilemma.

The National Confidential Enquiry into Perioperative Death (NCEPOD) recommends in their 2007 report Trauma: Who cares?, routine top to toe CT scanning for patients following major trauma if no indication for immediate intervention exists (40). The 2014 NICE guidance on head injury management provides much information pertaining to imaging of the cervical spine in children following head trauma (10). Specifically they advocate CT imaging of the cervical spine in children <10 years of age with a Glasgow Coma Scale of 8 or less within one hour of presentation if sufficiently stable. NICE recognizes the risks of irradiating the cervical spine in children, especially to the thyroid gland and only endorses this investigation for those children felt to be at the highest risk of having sustained an injury. This approach of only imaging those at highest risk is mirrored in the 2009 SIGN guideline on management of head injury (41).

The Royal College of Radiologists although not advocating MRI in any particular clinical scenario, do highlight that major trauma centers must have it available 24 h a day 7 days a week. They also highlight that

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in the setting of acute trauma and initial management, MRI is not the investigation of choice and would not be indicated.

Radiology

The traditional approach to imaging the spine following trauma involved plain AP and lateral radiographs, and in the case of the cervical spine, an odontoid peg view if the patient was deemed compliant. Similarly, mechanism of injury and clinical examination remained of prime importance. Follow-up CT scanning would be performed if an abnormality was demonstrated on plain film or clinical symptoms dictated further investigation. Such an approach recognized the increased cancer risk of CT scanning thus forcing clinicians to critically appraise each individual case and justify their investigations.

A plain film-based approach to cervical spine trauma was based on the knowledge that the negative predictive value for a three-view series with adequate films was between 93–98% (10). It is now known that in high-risk populations, the sensitivity of standard three-view x-rays only lies between 62–84% and in those who have sustained major trauma, specificity decreases to between 79–89% (10). It is recognized that in the setting of acute trauma, odontoid views in children younger than 5 years of age may not be helpful (42). Plain films of the odontoid peg are also notoriously difficult to carry out and interpret in children who are intubated.

CT scanning has a sensitivity that approaches 100% for bony injury to the spine (10). With the 'full body scan' approach advocated by NCEPOD in this patient group, it is relatively straightforward with modern scanning technology to reconstruct sagittal and coronal views of the axial skeleton as well as generate superb three-dimensional images.

In the adult population, this is extremely useful and lends itself to both diagnosing and clearing the spine (26). In children, however, with increased rates of soft tissue and cord injury, CT alone will not safely achieve either of these endpoints (18). CT scanning only provides the clinician with some of the information needed to make an informed decision. The evidence continues to mount for spinal MRI as both a diagnostic aid and a tool to guide spinal clearance in this specific group of patients (43–47). Protocols incorporating MRI to aid spinal clearance have been shown to have financial benefits for institutions (48).

The superiority of MRI in picking up even the smallest of soft tissue injuries is often cited as its achilles heel in the management of this patient group. How much significance to place on specific findings is often a point of debate (49). The role of MRI scanning in determining stability of the axial skeleton has also been called into question (50).

The optimum time frame to carry out a spinal MRI following trauma is unknown. Clinical stability and the risk of transferring a critically injured child for this investigation need to be weighed up against the need to achieve diagnosis or clearance. Some evidence exists that MRI detects a higher proportion of soft tissue injuries when performed within 48 h (51,52). Spinal precautions beyond 72 h lead to increased risk of morbidity (36).

A normal MRI scan, however, coupled with a normal CT of the axial skeleton in this group of children gives the clinician much to ponder. The potential for lasting and severe brain injury or even the age of the child may reduce the emphasis that can be placed on the clinical examination. The sensitivity of these modalities in diagnosing bony and soft tissue injuries respectively must surely give the physician caring for the child much license to make an informed decision weighing up the risks and benefits of continued spinal immobilization. A normal CT scan with an abnormality on MRI however must be discussed by all specialties caring for the child. Interpretation and further management should be multidisciplinary irrespective of the decision be that to remain with full spinal precautions or to clear.

Conclusion

The resuscitation and management of the critically injured child is extremely challenging. Good outcomes depend on multiple factors. When faced with unfamiliar clinical scenarios, the ability to make sound judgments lies in the ability to access relevant evidence-based guidance. No international guidance exists to aid clinicians tasked with spinal clearance in unconscious ventilated children following TBI. A recent survey of PICU departments in Great Britain and Ireland revealed huge variation in how these patients are managed (6). No consensus exists with respect to minimal imaging required to achieve clearance, maximum time frame in which clearance should be achieved if possible, seniority of clinician permitted to make the decision to clear the spine or speciality managing this clinical problem.

Pediatric spinal clearance is complex. Biomechanical differences in the immature and developing spine along with different patterns of injury negate the use of adult spinal clearance protocols in children. These group of children are in the highest risk category for having sustained some form of spinal injury. Clinicians must target radiological investigations to minimize risk of missing

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an injury as well as ensuring that spinal immobilization is not prolonged.

Spinal injury following traumatic brain injury although rare does occur often enough that most clinicians can expect to see one or two cases a year. A deficit definitely exists in the current literature describing best practice and opinion in this particularly challenging area. Part of the reason may be that the different specialities caring for this patient group each have differing agendas and priorities when it comes to informing decisions. Future research should be prospective and multicenter addressing the issues of feasibility and practicality of combining CT and MRI to diagnose clinically significant injuries as well as permit timely clearance in this high-risk group.

Spinal clearance in children following TBI must be multidisciplinary and consultant led. Processes should be laid down in units caring for these children to ensure that investigations are carried out in a timely manner. Radiological investigations must be interpreted by those with relevant experience and competence in doing so. With no current consensus, it is up to individual institutions to choose appropriate investigations to ensure that occult injuries are not missed as well as ensuring timely clearance.

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Conflict of interest

No conflicts of interest declared.

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