Pediatric Hangman's Fracture: A Comprehensive Review

Michael Montalbano^{a, c} Christian Fisahn^{b, c} Marios Loukas^a Rod J. Oskouian^b
Jens R. Chapman^b R. Shane Tubbs^c

^aDepartment of Anatomical Sciences, St. George's University, St. George's, Grenada; ^bSwedish Neuroscience Institute, Swedish Medical Center, and ^cSeattle Science Foundation, Seattle, WA, USA

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Abstract

Purpose: Over 170 years ago, traumatic spondylolisthesis of the axis or hangman's fracture was described. Most descriptions of this entity have focused on adult presentations. **Methods:** We review the literature on pediatric cases of hangman's fracture emphasizing the embryological as well as presentation aspects. **Results:** The majority of cervical spine fractures in children occur at C₁ and C₂ vertebrae. A normal anterolisthesis of C₂ can be seen in younger children and can mimic the anterolisthesis seen after traumatic spondylolisthesis. **Conclusions:** Traumatic spondylolisthesis of the axis in children requires further investigation due to the current emphasis in the literature on adult clinical findings and diagnostic challenges from the developmental immaturity of the pediatric skeleton.

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Introduction

Hangman's fracture, or traumatic spondylolisthesis of the axis (Fig. 1), was first described by Bouvier in 1843 [1], later correlated with judicial hangings by Wood-Jones in 1913 [2], and was given its epithet by Schneider et al. in 1965 [3]. These authors described the lesion as an avulsion of the neural arch of C₂ along the stress points of the weakest elements, i.e. the pars interarticularis, and concomitant anterolisthesis of the vertebral body of C₂, usually sparing the odontoid process [4–6].

In 1985, Levine and Edwards [7] crafted a classification system, modified from a system defined by Effendi et al. [8] years previously, to include multiple types of mechanisms of injury. Under this system, a type I fracture involves anterior displacement of the body of C₂ less than 3.5 mm, a type II (Fig. 2, 3) fracture requires anterolisthesis greater than 3.5 mm as well as angulation of greater than 11° between C₂ and C₃, and a type III fracture is characterized by a fixed displacement and angulation with locked facet joints [9, 10]. There are also variations in the presentations of a type IIA fracture, which is defined by significant angulation, i.e. greater than 11°, but with less

Fig. 1. Axial CT image noting bilateral pars interarticularis fractures in a 12-year-old restrained male passenger where the vehicle was struck from behind by another car. The child was neurologically intact on examination but complained of neck pain and headache. No other injuries were identified on imaging. Surgical treatment was performed using sublaminar wires.

Fig. 2. 15-year-old girl who fell from a trampoline and presented with neck tenderness. Radiographs were equivocal. CT of the spine noted a type II displaced C₂ (arrow). Pedicle screws were placed and at the 1-year follow-up, the patient is well with no neurological signs or complaints of neck pain.

Fig. 3. Same patient (15-year-old girl who fell from a trampoline and presented with neck tenderness) from Figure 2 but lateral bony anatomy illustrating the one side of the Hangman's fracture (arrow).

than 3.5 mm displacement due to an intact anterior longitudinal membrane, as well as the atypical spondylolysis of the axis characterized by a fracture of the C₂ body's posterior wall instead of the neural arch [1, 11].

Mechanism

The mechanism behind a hangman's fracture is, in accordance with the positioning of the submental rope knot during a hanging, hyperextension at the craniocervical junction with the subsequent downward force distributed across the vertebral body and articular processes resulting

in fracture of the weakest part, i.e., the neural arch [5]. These points of weakness correspond to areas of synchondroses before ossification is completed. At birth, there are 6 ossification centers in the C₂ vertebra separated by 4 synchondroses (Fig. 4). The ossification centers fuse on average between the age of 3 and 6 years, most epiphyseal plates are fused by 8 years, and the synchondroses close at varying times between the ages of 3 and 14 years. Before fusion, radiolucent synchondroses may resemble fractures on radiographs; therefore, the age of the patient at the time of injury plays an important role in the mechanism of injury and warrants the clinician's attention [12–14].

Fig. 4. Schematic drawing of the synchondroses of the C₂ vertebra.

Pediatric Prevalence

Traumatic spondylolisthesis of the axis is the second most frequent fracture of C₂ in adults, after odontoid fracture [15]. The fracture comprises 4% of all adult cervical fractures, and over 22% of all axis fractures in adults [4, 12]. It is rare in the pediatric population, where only 1–4% of all spinal injuries occur, and only 1.5% of all pediatric trauma results in cervical spine injury [12, 13]. For adults, cervical spine injuries constitute 30–40% of all vertebral injuries, whereas in pediatric cases 60–80% of vertebral injuries involve the cervical spine [14]. An analysis by Kokoska et al. [14] of 408 children over a 5-year period showed that most injuries ($n = 284$, 69.9%) occurred between the C₁ and C₄ vertebrae, with fracture being the most common type of injury ($n = 228$, 55.9%).

The pediatric population can be further subdivided with a bimodal peak for cervical spine injuries around the age of 5 years and either from 13 to 15 or 15 to 24 years of age [16, 17]. Younger children, defined as 10 years old or younger, are more likely to suffer from dislocations of the upper cervical spine and spinal cord injury without radiographic abnormality. Children older than 10 years are more likely to have cervical spine fracture after trauma. One paper found that 80% of fractures in children under 8 years old involved C_{1–2} vertebrae. The distribution corresponds appropriately with the existing medical literature, which suggests transition from an immature pediatric to a mature adult pattern of cervical spine injury at either 8–9 years old or as late as 15 years old, which correlates with the age of final synchondrosis closure as given above [14, 18].

Developmental patterns can partly explain the differential prevalence of spinal injuries in children compared to adults. Articular facets in children and infants are more horizontally oriented until they ossify and become more vertical between the ages of 7 and 10 years [13, 14]. This horizontal orientation, along with lax ligaments and underdeveloped cervical musculature in comparison to the adult population, provides more mobility, as does the greater elasticity provided by the interspinous ligaments, cartilaginous end plants, and joint capsules until their closure between 3 and 6 years of age [14, 18]. This mobility may justify a tendency toward anterolisthesis as well as the greater rate of dislocations, rather than fractures, found in younger children [19]. Younger children also have a higher center of gravity due to a relatively larger head mass that provides a higher pivot for cervical movement around C_{2–3}, compared to the pivot of motion for adolescents and adults around C_{5–6} [14, 20]. This higher pivot point may explain the lessened occurrence of lower cervical spine injuries as well as higher incidence of upper cervical lesions in children [19].

Besides developmental characteristics, there are also exogenous factors to consider. There is a 1.6-to-1 ratio disparity between male and female children as they near adolescence, possibly due to a differential participation rate in sports and subsequent related cervical spine injuries [16]. While older children are more likely to be injured from sports, and younger children are more likely to be injured from falls, motor vehicle accident trauma remains the principal mechanism of injury in both populations [18]. In light of this fact, it is imperative that seat belts be properly fastened in an age-appropriate manner. If improperly fastened, the passenger may “submarine” under the safety belt and sustain cervical injury secondary to torso flexion concurrent with deceleration [13]. Unfortunately, it has been found that proper fastening of restraints was applied to only 76% of infants, 41% of toddlers, and 13% of adolescents [14, 16].

Diagnosis and Differential Diagnoses

Diagnosing traumatic spondylolisthesis of the axis should be focused on the extent of fracture, resulting stability, and type of surgical approach if the fracture is unstable [11]. A proper neck examination is essential in a patient with suspected trauma to the cervical spine. In pediatric patients, a negative predictive value has been found to be 100% when a neck examination was negative along with negative findings for cervical pain, altered lev-

Fig. 5. Three-dimensional CT of teenage boy status posttraumatic spondylolisthesis of the axis: right side fracture seen between arrows. Conservative treatment was used to treat this fracture via a hard cervical collar for 2 months and at the 2-year follow-up, there were no neurological deficits or complaints from the patient, and the fracture was well healed on repeat imaging.

Fig. 6. Patient from Figure 5 with left-sided fracture site seen at arrow tip.

el of consciousness, involvement in motor vehicle accident, and closed head injury. Caution should be taken by the clinician in ruling out symptoms of pain in children under 3 years old as preverbal children may not properly express a clear symptomatology to the clinician [21]. Case-control analysis has shown 8 factors to be highly predictive of pediatric cervical spine injury following trauma, which includes: altered mental status, focal neurological deficits, neck pain, torticollis, injury to torso, predisposing condition, high risk motor vehicle accident, diving. Application of these results is estimated to be 98% sensitive while also reducing exposure to ionizing radiation in children by 25% [22].

Imaging that may be warranted includes CT to search for small bone fragments at the edge of the vertebral body indicative of ligament avulsion, or CT angiography if there is reason to suspect involvement of the vertebral artery or transverse foramen. However, it is important to be aware of radiological findings that can differentiate cases of unappreciated congenital disorders in pediatric patients. For example, in primary C₂ spondylosis, there may be sclerotic margins or calcifications, dysplastic facets, symmetric configuration of a pars articularis defect, or ossification centers within the pars defect. A callus formation on additional imaging or prevertebral hematoma would be more sugges-

tive of a traumatic spondylolisthesis (Fig. 5, 6) [6, 11]. Another finding that may present as a radiological discrepancy is pseudosubluxation. This can present with anterolisthesis of C₂ of more than 3 mm and may be a normal variant present in up to 24% of children under the age of 8 [6]. Differentiation between this condition and the anterolisthesis of hangman's fracture can be established by measuring angulation via lines drawn perpendicularly to the inferior end plate of C₂ and C₃ [23]. Alternatively, a line starting from the anterior spinous tip of C₁₋₃ that avoids the anterior cortex of the spinous process more than 1.5 mm should make the clinician suspect fracture [6].

Treatment and Prognosis

As the indications surrounding stability and justification of interventions should be comparable across both pediatric and adult populations, data are necessarily drawn from adult studies. Precaution should be taken in drawing too close a comparison to outcomes for pediatric patients due to the limitations that can be placed on growth as the result of cervical arthrodesis or physical sequelae that can develop in a child that has not yet fully developed [24].

The type of treatment recommended and associated prognosis are dependent on the type of injury sustained. In adults, type I and II stable injuries can be treated conservatively, while type IIA and III unstable fractures require surgical intervention, and indications for treatment are similar in the pediatric population. Stability is regarded as the degree of discoligamentous injury present at C₂₋₃. Conservative treatment requires semirigid immobilization for 6–12 weeks. For unstable fractures, surgical fusion of the C₂₋₃ vertebrae is usually recommended in adults due to a pseudoarthrosis rate of up to 50% with conservative orthosis alone; however, cervical arthrodesis requires further consideration in pediatric patients as the procedure could limit the growth potential or lead to secondary deformities [11, 24].

For adults, surgical intervention can be performed either through anterior or posterior fixation with posterior fixation showing biomechanical superiority, but also reduced range of motion and higher rate of dorsal pain [9, 10]. Rigid instrumentation is admissible in children over 10 years old, and sublaminar wiring can be used in patients over 3 years of age. Sublaminar wiring is preferred to more stable peduncular screws to avoid impinging on the vertebral artery or vertebral canal in cases of diminutive anatomy [24].

Prognosis following operations, in adults, leads to a high rate of pain-free patients with expectations of regaining the full range of motion in the same time period, although there is the possibility of neurological deficit. Studies have found that overall mortality and prognosis are significantly reduced in a correlation with decreasing age; however, such findings have still been limited to

adult populations [20]. Exceptions to this trend would include pediatric cases with comorbid fusion difficulties, such as os odontoideum [7]. Hangman's fracture rarely leads to spinal cord injury because the canal widens rather than narrows. However, in atypical hangman's fracture, the C₂ body may instead undergo posterolisthesis, which increases the risk of neurological damage [1, 11, 17].

Conclusion

Traumatic spondylolisthesis of the axis is a failure of the pars interarticularis to maintain structural integrity with concurrent anterolisthesis of the vertebral body. The fracture is classified by accounting for both the displacement of the body of the axis and the angulation between C₂ and C₃. Evaluation should consist of a proper neck examination with imaging if deemed appropriate, with attention paid to differential diagnostic mimicry. After evaluation, stable or unstable fractures should be treated conservatively or with surgical fixation, respectively.

Statement of Ethics

This paper is in compliance with ethical standards.

Disclosure Statement

The authors have no conflicts of interest.

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