Systematic Review

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Odontoid fractures in the pediatric population: a systematic review and management algorithm

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Abstract

Purpose: The management of odontoid fractures in adult patients has been widely described. However, there is sparse literature about this injury in the pediatric population. This study aimed to review published literature regarding the management and outcomes of pediatric odontoid fractures to develop a stepwise treatment algorithm.

Methods: A literature review was conducted using PRISMA guidelines on PubMed to identify studies between 1960 and 2023 that reported on the management and outcomes of odontoid fracture in pediatric patients. Studies were included if they were published in English and if their sample included at least four patients aged 0–18, minimum follow-up of 6 weeks, and outcomes for each patient clearly differentiated.

Results: In total, 15 studies including 125 pediatric patients with odontoid fractures were included. Treatment options varied from non-operative management with immobilization in rigid collars, halo vests, cervicothoracic orthosis, or soft collars to surgical management with fixation and/or arthrodesis. There were 73 patients initially treated nonoperatively, 47 initially treated surgically, 2 who healed with observation alone, and 3 who died acutely of concomitant injuries. The nonunion rate for nonoperative management was 5.5%. Surgery was successful, demonstrating bony union at final follow-up, in 94.6% of cases treated via a posterior approach and 85.7% of cases treated with an anterior approach.

Conclusions: Odontoid fractures must be considered in pediatric patients with cervical spine trauma. This is the largest literature review of pediatric odontoid fractures. Various management strategies exist and can be considered. The proposed algorithm offers an evidence-based framework for the management of pediatric odontoid fractures.

Keywords: Odontoid, pediatric, cervical spine trauma

Introduction

The odontoid process, or dens, refers to the projection of the second cervical vertebra which articulates with the anterior arch of the first cervical vertebra. Fractures of the odontoid process account for 15%–20% of all adult cervical spine fractures and are common in geriatric patients.[1–3] The mechanism of injury is usually a fall or motor vehicle accident, causing hyperextension of the upper cervical spine. These injuries can have serious sequelae for craniocervical stability and neurologic function.[4]

Anderson and D'Alonzo described odontoid fractures in 1974 with a novel classification system that is still used today.[5] Type I involves the upper part of the odontoid process; type II occurs at the base of the odontoid; and type III extends through the C2 vertebral body and into the lateral masses. In adults, type II is the most common, occurring in over half of cases, followed by type III, and then rarely type I.[3–6]

This classification system is not entirely applicable to children. The pediatric axis is divided by ossification centers, which have been previously described.[7–9] The base has one anterior ossification center and paired neural arch

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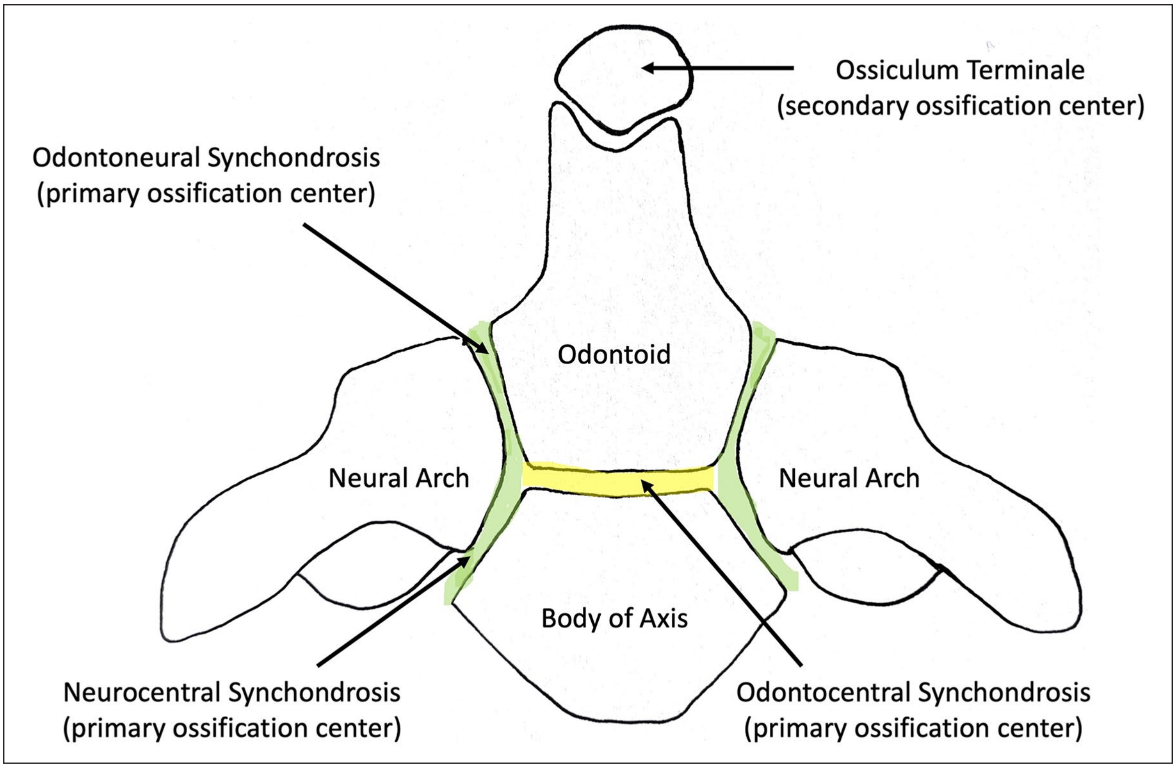

Figure 1. Odontoid ossification centers.

ossification centers that develop into the posterior elements.[7] The dens is formed from a separate primary ossification center, separated from the body by the odontocentral synchondrosis and from the neural arches by the odontoneural synchondroses.[8] The neural arches are separated from the body by the neurocentral synchondroses. A secondary ossification center called the ossiculum terminale occurs at the tip of the dens.[7,8] These ossification centers close around 7–8 years old[7,8] (Figure 1). Until these ossification centers are fully fused, they remain a weakened area vulnerable to traumatic injury.

Though spine injuries are more common in adults than in children, pediatric spine injuries occur more in the cervical spine than in other regions.[4,10–13] Furthermore, the frequency of cervical spine injuries in children is inversely related to age.[14] Contributors to pediatric cervical spine susceptibility include larger cranial size compared to the body, relatively weaker cervical muscles, and greater laxity in cervical spinous ligaments.[12] Dens fractures are just one of the cervical spine injuries that pediatric patients are predisposed to, and they most often occur through the synchondrosis cartilage between the odontoid and the axis body before 8 years old.[14–16] This fracture is similar to a type II fracture in adults, though the latter is an actual bony fracture. Once this synchondrosis is fused, dens fracture classification in older children and adolescents follows the Anderson and D'Alonzo criteria for skeletally mature adults.[5,16]

Many options exist for managing odontoid fractures in the adult population. These include conservative methods—such as a cervical collar, cervicothoracic orthosis, or halo vest, as well as surgical techniques, which have further variety in regard to the approach and hardware used.[17,18] Each method has advantages and disadvantages depending on the age and presentation of the patient, severity and degree of fracture, radiographic findings, and presence or absence of neurologic symptoms. Compared to adults, there is a dearth of evidence-based treatment guidelines for odontoid fractures in the pediatric population. Most relevant literature consists of retrospective reviews of adults, particularly geriatric patients. The limited pediatric studies are largely case reports or case series with three or fewer patients. For this reason, the specific incidence of dens fractures in the pediatric population is not reliably reported. Despite this, the pediatric odontoid is highly susceptible to injury, and the lack of consensus in management techniques can lead to variability in patient outcomes.

The purpose of this study was to review the literature on treatment methods for odontoid fracture in the pediatric population. Fassett et al.[19] conducted a similar review in 2006 describing a total of 52 pediatric patients treated for odontoid fractures. The goals for this review were multifold: (1) to continue this work by increasing the sample size and incorporating additional data from the last 17 years and (2) to compare outcomes associated with various treatments to design a step-by-step treatment algorithm to guide management.

Methods

Data collection

A literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[20] A search of MEDLINE (PubMed, Bethesda, MD) was conducted between November 12 and November 20, 2023. The search strategy utilized the following phrase: (pediatric OR child OR adolescent) AND (odontoid OR dens OR axis) AND fracture. Studies between 1960 and 2023 were screened. No additional filters, including article type, were used to further narrow the results.

All studies retrieved via the search process described above were screened and data were extracted when applicable by a single researcher. Inclusion criteria of at least four pediatric patients aged 0–18 with an odontoid fracture, treatment and outcome of each patient clearly described, and minimum 6-week follow-up had to be met. Exclusion criteria included exclusively adult population, mixed pediatric and adult population without outcomes distinguished by patients' age, pediatric sample size <4 patients, and non-English language.

Data extraction

Sixteen studies met the criteria for review. The full texts of these articles were analyzed. Data extracted included the following: title and author information, year of publication, number of odontoid fractures treated in the study, demographic information of the patients, clinical presentation, diagnostics and imaging, treatment (operative or non-operative), length of follow-up, outcomes, and complications. An outcome was considered successful if there was evidence of bony union without mortality or significant neurologic dysfunction limiting the quality of life at the end of follow-up.

Results

Included literature

The original search yielded 1321 studies that required screening. In all, 299 studies were excluded for non-English language. An initial screen of titles for relevance left 105 studies that met the criteria for an in-depth review of abstracts and/or full text for inclusion/exclusion criteria. In total, 16 studies were ultimately qualified. One of these studies, Fassett et al.,[19] was a literature review which included 5 other studies in the 16 eligible studies.[5,21–24] For this reason, Fassett et al.'s review was excluded, and the 5 sub-studies were individually included to avoid duplication of data. Fifteen studies remained in the final analysis (Figure 2).

Individual study synopses

There were 125 odontoid fractures across the 15 studies. Study characteristics are summarized below.

Anderson and D'Alonzo[5] examined 60 patients with odontoid fractures, 5 of whom were children. One passed away from their injuries before treatment. One underwent primary wiring and fusion of the first and second cervical vertebrae with a graft from a bone bank and achieved surgical union in a good position. The other three received cervical traction for 6 weeks, followed by Minerva casts, and achieved union in an average of 4 months without complications.

Griffiths[21] described four children with odontoid fractures, two of whom presented with arm weakness. Three patients were treated with traction for 3–4 weeks. One was placed in a Minerva plaster cast for 6 weeks. All patients achieved bony union without deformity or residual disability after 6 months to 2 years of follow-up.

Mandabach et al.[22] described 13 children with odontoid fractures. They were all initially managed with halo orthosis; however, two patients had delayed union, after 4.5 and 6 months respectively, and required late posterior C1–C2 fusion with autologous bone graft. Complications included four patients with skin inflammation around pin sites, one patient who needed halo revision secondary to pin loosening, and one patient who required replacement due to frame damage. There were no significant complications or morbidity. All eventually achieved a successful bony union.

Odent et al.[23] described 15 cases of children with odontoid process fractures. Eleven were treated conservatively: four via Minerva jacket without reduction; three with acute closed reduction in hyperextension and immobilization in halo cast; and four via gradual reduction with halo or collar traction followed by plaster Minerva cast. The average immobilization period was 3 months. Three patients received surgical treatment with posterior fusion with wiring of C1–C2 followed by immobilization in plaster Minerva cast for 2–5 months. One patient received no treatment because the odontoid fracture was identified 6 months after the original injury and had resolved on its own. All patients healed their fractures. Conservatively managed patients had no complications. Surgical complications included one deep wound infection, one recurrent displacement necessitating a closed reduction in a plaster cast for 3 months, and one case that achieved fusion at C2–C3 but not at C1–C2.

Sherk et al.[24] examined 11 children with odontoid process fractures. Five were reduced by recumbency with hyperextension of the neck for 1–12 days. Four were reduced by manipulation under sedation or general

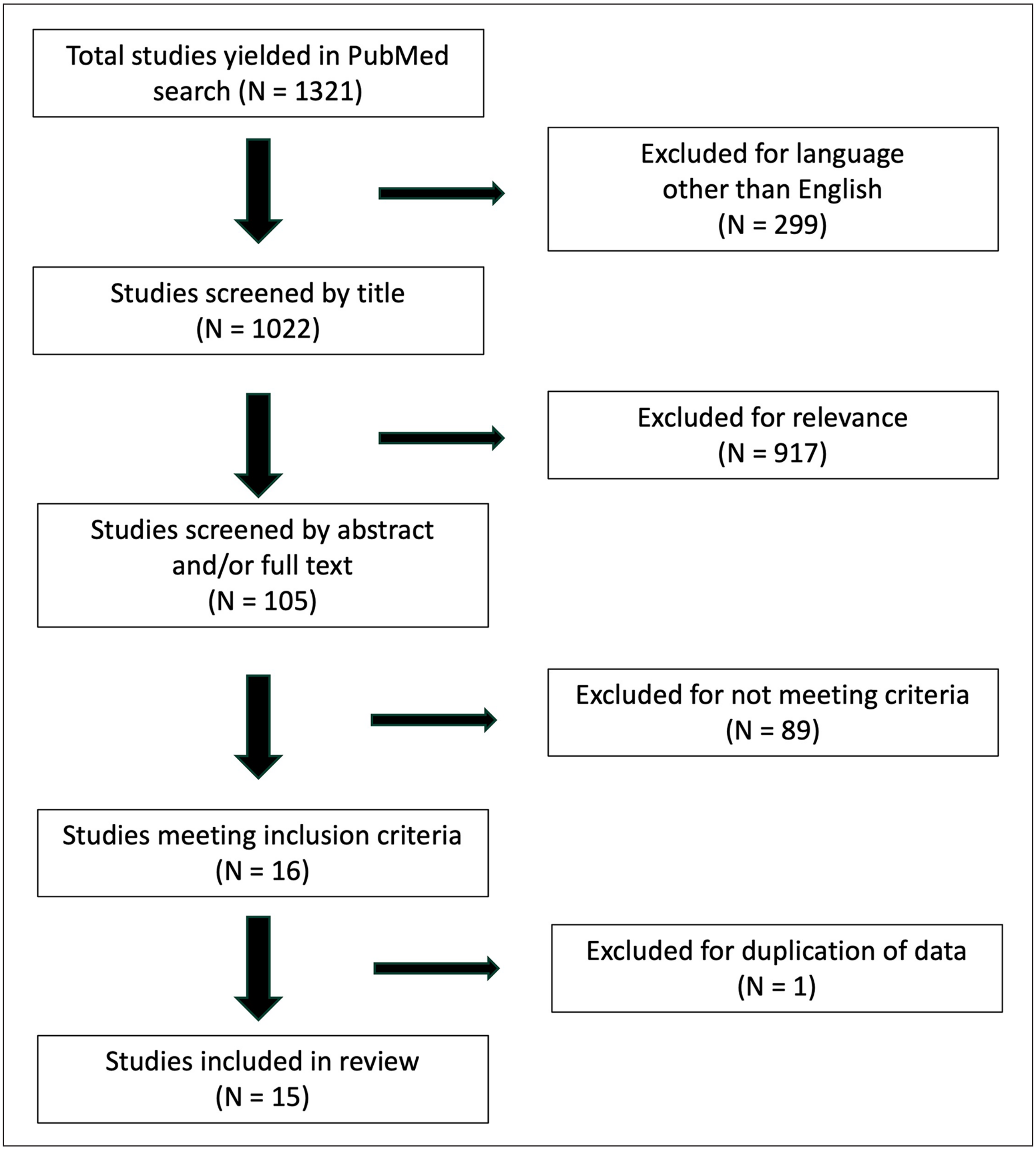

Figure 2. Literature search and identification of eligible studies.

anesthesia. One patient was reduced with halo traction, and one was reduced with Crutchfield tongs for 4 weeks. Immobilization following these reductions occurred for 6–16 weeks: 6 with Minerva jacket, 4 with halo cast, and 1 with soft collar. All fractures healed with no complications including non-union, avascular necrosis, or late neurologic deficits secondary to atlantoaxial instability. Nine achieved anatomic reductions, and two had residual angulation of the odontoid process of 15° or less (without clinical sequelae) on follow-up imaging.

Sawarkar et al.[25] described 13 patients with odontoid fractures: 11 type II and 2 type III. All underwent anterior screw fixation with a single screw followed by postoperative Philadelphia cervical hard collar for 12 weeks. Eleven of 13 had successful fixation, 1 had nonunion, and there was 1 perioperative mortality.

Gao et al.[26] reviewed seven pediatric patients with odontoid synchondrosis fracture. Three were managed by anterior release and reduction followed by posterior fixation of C1–C2. Four received only posterior fixation surgery via C1 lateral mass screw and C2 pedicle screw or lateral mass screw. There were no complications or fixation failures, and all patients had no neurologic deficits at the final follow-up.

Abou-Madawi et al.[27] treated 25 pediatric patients with atlantoaxial instability via Goel-Harms posterior C1–C2 fusion, 7 of whom had a presenting diagnosis of type II dens fracture. Five of the patients had C1–C2 fusion with C1 lateral mass and C2 pedicle screws with rod fixation. Notably, two patients were identified to have a high-riding vertebral artery on one side; these patients had two laminar screws rather than pedicle screws. There was no mortality, perioperative neural decline, infection, CSF leak, or arterial injury in any of the patients. All seven odontoid fractures achieved sound bone fusion.

Ozkan et al.[28] studied 75 children with traumatic spinal injury, and 10 of these presented with odontoid fracture. Five were managed conservatively by external immobilization in a Philadelphia collar for 3–5 weeks. The other five were managed operatively, four via posterior stabilization and fusion and one via anterior screw fixation. There were no growth arrests, spinal deformities, or compression neurologic symptoms. Neurologic function was improved or stable to preoperative baseline in all patients.

Tomaszewski et al.[29] studied six patients with upper cervical spine fractures, four of whom had lysis through the synchondrosis between the dens and body of C2. Two were treated with Minerva cast (duration 64 and 73 days, respectively), one with a soft collar, and one received no immobilization treatment due to severe concomitant open head injury requiring decompressive craniectomy. Of these four, the patient treated with the soft collar died 5 days after presentation due to severe head injury. The other three healed in correct alignment with no restriction of neck range of motion.

Lui et al.[30] examined 22 children and adolescents with C1–C2 fracture dislocations, 12 of whom had type II odontoid fractures. Seven of the odontoid fractures were reduced by skull tong traction and immobilized in a halo vest for 3 months; this was successful for 5, but two needed eventual posterior fusion of C1–C2 with wires and bone grafting due to persistent instability. Two of the 12 who presented with initial neurologic deficit were reduced and went directly to posterior C1–C2 fusion. Two could not be reduced and underwent transoral corpectomy for spinal cord decompression followed by posterior fusion. One patient expired from complete cord injury and respiratory failure before treatment could be offered. Of the 11 that were treated, 5 were completely neurologically intact and 6 were independent with mild neurologic deficit after 6 months. These latter six patients had initially presented with incomplete cord injury and sensorimotor deficits and appeared to improve at the final follow-up.

Fujii et al.[31] treated odontoid fractures in 58 patients, 6 of whom were under the age of 7 years and had epiphysiolysis. All seven were treated conservatively by a plaster cast or neck brace. All seven achieved bony union in 6–27 weeks.

Connolly et al.[32] treated seven children with odontoid synchondrosis fractures conservatively, six via halo traction, and one with plaster cast. Four had mild complications associated with halo traction. Six achieved normal neurologic outcomes, and one who presented with a closed head injury continued to have mild hemiparesis.

Goel et al.[33] treated 124 odontoid fractures surgically, 7 of whom were between age 11 and 18. They underwent posterior atlantoaxial fixation, and all patients showed a reduction of dislocation and resolution of malalignment. There were no postoperative complications, implant failures, or infections. All patients were independent and active at follow-up.

Henrys et al.[34] treated 18 pediatric patients with cervical spine injuries, 4 of whom had odontoid fractures at the base. They all were managed with traction followed by Minerva jacket and achieved fusion without any complications.

Collective results

Of the 125 odontoid fractures examined in this study, 73 were initially treated with external stabilization, 47 were initially treated with surgery, 2 received no initial treatment and healed spontaneously, and 3 died in the acute setting. Four patients failed external immobilization due to delayed union or persistent instability. These patients underwent delayed posterior fixation, yielding a total of 51 patients who were ultimately treated operatively. The failure rate for nonoperative management was 5.5% (4/73). Of the 51 patients who underwent surgical fixation, 14 received an anterior approach and 37 a posterior approach. There was one nonunion and one perioperative mortality in the anterior cases yielding a success rate of 85.7% (12/14). The nonunion was due to the migration of the screw head into the C2 body. The mortality was caused by K-wire migration during bicortical drilling resulting in vascular injury and subarachnoid hemorrhage. For posterior approach surgeries, two failed cases relied on postoperative immobilization to ultimately heal their fractures, yielding a success rate of 94.6% (35/37). The total operative success rate was 92.2% (47/51).

Based on this in-depth review of the existing literature on pediatric odontoid fracture management, a streamlined treatment algorithm was created (Figure 3).

Discussion

This review evaluated the current literature on odontoid fractures in the pediatric population to design a structured, stepwise management algorithm. Despite the variety of treatment options available, there is little consensus on how to manage this rare injury in children.

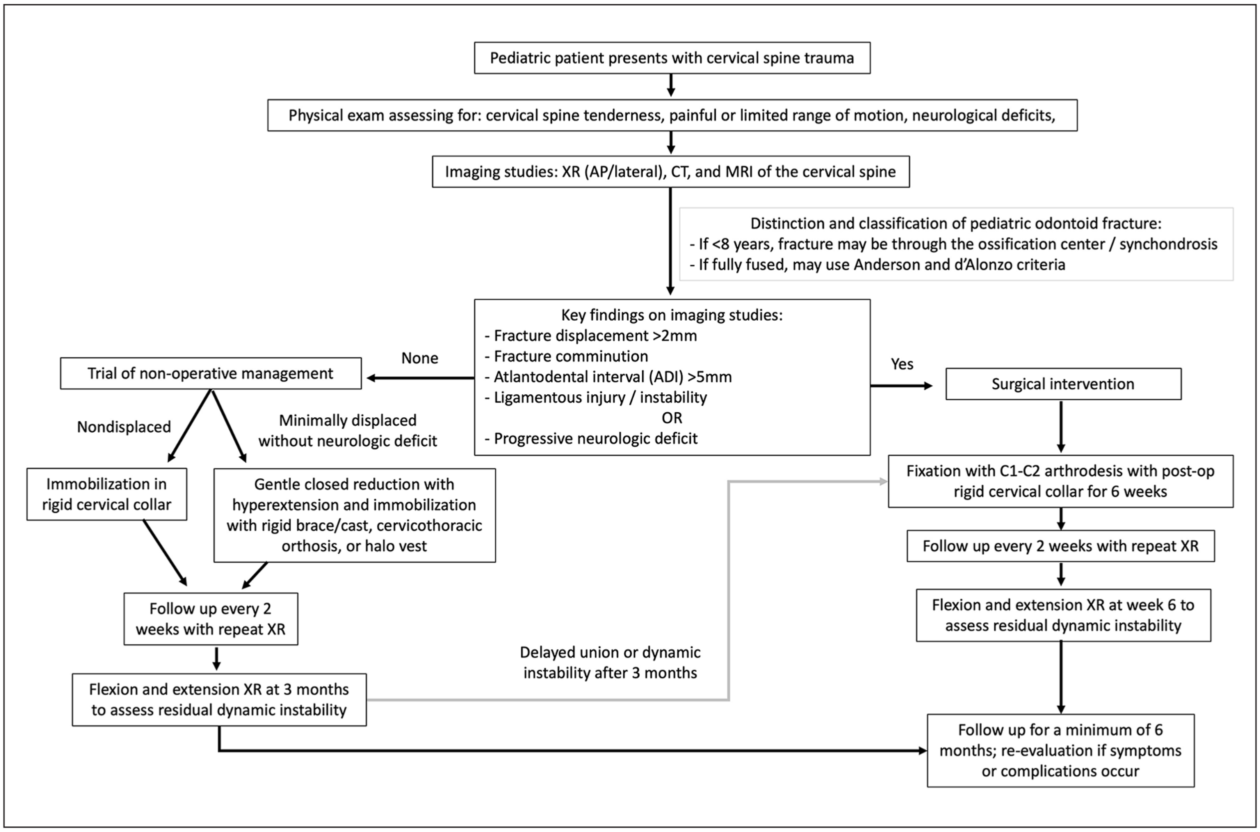

Figure 3. Treatment algorithm.

The first step in evaluation is a detailed physical examination including cervical spine tenderness, range of motion, and neurologic sequelae including weakness, paresthesia, or other sensorimotor deficits.[19,35] Providers should be suspicious of odontoid fractures in pediatric patients with head trauma, pharyngeal swelling or hematoma, dysphagia, and respiratory struggle after high-energy traumas like motor vehicle accidents or falls.[5,35]

Initial imaging is a critical next step for the proper characterization of the injury. X-ray imaging is typically sufficient for the diagnosis of odontoid fracture, utilizing at least anterior-posterior and lateral views. Open-mouth and flexion-extension radiographs provide further information. Radiographs can sometimes be difficult to interpret in young children, owing to features including hypermobility between C2 and C3, pseudo-widening of prevertebral soft tissue, and incomplete ossification of synchondroses.[13] Computed tomography (CT) scanning is generally more detailed and provides superior resolution for the identification and classification of fracture type. CT angiography may be necessary for planning surgical fixation in relation to the course of the vertebral arteries. Magnetic resonance imaging (MRI) is often needed to assess ligamentous stability and is necessary in patients with neurologic deficits.

Treatment options are first divided into non-operative and operative categories. Conservative (non-operative) management may be an appropriate option, especially if there is good alignment, normal atlantodens interval (ADI), no comminution, and no evidence of ligamentous instability or neurologic deficits. ADI is used to assess the relationship between the atlas and axis and is generally accepted as normal in children if equal to or under 5 mm.[36,37] If the fracture is nondisplaced, a rigid cervical collar may be carefully applied to immobilize and protect the cervical spine. If there is displacement under 2 mm with a normal ADI, intact ligamentous structures on MRI, and no neurologic deficits, gentle closed reduction may be considered followed by external immobilization with a rigid brace, cast, or cervicothoracic orthosis. Halo orthosis has been argued to provide the best control over cervical motion, including rotation, flexion and extension, and lateral movements.[22] However, due to its metallic composition, a halo vest may not be preferred, particularly if the patient requires subsequent CT or MRI scans which could be limited by metal artifacts.[22] These external forms of immobilization should be placed for at least 6 weeks, but ideally 3 months. The reported incidence of nonunion in adult odontoid fractures following nonoperative management ranges from 5% to 88%.[2,5,38] Risk factors for nonunion include older age, coronal tilt, lateral mass gap >2 mm, posterior subluxation, and complex fracture with secondary fracture lines into the pars interarticularis or

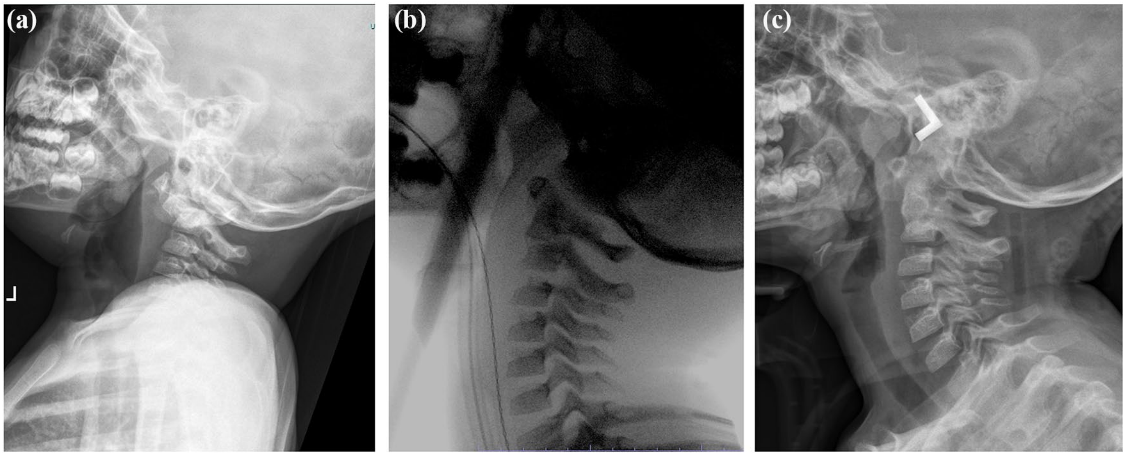

Figure 4. Example patient: 3-year-old boy. (a) C2 fracture. (b) CT fluoroscopy, treated with closed reduction and halo vest. (c) Lateral X-ray 8 weeks post-reduction.
CT, computed tomography.

vertebral body.[39,40] If at 3 months delayed union persists, surgical intervention is indicated. The failure rate for non-operative management in our selection of patients was 5.5%, suggesting that conservative management is reliably successful in the majority of uncomplicated presentations. Figure 4 shows imaging of a patient who was treated with non-operative management.

Previous studies have demonstrated that surgical stabilization of odontoid fractures is associated with a mortality benefit in adult and elderly patients when adjusting for factors including age, sex, and comorbidities.[41,42] Indications for surgery are numerous, but in the pediatric population, they include fracture comminution, fracture displacement >2 mm, ADI >5 mm, progressive neurologic deficits, or delayed union/persistent nonunion with external immobilization.[43] For adults, it has been shown that both anterior and posterior approaches are accepted for surgical fixation of odontoid fractures, though the decision is heavily dependent on individual clinical presentation and appearance on imaging.[43,44]

Posterior fusion in the studies examined in our review was achieved via C1–C2 arthrodesis, either with wiring technique or with screw and rod construct. More extensive surgery beginning at the occiput and/or extending further down the neck may be necessary if the injury has multilevel cervical involvement or occipitocervical instability.[45] Following surgery, patients should be immobilized for 6 weeks. Posterior fusion is thought to be more favorable, especially in the presence of significant neck pain, weakness, and multilevel cervical involvement.[43] It is also argued to have fewer complications and higher union rate,[5] lower risk of postoperative dysphagia, greater efficacy in treating nonunion in remote injuries, and can be used as a salvage procedure if anterior fusion fails.[31,43] It is not limited by fracture morphology or patient body habitus and can be performed without an intact transverse ligament, unlike the anterior approach.[43] Anterior fixation is less often seen as a first-line surgical treatment, though can be preferred because it allows for physiologic correction with preservation of C1–C2 motion, whereas the posterior procedure effectively eliminates the rotary motion at this joint.[25,43] However, anterior surgery requires an intact transverse ligament and is less effective for fixing old fractures.[31] In this 125-patient cohort, the anterior approach had a success rate of 85.7% and the posterior approach had a success rate of 94.6%. The only perioperative mortality seen in this cohort was during an anterior surgery.[25] Overall, our recommendation would be in favor of posterior fusion rather than anterior surgery, though the latter approach can be employed by surgeons who are well-versed in this technique, when preservation of rotation is critical, and when the clinical circumstances are appropriate.

Following surgery, patients should be followed regularly to assess for union. Radiographs should be obtained every 2 weeks. For patients treated with surgery, flexion and extension radiographs should be obtained at 6 weeks to assess for any residual dynamic instability. For patients treated nonoperatively, a prolonged period of immobilization is recommended, and flexion and extension radiographs should be obtained at 3 months. Depending on the patient's presentation, CT and/or MRI may be indicated to detect nonunion or residual ligamentous instability, respectively. Patients should be followed for a minimum of 6 months and to a year.

This study is limited by the nature of the retrospective literature review and the small amount of research available on this topic. Article screening for inclusion/exclusion was reliant on the researcher's judgment. Only one online database was used. All the studies included were retrospective reviews or observational cohort studies. No eligible randomized controlled trials were identified. Some of the studies included had limited follow-up periods and small sample sizes. There was also heterogeneity in the manner by which each study described the presentation, treatment, follow-up, and outcomes of their patients, which made it difficult to compare studies. For instance, regarding surgical treatment, some studies provided detail in their descriptions of procedures, while others simply stated the approach. Therefore, there remains some uncertainty about how to best manage these fractures.

Conclusion

Odontoid fracture is a rare, potentially life-threatening injury to consider in pediatric cervical spine trauma. There remains a shortage of literature on this topic in pediatric patients. We conducted the largest literature review to date summarizing methods of pediatric odontoid fracture management and outcomes. Using this information, a stepwise treatment algorithm for the diagnosis and management of these injuries was developed.

Author contributions

AMP, DSL, and GDH conceived the study idea and design. AMP performed the review and analysis. AMP, DSL, LC, and GDH contributed to the interpretation of the results. AMP drafted the manuscript and designed the figures. All authors contributed edits and provided critical feedback on the final manuscript.

Declaration of conflicting interests

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Ethical statement

There are no human participants in this article and informed consent is not required.

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Supplemental material

Supplemental material for this article is available online.

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