Treatment of Displaced Type II Odontoid Fractures in Elderly Patients

Hossein Elgafy, MD, MCh, FRCSEd, FRCSC, Marcel F. Dvorak, MD, FRCSC, Alexander R. Vaccaro, MD, PhD, and Nabil Ebraheim, MD

Abstract

Odontoid fractures are the most common cervical spine fractures for patients older than 70 years and are the most common of all spinal fractures for patients older than 80. Type II fracture, the most common type of odontoid fracture, is considered relatively unstable. It occurs at the base of the odontoid between the level of the transverse ligament and the C2 vertebral body.

In the geriatric population, it is important to look for any associated clinical comorbidities that might affect management. Treatment options for displaced odontoid fractures can be conservative or surgical. Conservative management includes immobilization in a cervical collar or in a halo vest. External immobilization with a cervical collar has had inconsistent results. Halo vest immobilization in the elderly is associated with a significant nonunion rate and several complications.

Generally accepted surgical indications are polytrauma, neurologic deficit, associated unstable subaxial spine injury that requires surgical fixation, and symptomatic nonunion. Surgical management includes either anterior odontoid screw fixation or posterior C1–C2 instrumentation with fusion.

Dr. Elgafy is Assistant Professor, Department of Orthopaedics, University of Toledo Medical Center, Toledo, Ohio.
Dr. Dvorak is Associate Professor, Department of Orthopaedics, University of British Columbia, Vancouver, British Columbia, Canada.
Dr. Vaccaro is Professor, Department of Orthopaedics, Thomas Jefferson University and Rothman Institute, Philadelphia, Pennsylvania.
Dr. Ebraheim is Professor, Department of Orthopaedics, University of Toledo Medical Center, Toledo, Ohio.

Address correspondence to: Hossein Elgafy, MD, MCh, FRCSEd, FRCSC, Department of Orthopaedics, University of Toledo Medical Center, 3065 Arlington Ave, Toledo, OH 43614-5807 (tel, 419-383-3515; fax, 419-383-3526; e-mail, helgafy@u.washington.edu).

Am J Orthop. 2009;38(8):410-416.

Odontoid fractures represent 9% to 15% of adult cervical spine fractures.[1-3] They commonly occur as a result of low-energy impacts, such as falls in the elderly.[4,5] Odontoid fractures are the most common cervical spine fractures for patients older than 70 years and are the most common spinal fractures for patients older than 80.[6] There is an equal male–female distribution in each population. The incidence of associated neurologic injury has ranged from 2% to 27% across multiple studies.[7-9] However, such injury is usually catastrophic because of the high level of spinal cord injury. Odontoid fracture combined with subaxial cervical spine injury is uncommon and seldom reported in the literature. Misdiagnosis or inappropriate management of such combined injuries might result in further neurologic deficit or late spinal instability. The mechanism of odontoid fracture can be either hyperextension, which often results in posterior displacement of the odontoid, or hyperflexion, which often results in anterior displacement.

It is difficult to explain the reasons for the increased incidence of odontoid fractures in the elderly compared with younger age groups. The difference might reflect the propensity for accidental falling in the elderly and its associated mechanism of trauma. Lakshmanan and colleagues,[10] who studied computed tomography (CT) images of the cervical spine in 23 older-than-70 patients with odontoid fractures, suggested an explanation for this increased incidence. In each patient, the type of odontoid fracture and the characteristics of the degenerative changes in each joint were analyzed. Of the 23 patients, 21 had type II odontoid fractures. The incidence of significant atlanto-odontoid degeneration in these patients was very high (90.48%), with relative sparing of the lateral atlantoaxial joints. Osteoporosis was found at the dens–body junction in 13 of the 23 patients and in the odontoid body in 7 patients. With aging, progressively more advanced degenerative changes develop in the atlanto-odon-

> "...the increased incidence of odontoid fractures in the elderly...might reflect the propensity for accidental falling in the elderly and its associated mechanism of trauma."

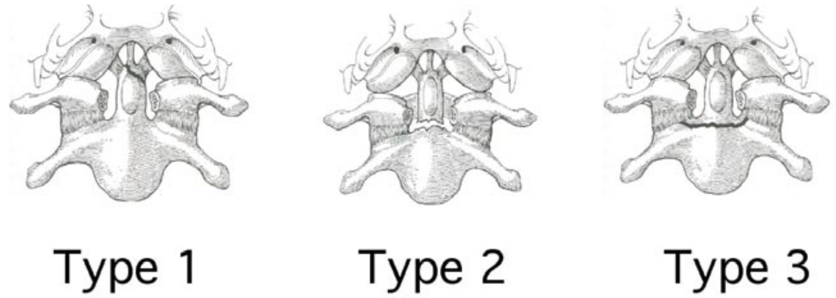

Figure 1. Odontoid classification by Anderson and D'Alonzo.[11]

toid joint. In some people, these changes might eventually obliterate the joint space and fix the odontoid to the anterior arch of the atlas. In contrast, the lateral atlantoaxial joints are hardly affected by osteoarthritis. Thus, atlantoaxial movements, including atlantoaxial rotation, are markedly limited by osteoarthritis of the atlanto-odontoid joint. However, there is still potential for movement in the lateral atlantoaxial joints, as they remain relatively free of degenerative change. The vulnerability of the atlantoaxial segment is further increased by markedly limited rotation below the axis vertebra, caused by advanced facet-joint degeneration. As a consequence, a relatively low-energy trauma to the lateral part of the face (eg, in a fall) will induce forced atlantoaxial rotation, which in turn, with marked limitation in movement at the atlanto-odontoid joint, will produce a torque force at the base of the odontoid process and potentially lead to a type II fracture.

Classification

In the 1970s, Anderson and D'Alonzo[11] proposed a classification system for odontoid fractures—now the most widely used (Figure 1). Least common is type I fracture, which occurs near the tip of the odontoid process, above the transverse ligament. It occurs by avulsion of the apical and/or alar ligaments and is considered relatively stable. However, this fracture type also might be associated with an unstable occipital-cervical dislocation, which can result from bilateral avulsion of the alar ligaments or a contralateral occipital condyle fracture. Type II fracture is the most common type of odontoid fracture and is considered relatively unstable. It occurs at the base of the odontoid, between the level of the transverse ligament and the C2 vertebral body. Type III fracture extends into the vertebral body and is relatively stable.

Anderson and D'Alonzo[11] suggested treatment algorithms based on the relative stability of each fracture type. Type I and type III fractures are usually treated conservatively, with external immobilization in either a cervical collar or a halo vest. However, there is ongoing debate about the best way to manage type II fractures. Options include cervical collar, halo vest, anterior odontoid screw fixation, and posterior C1–C2 instrumentation with fusion.[1-3,11-16]

Differentiating type II and type III fractures is often difficult. Grauer and colleagues[17] suggested using more precise definitions to differentiate these fractures. They defined type II as fractures caudal to the inferior border of the anterior C1 ring, without extension into the superior articular facets of C2, and type III fractures are type II fractures that extend into one of these facets. They also subclassified type II fractures on the basis of fracture line obliquity, displacement, and comminution, which clearly affect treatment recommendations (Figure 2). Type IIA

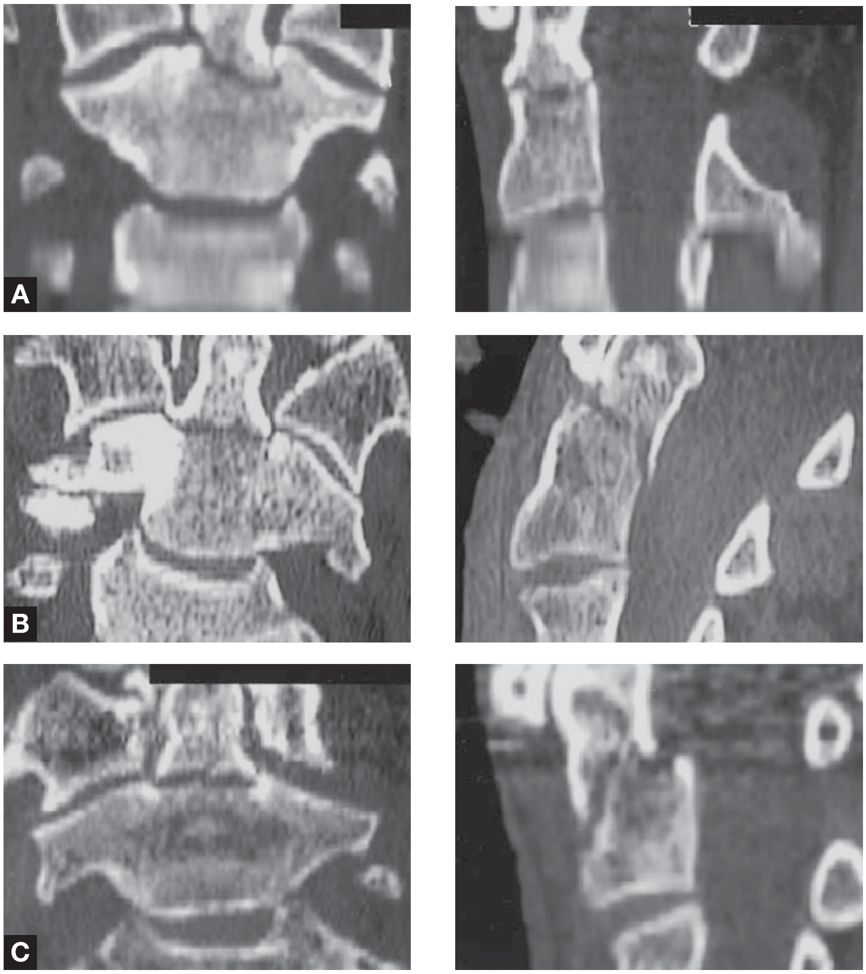

Figure 2. Anteroposterior and lateral radiographs show odontoid fractures: Grauer types (A) IIA, (B) IIB, and (C) IIC.

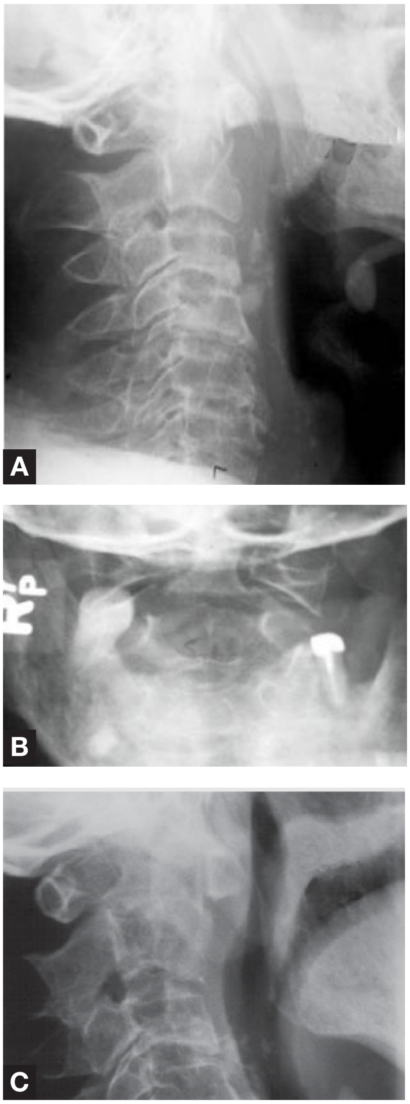

Figure 3. Lateral (A) and open-mouth (B) radiographs of a man in his late 70s show type II odontoid fracture sustained in a fall while walking. Patient was treated in Miami J collar for 3 months. (C) Six-month follow-up lateral radiograph shows bridging callus across fracture site.

fractures are minimally displaced or nondisplaced, with no comminution, and are usually treated with external immobilization. Type IIB fractures are displaced, extend from anterior-superior to posterior-inferior (ie, transverse fractures), and after reduction can be treated with anterior screw fixation, assuming adequate bone density. Type IIC fractures, which extend from anterior-inferior to posterior-superior or have significant comminution, are usually treated with posterior C1–C2 instrumentation plus fusion.

Clinical Assessment

In the geriatric population, it is important to look for any associated clinical comorbidities that might affect management. Next is a careful, complete physical examination of the entire spine—inspection, palpation, and neurologic evaluation with the head and neck stabilized in neutral alignment. Neurologic examination should include testing of cranial nerves, motor function, sensory perception, and reflexes in the extremities. Results of neurologic examination might range from normal functions to variable impairment, including incomplete to complete spinal cord injury. Evidence of cervical myelopathy, including fine hand motor control deficit, hypertonia, hyperreflexia, clonus, positive Babinski sign, and positive Hoffmann reflex, should be sought.

Imaging Studies

The entire spine should be imaged to rule out noncontiguous spinal injuries. There is a 34% risk for noncontiguous spine fractures associated with an odontoid fracture.[18] At some centers, CT of the cervical spine is the primary modality for assessment for cervical spine injury, as plain radiographs are inherently limited regarding the upper cervical spine and cervicothoracic junction.[19-21] Furthermore, Sanchez and colleagues[22] recently suggested that CT should be used for rapid and efficient cervical spine evaluation and that CT negates the need for plain radiographic imaging. However, they still recommended using the traditional cervical spine series of 3 plain radiographs (anteroposterior, cross-table lateral, open mouth) for initial assessment of patients with a suspected odontoid injury.[23,24] The rationale is that surgeons can familiarize themselves with a fracture on plain radiographs, the modality that is then used during any surgical management.

A transverse fracture line might be missed on a CT axial cut. Therefore, it is important to evaluate carefully the reformatted (sagittal, coronal) CT images. Magnetic resonance imaging should be used when there is a neurologic deficit or when a ligamentous injury is suspected.

Biomechanical Considerations

Richter and colleagues[25] conducted a biomechanical study on fresh-frozen cadavers to identify the stabilizing effects of different orthoses in the intact spine and unstable Anderson type II odontoid fracture. They compared halo thoracic vest (HTV), soft collar, prefabricated Minerva brace, and Miami J Cervical collar (Ossur Trauma & Spine, Paulsboro, NJ). All 4 orthoses reduced range of motion at both C1–C2 and C2–C3 of the intact spine. HTV provided the most stability; soft collar, no clinically relevant stability; and Minerva brace and Miami J Cervical collar, better control of rotational forces than motion in the sagittal plane. HTV did not allow any measurable motion in any plane. The investigators concluded that HTV is the first choice for conservative treatment of unstable injuries of the upper or axial cervical spine.

Management

Several important factors should be considered when deciding on a management plan for displaced type II odontoid fractures in elderly patients. These factors include decreased bone density interfering with adequate fixation using an anterior odontoid screw, elderly patients' not tolerating halo immobilization well, and, most important, associated medical comorbidities. The literature has shown 35% earlier mortality after treatment in patients older than 65 compared with patients younger than 40.[4-6,26,27]

Treatment options for displaced odontoid fractures can be conservative or surgical. Conservative management includes immobilization in a cervical collar or halo vest. Surgical management involves either anterior odontoid screw fixation or posterior C1–C2 instrumentation and fusion (achieved with either C1–C2 transarticular screws or a C1 lateral mass screw and C2 pars screws). Occiput to C2 fusion might be required in cases in which the C1 arch is removed.[1-3,11-16]

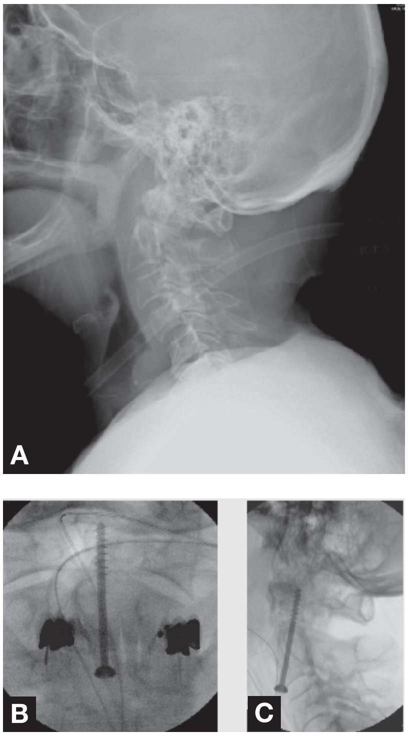

Figure 4. (A) Lateral radiograph of a man in his early 70s shows Grauer type IIB odontoid fracture. (B) Anteroposterior and (C) lateral radiographs show odontoid screw fixation.

Conservative Management With External Immobilization (Cervical Collar or Halo Vest)

External immobilization with a cervical collar has had inconsistent outcomes. The associated nonunion rate is thought to result from the high degree of instability in this fracture pattern.[28-30] This nonunion rate might also be related to decreased vascularity at the watershed region of the odontoid base, which reduces healing potential. Consequently, some surgeons have recommended halo vest immobilization for type II odontoid fractures.[29] In several series, however, halo vest immobilization is associated with a significant nonunion rate (range, 26%-80%).[5,8,9,28,31] Furthermore, use of the halo vest in the elderly has been associated with complications in the 26% range. These complications include poor reduction maintenance, pin-site infection, and cerebral spinal fluid leakage. Increased incidence of pneumonia and cardiac arrest has been linked to the higher mortality rate in this group of patients (Tables I, II).

Some surgeons believe that stable nonunion after external immobilization with a cervical collar in the elderly is an acceptable risk when considered against the potential morbidity of surgical intervention. Often, a semirigid cervical collar is the treatment of choice (Figure 3). When an odontoid fracture is treated with orthosis, however, careful follow-up with flexion-extension radiographs is needed to make sure that nonunion is not associated with cord impingement.[35]

Surgical Management

In light of the high incidence of nonunion with external immobilization in the elderly, several investigators have recommended primary surgical management consisting of either anterior odontoid screw fixation or posterior C1–C2 instrumentation and fusion.[27,29]

Generally accepted indications for surgical management in displaced type II odontoid fractures include polytrauma, neurologic deficit, and associated unstable subaxial spine injuries that require surgical fixation. In these cases, surgeons can use either anterior odontoid screw fixation or posterior C1–C2 instrumentation and fusion depending on patient's body habitus, presence of osteoporosis, obliquity of fracture line, and ability to achieve successful anatomical fracture reduction. Posterior C1–C2 fusion rather than anterior odontoid screw fixation is used in displaced type II odontoid fractures that are associated with C1–C2 instability secondary to transverse ligament injury and symptomatic nonunion that develops after either external immobilization or anterior odontoid screw fixation.[27,29]

Odontoid fracture combined with subaxial unstable cervical spine injury is uncommon and seldom reported in the literature. Closed reduction should be tried first, and then both fractures can be fixed, if possible, under the same anesthesia. In the patient with neurologic deficit, the surgical management priority should be the fracture that causes the spinal cord injury. In the neurologically intact patient, the priority is the fracture that could not be successfully reduced with preoperative traction. In the neurologically intact patient in whom both fractures are successfully reduced with preoperative traction, considerations are the extent of instability between the odontoid fracture and the subaxial cervical

"Some surgeons believe that stable nonunion after external immobilization with a cervical collar in the elderly is an acceptable risk when considered against the potential morbidity of surgical intervention."

Table I. Mortality Rates for Halo Vest Immobilization (HVI) and Other Treatments

Study	Patients (N)	Treatment	Mortality Rate (%)
Tashjian et al[31]	40	No HVI	20
Frangen et al[32]	27	Posterior C1–C2 fusion	22
Hanigan et al[4]	19	HVI, cervical collar	30
Müller et al[27]	18	3 HVI, 13 cervical collar	34.8
Weller et al[33]	5	HVI	40
Majercik et al[34]	129	HVI	40
Tashjian et al[31]	38	HVI	42

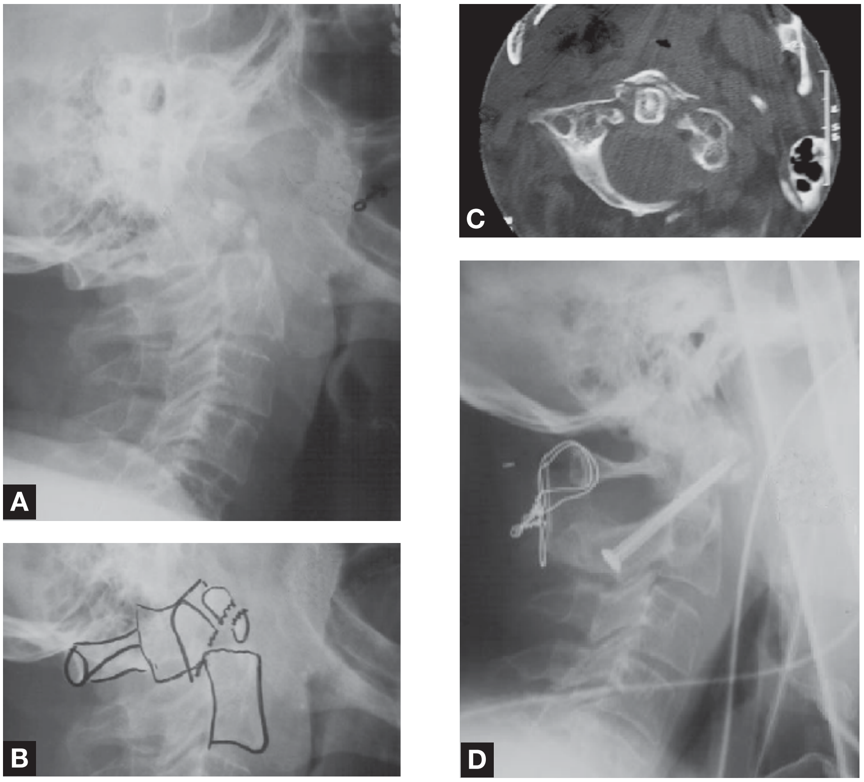

Figure 5. (A,B) Lateral radiographs of a man in his mid-80s shows comminuted type II odontoid fracture with posterior displacement and posterior angulation sustained in motor vehicle accident. (C) Axial computed tomography scan shows associated C1 anterior arch fracture. (D) Lateral radiograph shows C1–C2 posterior fusion with transarticular screws and sublaminar wire.

spine injury and the risk for surgical intervention involving each injury. Many surgeons surgically stabilize both injuries, whereas others prioritize stabilizing the subaxial cervical spine when the odontoid fracture is successfully anatomically reduced with preoperative traction.

Anterior Odontoid Screw Fixation. To avoid loss of 50% of cervical rotation with C1–C2 fusion, Bohler[36] in 1982 used anterior odontoid screw fixation (Figure 4). Specifically designed retractors and biplanar fluoroscopy are important for this procedure. After the patient is positioned on the operating table, an appropriate trajectory for screw placement is ensured with use of fluoroscopy, and adequate fracture reduction is obtained, a low cervical approach is made around the C5–C6 level. The prevertebral plane is then developed to allow access to the C2–C3 disc space. The entry site for the screw is at the anterior-inferior corner of the C2 endplate, and, though preservation of the C2–C3 disc space is important, most surgeons apply the screw through the C2–C3 disc space to ensure an adequate screw trajectory. Two screws were initially used with this technique, but now most surgeons use a single screw, as studies showed no significant difference between 1 or 2 screws in biomechanical stability or nonunion rates. Furthermore, placing 2 screws is often not safe.[37,38]

The reported fusion rates for anterior odontoid screw fixation have ranged from 83% to 100%.[12,37,39,40] However, anterior odontoid screw fixation is not suitable for every type II odontoid fracture. This method is appropriate only for type II fractures that can be adequately reduced. Patients with cervical or thoracic kyphosis and short, thick necks might also not allow an appropriate trajectory for screw placement. Furthermore, the fracture should have right obliquity to allow compression across the fracture site and avoid displacement with lag screw fixation. The ideal fracture geometry is a Grauer type IIB fracture, which is a displaced fracture extending from anterior-superior to posterior-inferior, or a transverse fracture.[17] In addition, this fixation method should be avoided in osteoporotic bone, pathologic fracture, or nonunion in which fracture fixation and subsequent healing are impaired. Given these facts, surgeons would not be expected to use anterior odontoid screw fixation in elderly patients in whom osteoporosis is prevalent.

Posterior C1–C2 Fusion. Several surgical techniques have been used for posterior C1–C2 fusion. These include sublaminar wiring, C1–C2 transarticular screws, and Harms posterior C1 lateral mass and C2 pars screws.[12-14,41] Gallie[13] described the first posterior C1–C2 wiring technique. A single central wire was placed in a sublaminar position, under the ring of C1 and around the C2 spinous process. The wire provided stability and secured a structural autograft. Brooks and Jenkins[14] later introduced a wiring technique that used bilateral sublaminar C1–C2 wires and 2 structural autograft blocks. A major disadvantage of sublaminar wiring is the potential risk for

Table II. Complication Rates for Halo Vest Immobilization (HVI) and Non-HVI[31]

Complication	HVI	Non-HVI	*P*
Pneumonia	13 (34%)	3 (8%)	.003
Cardiac arrest	10 (26%)	2 (5%)	.01
Deep venous thrombosis/ pulmonary embolism	2 (5%)	1 (3%)	.48
Urinary tract infection	3 (8%)	3 (8%)	.63
Overall	25 (66%)	15 (38%)	.01

Figure 6. Lateral radiograph shows C1–C2 posterior fusion with Harms and Melcher[41] fixation using posterior C1 lateral mass and C2 pars screws.

spinal cord injury during wire passing. Furthermore, sublaminar wires cannot be used concomitant with C1 posterior arch fracture.

An alternative C1–C2 stabilization method involves transarticular screws (Figure 5).[15] Screw trajectory should be confirmed with fluoroscopy after the patient is positioned on the operating table. The procedure should be abandoned and an alternative fixation method used when an appropriate screw trajectory cannot be achieved because of the patient's body habitus, as with morbid obesity and advanced thoracic or cervical kyphosis. After open posterior exposure of the upper cervical spine—usually extending from C1 to C3—the starting point for screw insertion on the C2 lateral mass is identified. The screws are then inserted percutaneously through 2 small stab incisions at the cervicothoracic junction. The screw is advanced along the isthmus of C2 and into the C1 lateral mass. As originally described, this technique involved adjuvant sublaminar wiring and structural bone graft applied over the posterior arch of the C1 and C2 laminae. The fusion rates reported for this technique have been near 100%.[15,16,42] However, some surgeons recently started using C1–C2 transarticular screws without adjunctive sublaminar wiring and decorticating and applying bone graft within the C1–C2 joint and over the C1 posterior arch and C2 lamina. However, elimination of posterior wiring produces only 2-point fixation, which has been associated with increased flexion and extension motion.[43]

Limitations to C1–C2 transarticular screw technique include required reduction of C1 on C2 before screw placement, risk for vertebral artery injury, and potential bleeding from dissection surrounding the C2 pedicle.[41] When transarticular screws are considered, preoperative CT should be evaluated to make sure that an appropriate and safe screw trajectory exists.

To avoid the limitations of transarticular fixation, Harms and Melcher[41] introduced a screw fixation technique that uses posterior C1 lateral mass and C2 pars screws (Figure 6). Once the screws are placed, reduction of C1 relative to C2 can be adjusted if necessary before securing the screws with a short rod construct. This technique produced 100% fusion in all 37 patients at 1 year and had no neurologic, vascular, or implant complications.

Biomechanical studies have shown that the wiring technique of Brooks and Jenkins[14] was 2.5 times more stable than that of Gallie[13] and that C1–C2 transarticular screw constructs have had 10-fold increased rotational stiffness and similar lateral bending stiffness when compared with that of posterior wiring techniques.[44-46] Biomechanical comparison of Harms posterior C1 lateral mass and C2 pars screws with bilateral C1–C2 transarticular screws with Gallie wiring showed significantly decreased motion in lateral bending and axial rotation with both the Harms and transarticular screw constructs. Furthermore, no significant difference was documented between the transarticular and Harms methods.[47]

Nonunion

Type II odontoid fractures are less stable than type I and type III odontoid fractures and are associated with higher nonunion rates. Factors associated with increased incidence of nonunion for type II odontoid fractures include posterior fracture displacement, displacement of more than 5 mm, more than 10° of angulation, fracture comminution, delayed treatment, and age over 40.[7,48-50]

Asymptomatic nonunions are often found without any active surgical intervention, though this often spurs debate. Patients with a symptomatic nonunion often present with persistent neck pain, myelopathy, or both. In such a case, surgical management should be considered. Several factors should be carefully evaluated before deciding on a surgical option. These factors include associated medical comorbidities, presenting symptom (pain only or pain associated with myelopathy), and status of subaxial spine. In patients with severe medical comorbidities that make surgical management risky, some surgeons continue with conservative management. Posterior C1–C2 fusion is the procedure of choice for patients whose chief complaint on presentation is pain. Patients who present with myelopathy might require decompression, which is achievable with resection of the posterior C1 arch and possibly a portion of the C2 lamina.[51] Surgeons might also extend instrumentation and fusion to the subaxial spine in patients with advanced subaxial spondylosis and spinal canal stenosis. In these cases, it is difficult to know if myelopathy is related to odontoid nonunion or to subaxial spinal canal stenosis.

Summary

Despite the frequency of odontoid fractures in the elderly, there is still no consensus about the best treatment for displaced type II odontoid fractures—reflecting the reality that there is not yet a single ideal solution for this clinical problem. Imaging should be used to assess the odontoid fracture itself and to exclude other contiguous or noncontiguous fractures. External immobilization with a cervical collar has had inconsistent results. Halo vest immobilization in the elderly is associated with a significant nonunion rate and several complications.

However, some surgeons believe that a stable nonunion after external immobilization with a cervical collar in the elderly is an acceptable risk when considered against the potential morbidity of surgical intervention. Well-accepted surgical indications are polytrauma, neurologic deficit, associated unstable subaxial spine injury that requires surgical fixation, and symptomatic nonunion. Surgical management includes either anterior odontoid screw fixation or posterior C1–C2 instrumentation and fusion.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

References

1. Vaccaro AR, Madigan L, Ehrler DM. Contemporary management of adult cervical odontoid fractures. *Orthopedics*. 2000;23(10):1109-1113.
2. Subach BR, Morone MA, Haid RW Jr, McLaughlin MR, Rodts GR, Comey CH. Management of acute odontoid fractures with single-screw anterior fixation. *Neurosurgery*. 1999;45(4):812-819.
3. Maak TG, Grauer JN. The contemporary treatment of odontoid injuries. *Spine*. 2006;31(11 suppl):S53-S60.
4. Hanigan WC, Powell FC, Elwood PW, Henderson JP. Odontoid fractures in elderly patients. *J Neurosurg*. 1993;78(1):32-35.
5. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. *Clin Orthop*. 1985;(193):178-183.
6. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. *Injury*. 1992;23(1):38-40.
7. Clark CR, White AA 3rd. Fractures of the dens. A multicenter study. *J Bone Joint Surg Am*. 1985;67(9):1340-1348.
8. Hanssen AD, Cabanela ME. Fractures of the dens in adult patients. *J Trauma*. 1987;27(8):928-934.
9. Schweigel JF. Management of the fractured odontoid with halo-thoracic bracing. *Spine*. 1987;12(9):838-839.
10. Lakshmanan P, Jones A, Howes J, Lyons K. CT evaluation of the pattern of odontoid fractures in the elderly—relationship to upper cervical spine osteoarthritis. *Eur Spine J*. 2005;14(1):78-83.
11. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am*. 1974;56(8):1663-1674.
12. Geisler FH, Cheng C, Poka A, Brumback RJ. Anterior screw fixation of posteriorly displaced type II odontoid fractures. *Neurosurgery*. 1989;25(1):30-37.
13. Gallie WE. Fractures and dislocations of the cervical spine. *Am J Surg*. 1939;3:495-499.
14. Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by the wedge compression method. *J Bone Joint Surg Am*. 1978;60(3):279-284.
15. Jeanneret B, Magerl F. Primary posterior fusion C1/2 in odontoid fractures: indications, technique, and results of transarticular screw fixation. *J Spinal Disord*. 1992;5(4):464-475.
16. Coyne TJ, Fehlings MG, Wallace MC, Bernstein M, Tator CH. C1–C2 posterior cervical fusion: long-term evaluation of results and efficacy. *Neurosurgery*. 1995;37(4):688-692.
17. Grauer JN, Shafi B, Hilibrand AS, et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. *Spine J*. 2005;5(2):123-129.
18. Green RA, Saifuddin A. Whole spine MRI in the assessment of acute vertebral body trauma. *Skeletal Radiol*. 2004;33(3):129-135.
19. Shaffer MA, Doris PE. Limitation of the cross table lateral view in detecting cervical spine injuries: a retrospective analysis. *Ann Emerg Med*. 1981;10(10):508-513.
20. Diaz JJ Jr, Gillman C, Morris JA Jr, May AK, Carrillo YM, Guy J. Are five-view plain films of the cervical spine unreliable? A prospective evaluation in blunt trauma patients with altered mental status. *J Trauma*. 2003;55(4):658-663.
21. Barker L, Anderson J, Chesnut R, Nesbit G, Tjauw T, Hart R. Reliability and reproducibility of dens fracture classification with use of plain radiography and reformatted computer-aided tomography. *J Bone Joint Surg Am*. 2006;88(1):106-112.
22. Sanchez B, Waxman K, Jones T, Conner S, Chung R, Becerra S. Cervical spine clearance in blunt trauma: evaluation of a computed tomography–based protocol. *J Trauma*. 2005;59(1):179-183.
23. Pasquale M, Fabian TC. Practice management guidelines for trauma from the Eastern Association for the Surgery of Trauma. *J Trauma*. 1998;44(6):941-956.
24. Keats TE, Dalinka MK, Alazraki N, et al. Cervical spine trauma. American College of Radiology. ACR Appropriateness Criteria. *Radiology*. 2000;215(suppl):243-246.
25. Richter D, Latta LL, Milne EL, et al. The stabilizing effects of different orthoses in the intact and unstable upper cervical spine: a cadaver study. *J Trauma*. 2001;50(5):848-854.
26. Bednar DA, Parikh J, Hummel J. Management of type II odontoid process fractures in geriatric patients: a prospective study of sequential cohorts with attention to survivorship. *J Spinal Disord*. 1995;8(2):166-169.
27. Müller EJ, Wick M, Russe O, Muhr G. Management of odontoid fractures in the elderly. *Eur Spine J*. 1999;8(5):360-365.
28. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. *Neurosurgery*. 1986;18(3):306-310.
29. Ziai WC, Hurlbert RJ. A six year review of odontoid fractures: the emerging role of surgical intervention. *Can J Neurol Sci*. 2000;27(4):297-301.
30. Kuntz C 4th, Mirza SK, Jarell AD, Chapman JR, Shaffrey CI, Newell DW. Type II odontoid fractures in the elderly: early failure of nonsurgical treatment. *Neurosurg Focus*. 2000;8(6):e7.
31. Tashjian RZ, Majercik S, Biffl WL, Palumbo MA, Cioffi WG. Halo-vest immobilization increases early morbidity and mortality in elderly odontoid fractures. *J Trauma*. 2006;60(1):199-203.
32. Frangen TM, Zilkens C, Muhr G, Schinkel C. Odontoid fractures in the elderly: dorsal C1/C2 fusion is superior to halo-vest immobilization. *J Trauma*. 2007;63(1):83-89.
33. Weller SJ, Malek AM, Rossitch E Jr. Cervical spine fractures in the elderly. *Surg Neurol*. 1997;47(3):274-281.
34. Majercik S, Tashjian RZ, Biffl WL, Harrington DT, Cioffi WG. Halo vest immobilization in the elderly: a death sentence? *J Trauma*. 2005;59(2):350-357.
35. Müller EJ, Schwinnen I, Fischer K, Wick M, Muhr G. Non-rigid immobilisation of odontoid fractures. *Eur Spine J*. 2003;12(5):522-525.
36. Bohler J. Anterior stabilization for acute fractures and non-unions of the dens. *J Bone Joint Surg Am*. 1982;64(1):18-27.
37. Sasso R, Doherty BJ, Crawford MJ, Heggeness MH. Biomechanics of odontoid fracture fixation. Comparison of the one- and two-screw technique. *Spine*. 1993;18(14):1950-1953.
38. Jenkins JD, Coric D, Branch CL Jr. A clinical comparison of one- and two-screw odontoid fixation. *J Neurosurg*. 1998;89(3):366-370.
39. Aebi M, Etter C, Coscia M. Fractures of the odontoid process. Treatment with anterior screw fixation. *Spine*. 1989;14(10):1065-1070.
40. Dickman CA, Foley KT, Sonntag VK, Smith MM. Cannulated screws for odontoid screw fixation and atlantoaxial transarticular screw fixation. Technical note. *J Neurosurg*. 1995;83(6):1095-1100.
41. Harms J, Melcher RP. Posterior C1–C2 fusion with polyaxial screw and rod fixation. *Spine*. 2001;26(22):2467-2471.
42. Dickman CA, Sonntag VK. Posterior C1–C2 transarticular screw fixation for atlantoaxial arthrodesis. *Neurosurgery*. 1998;43(2):275-280.
43. Henriques T, Cunningham BW, Olerud C, et al. Biomechanical comparison of five different atlantoaxial posterior fixation techniques. *Spine*. 2000;25(22):2877-2883.
44. Hanley EN Jr, Harvell JC Jr. Immediate postoperative stability of the atlantoaxial articulation: a biomechanical study comparing simple midline wiring, and the Gallie and Brooks procedures. *J Spinal Disord*. 1992;5(3):306-310.
45. Montesano PX, Juach EC, Anderson PA, Benson DR, Hanson PB. Biomechanics of cervical spine internal fixation. *Spine*. 1991;16(3 suppl):S10-S16.
46. Grob D, Crisco JJ 3rd, Panjabi MM, Wang P, Dvorak J. Biomechanical evaluation of four different posterior atlantoaxial fixation techniques. *Spine*. 1992;17(5):480-490.
47. Melcher RP, Puttlitz CM, Kleinstueck FS, Lotz JC, Harms J, Bradford DS. Biomechanical testing of posterior atlantoaxial fixation techniques. *Spine*. 2002;27(22):2435-2440.
48. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute axis fractures: a review of 229 cases. *J Neurosurg*. 1989;71(5 Pt 1):642-647.
49. Hadley MN, Browner C, Sonntag VK. Axis fractures: a comprehensive review of management and treatment in 107 cases. *Neurosurgery*. 1985;17(2):281-290.
50. Koivikko MP, Kiuru MJ, Koskinen SK, Myllynen P, Santavirta S, Kivisaari L. Factors associated with nonunion in conservatively-treated type-II fractures of the odontoid process. *J Bone Joint Surg Br*. 2004;86(8):1146-1151.
51. Zhang J, Hirabayashi S, Saiki K, Sakai H. Effectiveness of multiple-level decompression in laminoplasty and simultaneous C1 laminectomy for patients with cervical myelopathy. *Eur Spine J*. 2006;15(9):1367-1374.