CHAPTER 17

Isolated Fractures of the Axis in Adults

RECOMMENDATIONS

FRACTURES OF THE ODONTOID:

Standards: **There is insufficient evidence to support treatment standards.**

Guidelines: **Type II odontoid fractures in patients 50 years and older should be considered for surgical stabilization and fusion.**

Options: **Type I, Type II, and Type III fractures may be managed initially with external cervical immobilization. Type II and Type III odontoid fractures should be considered for surgical fixation in cases of dens displacement of 5 mm or more, comminution of the odontoid fracture (Type IIA), and/or inability to achieve or maintain fracture alignment with external immobilization.**

TRAUMATIC SPONDYLOLISTHESIS OF THE AXIS (HANGMAN'S FRACTURE):

Standards: **There is insufficient evidence to support treatment standards.**

Guidelines: **There is insufficient evidence to support treatment guidelines.**

Options: **Traumatic spondylolisthesis of the axis may be managed initially with external immobilization in most cases. Surgical stabilization should be considered in cases of severe angulation of C2 on C3 (Francis Grade II and IV, Effendi Type II), disruption of the C2–C3 disc space (Francis Grade V, Effendi Type III), or inability to establish or maintain alignment with external immobilization.**

FRACTURES OF THE AXIS BODY (MISCELLANEOUS FRACTURES):

Standards: **There is insufficient evidence to support treatment standards.**

Guidelines: **There is insufficient evidence to support treatment guidelines.**

Options: **External immobilization is recommended for treatment of isolated fractures of the axis body.**

RATIONALE

Fractures of the axis represent unique cervical vertebral injuries owing to the unique anatomy and biomechanics of the C2 vertebra and the stresses applied to the dynamic atlantoaxial complex during trauma. Fractures of the axis may be associated with other cervical fractures or ligamentous injuries. Isolated fractures of the axis are common and warrant independent consideration. Fractures of the axis have been divided into three general subtypes: fractures of the odontoid process, traumatic spondylolisthesis of the axis (hangman's fractures), and miscellaneous non-odontoid non-hangman's fractures of the C2 vertebra. Each of these fracture subtypes has been further subdivided on the basis of the anatomic features and the functional significance of the individual fracture injury. The purpose of this review is to identify evidence-based management strategies for each injury subtype of traumatic fractures of the second cervical vertebra.

SEARCH CRITERIA

A computerized search of the National Library of Medicine database of the literature published from 1966 to 2001 was undertaken. The medical subject heading "spinal cord injury" in combination with "axis," "vertebrae," "fracture," and "human" yielded 711 articles. Those manuscripts focusing on the clinical management of acute traumatic axis fractures were selected for review. The bibliographies of these papers were scanned for additional references to confirm completeness of the literature review. Relevant papers addressing the mechanism of injury or the biomechanics and radiology of the C2 vertebra were included. The articles were reviewed and classified using established methodology. Thirty-eight articles for odontoid fracture, 17 for traumatic spondylolisthesis, and 8 for miscellaneous axis fractures provided the basis for the scientific foundation of this guideline. Data from articles describing axis fractures and/or their management were categorized and are provided in *Tables 17.1 to 17.4*). Fifteen additional articles are referenced in the reference list as supporting information.

SCIENTIFIC FOUNDATION

Odontoid fractures

Overview

The most common traumatic axis injury is fracture through the odontoid process, either through the tip of the dens (Type

TABLE 17.1. Initial Management of Isolated Axis Fracture in the Adult

Fracture Type	Treatment Options
Odontoid fracture	
Type I	Collar, halo
Type II	Consider for early surgery or halo, collar
Type IIA	Consider for early surgery or halo
Type III	Collar, halo, surgical fusion
Traumatic spondylolisthesis of the axis (hangman's fracture)	
Effendi Type I, Francis Type I, II	Halo, collar
Effendi Type II, III, Francis Type III, IV, V	Halo, consider surgical stabilization
Miscellaneous axis fractures	Collar or halo

I), through its base (Type II), or involving the odontoid but extending into the C2 body (Type III) (1, 6, 40). The anatomy and biomechanics of the C1–C2 complex provide for weight-bearing support for the head on the spine and for the most motion of any intervertebral unit in the cervical spine. Motion at C1–C2 is primarily rotational, accounting for one-half of the axial rotation of the head on the neck (76). Translational motion of C1 on C2 is restricted by the transverse atlantal ligament that approximates and secures the odontoid process to the anterior arch of the ring of C1. With a fracture of the odontoid process, restriction of translational movement of C1 on C2 may be lost. Anterolisthesis or retrolisthesis of the C1-odontoid complex may occur relative to the body of C2. If substantial subluxation of C1 on C2 occurs, spinal cord injury may result. The atlantoaxial complex is one of the most common sites of dislocation in fatal cervical spinal injuries (21).

Earlier publications using evidence-based methodology for evaluating the literature on odontoid fracture management have focused on fusion as the primary outcome criterion with a minimum follow-up of 18 months (44, 72). Articles on odontoid fractures containing this information were included in this survey. Although it has been argued that the radiographic determination of fusion may be difficult and subject to observer variability, it seems to be the most appropriate outcome measure and is described in most of the clinical articles addressing odontoid fractures. It is recognized that outcome measures that incorporate patient satisfaction, quality of life measures, and function would perhaps be superior, but this information is sparse and less objective than the fusion criteria described in the literature.

Classification of odontoid fractures

In 1974, Anderson and D'Alonzo (1) classified fractures of the odontoid into three types. This categorization has met with general acceptance and remains in use with minor modification. On the basis of a series of 49 patients managed from 1954 through 1972 with an average follow-up of 22 months, the authors defined three odontoid fracture types. Type I fractures are oblique fractures through the upper portion of the odontoid process. Type II fractures cross the base of the odontoid process at the junction with the axis body. Type III fractures are fractures through the odontoid that extend into the C2 body. The authors considered the Type III odontoid fracture to be more accurately described as a fracture of the body of the axis. Using this scheme, the authors identified and treated 2 Type I fractures, 32 Type II fractures, and 15 Type III fractures.

In 1988, Hadley et al. (38) added another fracture subtype to this classification scheme. They described the Type IIA odontoid fracture as a comminuted fracture involving the base of the dens with associated free fracture fragments. The incidence of a Type IIA fracture was estimated as 5% of all Type II fractures (3 of 62 Type II fractures in their series) and was associated with severe instability and inability to obtain and maintain fracture reduction and realignment. The authors proposed that Type IIA odontoid fractures be managed with early posterior surgical fixation and fusion of C1–C2.

Treatment

A variety of treatment strategies have been proposed for odontoid fractures based on the fracture type, the degree of initial dens displacement, the extent of angulation of the dens with respect to the body of C2, and the age of the patient. These include nonoperative and operative methods (1, 15, 16, 30, 34, 38–40, 44, 50, 58, 72). Patients with odontoid fracture injuries have been treated with external immobilization using a variety of orthoses with varying results (1, 15, 16, 30, 34, 38–40, 44, 50, 58, 72). Surgical options include posterior cervical fusion with or without transarticular screw fixation or anterior odontoid screw fixation techniques.

No treatment

In 1985, the Cervical Spine Research Society (16) published a multicenter review addressing the management of odontoid fractures. This report includes 18 patients with Type II odontoid fractures and 3 patients with Type III odontoid fractures who received no treatment. None of these cases achieved subsequent bony fusion. The authors concluded that nontreatment of odontoid fractures should be eliminated as a management choice.

Traction

Reviews by Traynelis (72) and Julien et al. (44) include evidentiary tables describing seven articles containing Class III medical evidence addressing the treatment of odontoid fractures with traction and subsequent immobilization in a cervical collar (1, 15, 16, 30, 34, 50, 58). All patients with Type I odontoid fractures achieved radiographic fusion (3 of 3 patients). Of patients with Type III fractures, 87% (55 of 63 patients) achieved fusion. The failure rate for patients with Type II fractures treated in this fashion was 43% (42 of 97 patients); 57% achieved bony union. It seems that traction and then cervical collar immobilization may be considered a management option for patients with odontoid fractures, particu-

TABLE 17.2. Summary of Reports on Odontoid Fractures

Series (Ref. No.)	Study Design	Evidence Class	Comments
Andersson et al., 2000 (2)	Retrospective nonrandomized report of 29 patients age >65 with odontoid fractures managed with posterior fusion, anterior odontoid fixation, or immobilization.	III	Posterior fusion resulted in 7/7 fused (100%), anterior odontoid screw resulted in 3/11 fused (27%), and halo immobilization resulted in 3/10 fused (30%). The authors argue for posterior fusion in the elderly patient with an odontoid fracture.
Apfelbaum et al., 2000 (3)	Retrospective review of 2-institution experience with anterior odontoid screw fixation. 147 odontoid fractures (Type II [n = 138] and Type III [n = 9]) divided into recent (<6 mo, 129 patients) and remote (>6 mo from injury, 18 patients) groups.	III	The fusion rate was significantly higher in the recent group comparing fusion rates of 88% versus 25% ($P < 0.05$) with a mean follow-up of 18 mo. A positive correlation was seen between fusion and fractures oriented in the horizontal or posterior oblique planes. No effect of age, sex, number of screws placed, or displacement was demonstrated.
Dai et al., 2000 (20)	Review of 57 cases of failed management for odontoid fracture.	III	50 treated with occipitocervical fusion and 7 with atlantoaxial fusion. 2 cases of nonunion after atlantoaxial fusion alone. 38 achieved an excellent result.
Lennarson et al., 2000 (46)	33 patients with isolated Type II odontoid fractures treated with halo vest immobilization. Cases defined as nonunions in halo and controls defined as unions.	II Case-control	Patients age ≥50 yr had a risk for failure 21 times higher than age <50 yr. No significant difference in medical conditions, sex, amount of fracture displacement, direction of fracture displacement, length of hospital stay, or length of follow-up between groups.
Julien et al., 2000 (44)	Evidence-based review of management of odontoid fractures.	III	Authors conclude that there is insufficient evidence for standards or guidelines. Type I and III odontoid fractures can be managed with external immobilization (100% and 84% fusion, respectively). Anterior fixation for Type III odontoid fractures appears to improve the fusion rate to nearly 100%. Type II fractures can be managed with external immobilization with an expected fusion rate of approximately 65%. Surgical instrumentation and fusion appear to improve the fusion rate and include posterior cervical fusion (74%) or anterior odontoid screw fixation (90%) with acceptable morbidity.
Campanelli et al., 1999 (14)	7 patients with displaced Type II odontoid fractures underwent posterior transarticular screw fixation.	III	6/7 (86%) achieved rigid immobilization. 1 vertebral injury. The authors conclude that this is a reasonable option.
Muller et al., 1999 (56)	Retrospective review of 23 patients >70 yr of age with odontoid fractures.	III	Complication rate significantly increased in the elderly group (52% versus 33%) primarily owing to nonunion after nonoperative treatment. The authors suggest that the elderly patient is at high risk for morbidity and mortality and suggest early halo fixation or primary stabilization.
Morandi et al., 1999 (55)	17 cases of odontoid screw fixation.	III	Fusion in 16/17 (94%). The authors suggest patient selection for anterior fixation be based on the orientation of the fracture line.
Subach et al., 1999 (69)	26 patients (mean age, 35 yr) with Type II fractures treated with anterior odontoid screw fixation (single screw) plus collar (median, 7.2 wk).	III	25/26 fusion (96%). 1 patient required posterior fusion for inadequate reduction.
Seybold and Bayley, 1998 (67)	Retrospective review of 37 Type II and 20 Type III odontoid fractures divided into age groups. Age <60 and >60 yr.	III	Age <60: Type II, 7/12 fused (58%). Age >60: Type II, 8/11 fused (73%). Type III: all treated with halo, 95% fusion regardless of type. Fusion rates did not differ significantly between the 2 groups. The authors noted a decreased tolerance in the elderly patient for halo immobilization and, as a result, favor surgery in selected cases.
Jenkins et al., 1998 (43)	Comparison of 1 versus 2 screws in nonselected patients with Type II odontoid fractures divided into 2 groups: 20 (1 screw) versus 22 (2 screws). Follow-up, 9 mo.	III	The difference in fusion rate, 81% (1 screw) versus 85% (2 screws), was not significant.
Berlemann and Schwarzenbach, 1997 (7)	19 patients >65 yr with Type II odontoid fractures treated with anterior odontoid screw fixation with a follow-up of 4.5 yr.	III	Bony fusion in 16/19 (84%). 15/19 (79%) were asymptomatic. The authors favor anterior fixation in this age group.
Traynelis, 1997 (72)	Evidence-based review of Type II odontoid fractures.	III	First evidence-based report on odontoid fracture management. Indicates that insufficient data were available for standards or guidelines and that 4 treatment options for Type II odontoid fractures were available, including: traction followed by immobilization, immobilization with halo or Minerva, posterior cervical fusion, or anterior screw fixation. The author notes that the higher fusion rate reported with anterior screw fixation might be offset by its higher complication rate and learning curve.

TABLE 17.2. *Continued*

Series (Ref. No.)	Study Design	Evidence Class	Comments
Greene et al., 1997 (36)	Retrospective review of 340 cases of axis fractures, including 199 odontoid fractures.	III	*Type I*: 2 patients, 2/2 healed with halo immobilization (12 wk). *Type II*: 120 patients, 20 treated with early surgery. 8 had Type II with >6 mm, 4 Type IIA with instability despite external immobilization (1 Type IIA treated successfully with a halo), 7 patients underwent surgical fusion to avoid halo immobilization. 95 were treated with external immobilization (median, 13 wk). 88 were available for follow-up. Solid fusion failed in 25 (28.4%). 7 were successfully treated with additional immobilization, and 18 were successfully treated with posterior fusion (late surgery). Significant factor was dens displacement >6 mm (χ^2 33.74, $P < 0.0001$), giving an 86% failure rate in the halo treatment group; 5 died. *Type III*: 77 patients, 69 managed nonoperatively with external immobilization. 68 fused (median, 12 wk). The one that failed also had a C1 posterior arch fracture and required posterior fusion. 6 patients were treated with early surgery: 5 because the halo failed to maintain alignment and 1 because of a combined C2–C3 subluxation. 2 had concomitant lateral mass fractures of the atlas with avulsion of the ligamentous insertion on the tubercle; 2 died. *Conclusions*: The highest nonunion rate was observed in Type II odontoid displaced ≥6 mm. Surgery was recommended for 1) acute fracture instability despite external immobilization, 2) transverse ligament disruption, and 3) Type II odontoid fracture with >6 mm displacement.
Polin et al., 1996 (60)	Retrospective review of 36 Type II fractures treated with Philadelphia collar (16) or halo vest immobilization (20).	III	Type II: 54% fused with collar. 74% fused with halo.
Chiba et al., 1996 (15)	104 patients with odontoid fractures: Type I, 2 patients. Type II, 62 patients. Type III, 32 patients. 2 groups: Fresh group, 72 patients whose fractures were identified within 3 wk of traumatic event. Old group, 32 patients who had an extended period before definitive treatment: 1 Type I, 21 Type II, and 8 Type III.	III	*Type I*: 2 patients, collar 2/2, both fused (100%). *Type II*: 62 patients, immobilization 10/62, surgery 52/62. In fresh fracture group treated with surgery, 31/32 fused (97%). In delayed fracture group treated with surgery, 13/19 fused (68%). *Type III*: 32 patients, surgery 15/32 (47%) fused, immobilization 17/32 (53%) fused, 10/15 (66%) treated with surgery fused. 11/17 (65%) treated with immobilization fused. Every patient treated with a halo fused, 5/5 (100%). *Surgical procedures*: 66 patients: *Posterior cervical fusion*: 10 patients. Type II: 9/9 successful fusions (100%). Type III: 1/1 successful fusions (100%). *Anterior screw fixation*: 46 patients. 36 Type II, 10 Type III, 42/45 patients achieved bony union (93.3%). *Transoral fusion*: 9 patients, 6/8 Type II. Successful fusions (75%), 1/1 Type III successful fusion (100%). *The authors of this large series conclude*: Type I fractures can generally be managed nonoperatively. Anterior screw fixation recommended for most Type II and unstable Type III fractures. Contraindications include old established nonunions, irreducible fractures, caudal displacement, severe osteoporosis. Type III fractures can be treated with halo immobilization or anterior screw fixation. Established nonunions and irreducible fractures should be treated with posterior fusion. Transoral fusion reserved for rare cases of anterior cord compression.
Bednar et al., 1995 (5)	Prospective report of early surgical stabilization in 11 geriatric patients with odontoid fractures.	III	The authors suggest that mortality can be reduced by surgical intervention and avoiding the use of halo immobilization.
Dickman and Sonntag, 1995 (22)	14 patients with either acute or subacute Type II fractures treated with anterior odontoid screw fixation. Radiographic criteria for fusion: postoperative x-rays and computed tomographic scans.	III	Type II: 14/14 successful fusions (100%).
Dickman et al., 1995 (23)	Describes salvage procedures for failed atlantoaxial nonunions.	III	Report includes 2 cases in which anterior atlantoaxial transarticular screws were used and 8 cases of posterior transarticular screws.
Coyne et al., 1995 (18)	15 patients treated with posterior wire fusion and immobilized postoperatively in either Philadelphia collar or halo. Minimum follow-up, 2 yr; mean, 4.7 yr. Radiographic criteria for fusion: absence of C1–C2 movement on lateral flexion/extension x-rays and evidence of continuity of trabecular bone formation between C1 and C2 across the graft.	III	Type II: 13/14 successful fusions (93%). Type III: 2/2 successful fusions (100%).

TABLE 17.2. *Continued*

Series (Ref. No.)	Study Design	Evidence Class	Comments
Hanigan et al., 1993 (41)	19 patients >80 yr of age with odontoid fractures (16 Type II, 3 Type III).	III	5 patients with displacement >5 mm required posterior surgical fixation with good results. There was 27% mortality in the conservative treatment group, with prolonged immobilization noted as one of the contributing factors.
Waddell and Reardon, 1983 (74)	24 patients with odontoid fracture: 20 Type II and 4 Type III fractures. 16/20 Type II fractures were treated with C1–C2 arthrodesis (Gallie procedure). All Type III fractures were treated nonoperatively.	III	Type II: 15/16 successful fusions (94%); 1 patient was lost to follow-up. Type III: 3/4 successful fusions (75%), 1/4 nonunion (25%).
Ryan and Taylor, 1993 (63)	30 patients >60 yr of age with Type II fractures.	III	The fusion rate in the patients age >60 treated with immobilization was only 7/29 (23%). Despite the low fusion rate for this age group, the authors favor halo immobilization over surgical fixation.
Bucholz, 1981 (12)	26 patients; 0 Type I, 17 Type II, 9 Type III. Patients were immobilized in halo for a minimum of 3 mo and, if no movement on flexion/extension x-rays, placed in a Philadelphia collar for an additional 4 wk. Radiographic criteria for fusion: no movement or subluxation at the fracture site on flexion/extension x-rays.	III	Type II: 15/17 successful fusions (88%). 2/17 nonunions (12%). Type III: 9/9 successful fusions (100%). 3 deaths: 2 patients had Type II fractures while being treated in halo, and 1 patient with Type III fracture.
Hadley et al., 1988 (38)	Retrospective study including 62 patients with Type II odontoid fractures, including 3 with comminution at the base.	III	The subgroup of Type II odontoid fracture with comminution at the base was defined as the Type IIA odontoid fracture. The clinical significance of this observation was that the fracture fused poorly with immobilization and was considered for early surgery.
Govender and Grootboom, 1988 (34)	Review of 41 patients with odontoid fractures: 26 Type II, 15 Type III. 1 mo in traction (2–4 kg), then a rigid collar for 6–8 wk, and assessed at 3 mo. Radiographic criteria for fusion: bony continuity across fracture site and no movement on flexion/extension tomograms.	III	Type II: 19/26 successful fusions (73%). 2/26 fibrous unions (8%). 5/26 nonunions (19%). Type III: 15/15 successful fusions (100%). No mortality. 7 halo pin-site infections. 3 patients had skin excoriation over chin secondary to halter traction.
Fujii et al., 1988 (30)	Retrospective review of 52 patients with odontoid fractures, including data on 24 treated with immobilization, 10 treated with anterior screw fixation, and 7 treated with posterior fusion. Radiographic criteria for fusion: anteroposterior and lateral tomograms.	III	*Immobilization*: Type I: 1/1 successful fusion (100%). Type II: 3/7 successful fusions (43%). Type III: 10/14 successful fusions (72%). *Posterior fusion*: Type II: 7/7 successful fusions (100%). *Anterior screw fixation*: Type II: 6/8 successful fusions (75%). Type III: 2/2 successful fusions (100%).
Lind et al., 1987 (48)	Review of 14 patients with odontoid fractures managed with halo immobilization and evaluated at 12 wk with flexion/extension x-rays. Included 9 Type II and 5 Type III fractures with a 2-yr follow-up. Radiographic criteria for fusion: flexion-extension x-rays.	III	10/11 successful fusions (91%) combined Type II and Type III fractures. Authors support the use of halo immobilization as the initial treatment for Type II and III odontoid fractures.
Dunn and Seljeskog, 1986 (24)	Retrospective report of 80 patients with odontoid fractures including data on 74 patients treated primarily with rigid bracing for 3–6 mo followed by additional collar support for 6 wk and 41 patients undergoing posterior cervical fusion. Minimum follow-up period was 6 mo; 80% of the patients had follow-up longer than 8 mo. Radiographic criteria for fusion: lateral flexion-extension x-rays at 3–4 mo.	III	*Rigid immobilization*: Type II: 40/59 successful fusions (68%). 19/59 nonunions (32%). Type III: 15/15 successful fusions (100%). *Posterior fusion*: 40/41 successful fusions (98%) for combined Type II and Type III fractures.
Clark and White, 1985 (16)	Multicenter review including 144 patients managed by 27 different surgeons. Fusion rates reported based on fracture type and treatment. Radiographic criteria for fusion: evidence of trabeculation across the fracture site and absence of movement on lateral flexion-extension x-rays.	III	*No treatment*: Type II: 0/18 successful fusions (0%). Type III: 0/3 successful fusions (0%). *Collar*: Type II: 0/3 successful fusions (0%).Type III: 5/10 successful fusions (50%). *Traction*: Type II: 2/3 successful fusions (66%). Type III: 7/8 successful fusions (88%). *Halo*: Type II: 25/38 successful fusions (66%). Type III: 13/16 successful fusions (81%). *Anterior fusion*: Type II: 7/8 successful fusions (88%). Type III: 2/2 successful fusions (100%). *Posterior fusion*: Type II: 25/26 successful fusions (96%). Type III: 4/4 successful fusions (100%).

TABLE 17.2. *Continued*

Series (Ref. No.)	Study Design	Evidence Class	Comments
Pepin et al., 1985 (58)	Retrospective review of 41 patients with odontoid fractures including 26 treated conservatively with tongs, four-poster brace, collars, and/or halo vests (0 Type I, 13 Type II, 13 Type III). 12 patients underwent posterior cervical fusion (1 Type I, 4 Type II, and 7 Type III). Radiographic criteria for fusion: union on plain x-rays and tomograms as well as lateral flexion-extension views. Nonunion was defined as movement of the dens fragment on lateral flexion-extension x-rays.	III	*Halo/traction*: Type II: 6/13 successful fusions (46%). Type III: 11/13 successful fusions (85%). *Posterior cervical fusion*: Type I: 1/1 successful fusions (100%). Type II: 4/4 successful fusions (100%). Type III: 7/7 successful fusions (100%). The authors noted that the halo vests were poorly tolerated in patients age >75 yr.
Wang et al., 1984 (75)	Retrospective review of 25 patients with odontoid fractures treated with a variety of cervical immobilization techniques.	III	Type I: 1/1 fused with halo (100%). Type II: 4/7 fused with collar (57%). 4/5 fused in halo (80%). Type III: 2/2 fused with collar (100%). 10/12 fused with halo (83%).
Bohler, 1982 (9)	15 patients. With odontoid fractures, both acute and chronic treated with anterior screw fixation followed by a period of cervical fixation in a plastic collar for a period of 4–16 wk. Fracture distribution: 0 Type I, 8 Type II, and 7 Type III. Radiographic criteria for fusion: not given.	III	Type II: 8/8 successful fusions (100%). Type III: 7/7 successful fusions (100%).
Maiman and Larson, 1982 (49)	Retrospective review of 49 cases of odontoid fracture, including 34 Type II fractures treated with early posterior wire/graft stabilization. Post-operative immobilization with a Minerva for an average of 5 wk. 2 Type III fractures were included. Radiographic criteria for nonunion: tomographic evidence of avascular necrosis, gross instability with a demonstrable gap at the fracture line, and no evidence of healing. Fusion results evaluated 6 mo postsurgery.	III	The authors observed a 100% fusion rate at the posterior surgical site, but only a 35% fusion rate across the fracture site.
Ryan and Taylor, 1982 (62)	Retrospective review of 23 patients with odontoid fractures over a 10-yr period, including 1 Type I, 16 Type II, and 6 Type III. Radiographic criteria for fusion: no movement on lateral flexion-extension x-rays.	III	Halo/Minerva/Suboccipital-mandibular immobilizer: Type I: 1/1 successful fusion. Type II: 9/15 successful fusions (60%). Type III: 6/6 successful fusions (100%).
Ekong et al., 1981 (26)	Retrospective review of 22 cases of odontoid fracture treated with halo immobilization for 3 mo. Type I, 0 patients. Type II, 16 patients. Type III, 6 patients. Includes outcome on 17 patients with an average follow-up of 30 mo. Radiographic criteria for fusion: lateral flexion-extension x-rays.	III	Type II: 6/12 successful fusions (50%). Type III: 4/5 successful fusions (80%).
Marar and Tay, 1976 (50)	Review of 26 cases of odontoid fracture including 24 Type II and 2 Type III treated with cervical traction for ≤10 wk. Radiographic criteria for fusion: fibrous union at fracture site.	III	Type II: 9/24 successful fusions (37.5%). Type III: 2/2 successful fusions (100%).
Anderson and D'Alonzo, 1974 (1)	Retrospective review of 49 patients with odontoid fractures classified into Type I, II, and III based on fracture.	III	*Non-operative treatment*: 37 patients. Type I: collar/brace, 2/2 successful fusions (100%). Type II: halo, 14/22 successful fusions (64%). 8/22 nonunions (36%). Type III: halo, 12/13 successful fusions (92%). 1/13 nonunion (8%). *Operative treatment*: 12 patients. Type II: 8/10 successful fusions (80%). Type III: 2/2 (100%).

TABLE 17.3. Summary of Reports on Traumatic Spondylolisthesis of the Axis

Series (Ref. No.)	Study Design	Evidence Class	Comments
Barros et al., 1999 (4)	Case report of surgical fixation in hangman's fracture.	III	Surgical treatment for hangman's fracture is an option.
Verheggen and Jansen, 1998 (73)	Retrospective study of 16 patients treated with early posterior screw fixation of the neural arch after hangman's fracture.	III	The authors suggest that this is the optimal therapy for Edwards and Levine (Effendi) Type II and III fractures, describing excellent results in their series.
Greene et al., 1997 (36)	340 cases of axis fractures, including 74 patients with traumatic spondylolisthesis of the axis. Follow-up available on 72 patients.	III	Most common: Effendi Type I (72%), Francis Grade I (65%). 65 treated successfully with immobilization (12 wk). 7 required early surgery (posterior fusion) owing to poor alignment in the halo (Effendi II, 6 patients; Effendi III, 1 patient; Francis Grade I, 1 patient; II, 1 patient; III, 2 patients; IV, 3 patients). 33% of all Effendi Types II and III and 36% of all Francis Types III, IV, V patients required surgery. Strong correlation observed between Effendi I and Francis I and Effendi III and Francis IV. *Conclusions*: Immobilization is generally sufficient treatment. Surgery may be considered for severe Francis or Effendi type hangman's fractures.
Coric et al., 1996 (17)	Retrospective review of hangman's fracture including 39 nondisplaced (<6 mm C2 on C3) treated with nonrigid immobilization (Philadelphia collar for an average of 12 wk) and 10 displaced (>6 mm) treated with halo (3), collar (6), or surgery (1).	III	Nondisplaced group: 39/39 fused using collar alone. Displaced group: also fused regardless of treatment. C1–C3 fusion required in 1 patient for failure of closed reduction.
Starr and Eismont, 1993 (68)	Review of 19 cases of axis fracture including 6 cases of a pattern occurring through the posterior aspect of the vertebral body continuity of the posterior cortex with subluxation resulting in narrowing of the spinal canal.	III	Hangman's fracture variation occurred in 6/19 patients, including 2 with spinal cord injury from the associated subluxation.
Tan and Balachandran, 1992 (70)	Retrospective study of 33 patients with hangman's fracture. Classified by Effendi: 21 Type I, 11 Type II, and 1 Type III.	III	20/26 had no neurological deficit on admission. 28/33 with complete recovery after 1 yr.
Torreman, 1990 (71)	Long-term study of 23 patients with hangman's fractures treated with immobilization. Average follow-up, 9.6 yr.	III	100% long-term fusion rate with cervical immobilization.
Govender and Charles, 1987 (33)	Prospective study of 39 patients.	III	All patients successfully managed with traction and immobilization.
Grady et al., 1986 (35)	Retrospective review of 27 patients including 16 managed with halo, 8 with a collar, and 3 with bedrest.	III	All achieved fusion with no residual symptoms. The authors recommend the use of a Philadelphia collar alone in fractures with minimal displacement.
Levine and Edwards, 1985 (47)	Retrospective case series of 52 patients with traumatic spondylolisthesis of the axis classified using the Effendi criteria.	III	Isolated Type I, II, and IIa were all managed nonoperatively. 3 of 5 Type III patients underwent surgical stabilization for failure to obtain or maintain reduction in a halo. The authors identify the Type IIa subgroup of the Effendi Type II patients who distract significantly with the application of traction and note the mechanism of injury for this group is likely flexion-distraction. 3/3 Type IIa patients were treated with gentle extension and compression under fluoroscopic guidance followed with halo immobilization.
Borne et al., 1984 (10)	Retrospective review of 18 cases of "pedicle" fracture of the axis treated with direct internal fixation.	III	Aggressive surgical approach for fixation of pedicle-isthmus fractures of the axis with 100% fusion rate.
Mestdagh et al., 1984 (52)	Combined clinical and anatomic study describing 41 fractures of the posterior neural arch of the axis. 11 cases treated with anterior C2–C3 interbody fusion. 30 treated with traction and immobilization. Follow-up available on 30 patients.	III	Cadaveric study demonstrated that fractures with displacement of ≤5 mm were stable. Cervical mobility was maintained better in the conservative management group. The authors recommend conservative measures except in cases of marked instability or nonunion.
Francis et al., 1981 (29)	Classification paper based on 123 cases of fractures of the posterior arch of the axis. Grade based on displacement and angulation.	III	Grade I (15% of total series): 0% nonunion with immobilization. Grade II (7%): 33% nonunion. Grade III (37%): 0% nonunion. Grade IV (34%): 2% nonunion. Grade V (6%): 28% nonunion.
Bucholz, 1981 (12)	Autopsy study of 170 cases of traumatic death.	III	38 had cervical spine fractures and 8/38 had traumatic spondylolisthesis of the axis.
Pepin and Hawkins, 1981 (57)	Defined an early classification scheme for hangman's fracture based on 42 cases.	III	*Type I*: a nondisplaced fracture of the posterior elements. *Type II*: displaced fracture involving posterior and anterior structures. All 42 patients were successfully treated nonsurgically.
Effendi et al., 1981 (25)	Classification paper based on 131 cases of patients with fractures of the ring of the axis. Fractures divided into 3 groups based on mechanism of injury, displacement, and stability.	III	Type I (65% of total group): Isolated hairline fractures of the ring of the axis with minimal displacement of the body of C2 caused by axial loading and hyperextension. Type II (28%): Displacement of anterior fragment with disruption of the disc space below the axis caused by hyperextension and rebound flexion. Type III (7%). Displacement of anterior fragment with C2–C3 facet dislocation caused by primary flexion and rebound extension. Although 5 patients underwent surgery, the authors conclude that the vast majority of these patients are best managed with cervical immobilization.
Brashear et al., 1975 (11)	29 patients with hangman's fractures followed for an average of 6 yr.	III	No case of neurological deficit. 23/23 (100%) treated with immobilization achieved fusion. Supports nonoperative management.

TABLE 17.4. Summary of Reports on Miscellaneous Axis Fractures

Series (Ref. No.)	Study Design	Evidence Class	Comments
Greene et al., 1997 (36)	340 cases of axis fractures, including 67 non-odontoid, non-hangman's fractures (miscellaneous), most involving the body of lateral masses.	III	60/61 (98%) were successfully treated with external mobilization in all but 1 patient (1.6% nonfusion rate). 4 patients died, and 1 underwent early surgery for 5-mm luxation of C2 on C3.
Fujimura et al., 1996 (31)	31 cases of axis body fractures categorized into 4 types based on radiographic imaging.	III	4 types: *Avulsion*: 9/9 fused with immobilization. *Transverse*: 2/2 healed with immobilization. *Burst*: 2/3 treated with C2–C3 fusion. *Sagittal fractures*: 15/17 healed with immobilization. 8 sagittally oriented fracture patients still had pain despite a bony union.
Benzel et al., 1994 (6)	Retrospective report of 15 patients described with fractures of the axis body.	III	The authors propose classification into: Type 1: coronal (n = 12). Type 2: sagittal (n = 3). Type 3: oblique and equivalent to the Type III odontoid fracture.
Korres et al., 1994 (45)	14 cases of avulsion fracture of the anteroinferior portion of the axis secondary to extension-type injuries. Mean follow-up, 8.5 yr.	III	3% of the cervical spine trauma cases over a 12-yr period. All patients treated successfully with cervical immobilization.
Bohay et al., 1992 (8)	Describes 3 cases of vertical fractures of the axis.	III	Notes that this is an unusual variant fracture of the axis body. All treated with immobilization.
Craig and Hodgson, 1991 (19)	Describes 9 cases of superior facet fracture of the axis vertebra.	III	5 treated with reduction and immobilization. 3 required open reduction and posterior fusion.
Burke and Harris, 1989 (13)	Review of 165 patients with axis fractures. 31 miscellaneous body fractures identified and classified on mechanism of injury.	III	Identified 31 patients with axis body fractures. 21/38 (68%) were extension teardrop; 10/31 (32%) were hyperextension.
Jakim and Sweet, 1988 (42)	Case report of a transverse fracture of the axis and literature review. A classification scheme is proposed.	III	3 types of axis body fractures were described: the Type III odontoid fracture of Anderson and D'Alonzo, the transverse body fracture, and the avulsion fracture.

larly those with Type I and Type III fractures. The low fusion success rate reported for Type II odontoid fractures managed with traction and collar immobilization (57%) implies that perhaps collar immobilization is not the ideal strategy for Type II fracture patients.

Cervical collar

Several authors have proposed treatment of odontoid fractures with cervical collars. Polin et al. (60) in 1996 describe a series of 36 Type II fractures treated with either a Philadelphia collar or halo vest immobilization. The fusion rate was lower in the patients treated with collars (53%) compared with 74% for patients managed in halos. An earlier report from the same institution described a similar rate of fusion (57%) in a study including seven Type II fractures treated with a collar alone (75). The infrequent Type I odontoid fracture seems to have an acceptable rate of fusion with rigid cervical collar immobilization, approaching 100% in one study (1, 15, 16). Type III odontoid fractures have been treated with cervical collars as well, but they have a less favorable union rate, with fusion rates ranging from 50 to 65% in small series (16, 75).

Halo immobilization

In a series of publications resulting in the largest institutional series of axis fractures published to date, 340 cases of axis fractures were reviewed, including 199 odontoid fractures (2 Type I, 116 Type II, 4 Type IIA, 77 Type III (36, 39, 40). Excellent results were obtained with rigid external immobilization in the Type I and Type III fracture patients (2 of 2 and 68 of 69 patients with successful fusion, respectively). Of the Type II patients, 95 were treated with external immobilization for a median of 13 weeks. The authors reported a 28% failure rate. Seven failures were successfully treated with additional external immobilization, and 18 patients underwent subsequent posterior C1–C2 fusion. The authors found that a displacement of the dens of 6 mm or more was associated with a high nonunion rate, irrespective of patient age, direction of displacement, or neurological deficit (86% failure rate; χ^2 33.74; $P < 0.001$). The degree of dens displacement and a negative correlation with fusion was noted by at least four other investigators (16, 24, 26, 48). The amount of odontoid displacement observed ranged from 2 to 6 mm in these studies.

Julien et al. (44) reviewed nine articles that dealt with treatment of odontoid fractures (total, 269 patients) using halo/Minerva fixation for 8 to 12 weeks (12, 15, 16, 24, 26, 30, 48, 58, 62). All patients with Type I odontoid fractures were found to have successful fusion (3 of 3 patients) (15, 30, 62). One hundred sixty-eight patients with Type II odontoid fractures were treated with halo immobilization; 110 (65%) had successful fusion. There was a 30% nonunion rate (50 of 168 patients). Eight patients were described as having a malunion. Of patients with Type III odontoid fractures, 84% (67 of 80 patients) achieved a solid fusion. There was an 8% failure rate (6 of 80 patients), and 7 cases were described as malunions. The authors of these series generally concluded that rigid external immobilization can be considered a viable treatment option for Type I, Type II, and Type III odontoid fractures. Rigid external immobilization seems to be most successful for patients with Type I, Type III, and nondisplaced Type II odontoid fractures, but it should be considered with caution in elderly patients.

Posterior cervical fixation

Posterior cervical fixation and fusion has been successfully used in the treatment of acute traumatic odontoid fractures. Although no criteria defining the indications for surgical fixation have been established, a number of retrospective case series suggest treatment options (15, 16, 18, 24, 30, 49, 58, 74). These papers describe a total of 147 patients who underwent posterior cervical fixation and fusion for Type II odontoid fractures and 29 patients treated similarly for Type III fractures. One patient with a Type I fracture was treated successfully with posterior fusion. The overall fusion rates for Type II and Type III fractures managed with surgical fixation and fusion were 87 and 100%, respectively, in these series. The report of Maiman and Larson (49) described a fusion rate of only 35% across the fracture line but a fusion rate of 100% at the posterior operative site.

The aforementioned series typically describe an instrumented (wire or cable) posterior C1–C2 arthrodesis and then cervical immobilization in a rigid orthosis. More recently, transarticular screw fixation and fusion of C1–C2 has been used for traumatic odontoid fractures, particularly in cases of failed fusion after initial management (14, 43). The reported surgical morbidity and mortality is 2 to 4% and includes failure of fracture reduction, vertebral artery injury, and the new onset of neurological deficit. Loss of motion at the atlantoaxial joint after posterior C1–C2 fusion results from of dorsal C1–C2 arthrodesis. Despite this, several authors favor posterior C1–C2 fusion rather than anterior odontoid screw fixation as the ideal treatment of unstable odontoid fractures (2, 14, 56).

Anterior cervical fixation

Anterior single and double screw fixation of odontoid fractures has been accomplished with success. The technical challenges associated with this procedure have limited widespread application. If successful, this technique has the potential to maintain rotational motion at the atlantoaxial joint. It has been suggested that this is an appropriate strategy when the odontoid fracture line is either horizontal or oblique and posterior and that it is contraindicated in situations where the fracture line is oblique and anterior (2, 3, 20, 55). In cases of transverse atlantal ligament disruption, anterior screw fixation can result in an unsatisfactory outcome despite union of the odontoid fracture owing to persistent transverse atlantal ligament incompetence. Julien et al. (44) summarized a series of articles that describe retrospective experiences with anterior screw fixation for odontoid fractures (9, 15, 22, 30, 43). The combined fusion rate of Type II fractures treated in these reports is 89% (112 of 126 patients). Patients with Type III odontoid fractures achieved radiographic fusion in 20 of 20 patients (100%). In a recent series reported by Subach et al. (69), 26 patients with Type II fractures (mean age, 35 yr) underwent anterior odontoid fixation with a single screw and then immobilization in a cervical collar (median, 7.2 wk). Twenty-five (96%) of 26 patients achieved successful fusion. The one failure was attributed to inadequate fracture reduction. That patient required subsequent posterior C1–C2 fusion. Jenkins et al. (43), in 1998, described a retrospective nonrandomized series of 42 patients undergoing anterior screw fixation for Type II odontoid fractures. The authors compared single-screw with two-screw techniques. The fusion rate in their experience was similar for single-screw fixation (81%) compared with two-screw fixation (85%). Use of lag screws to achieve anterior odontoid fixation is recommended. Complications of the procedure include retropharyngeal wall injury, screw fracture, infection, and screw misplacement with injury to surrounding vascular and neural structures (9, 22, 30). Attempts at anterior odontoid fixation using a transoral approach was associated with multiple significant complications (15).

Apfelbaum et al. (3) compared anterior screw fixation for recent and remote odontoid fractures at two institutions. One hundred forty-seven patients with Type II ($n = 138$) and Type III ($n = 9$) odontoid fractures underwent anterior screw fixation either within 6 months of injury (129 patients) or more than 18 months after injury (18 patients). The fusion rates were 88% in the <6-month group versus 25% in the remote fracture injury group ($P < 0.05$), with a mean follow-up of 18 months. A positive correlation was identified between fusion and fractures oriented in the horizontal or posterior oblique planes. No effect of age, sex, number of screws placed, or degree of dens displacement was identified. Their experience suggests that anterior odontoid screw fixation for odontoid fractures is most effective when performed early after injury, particularly within 6 months of fracture.

Odontoid fracture management in the elderly patient

One of the controversial issues in the management of odontoid fractures is the influence of age on treatment selection. A number of studies have examined the circumstance of acute odontoid fracture in the older patient. Three case series argue against surgical fixation in the elderly patient (36, 62, 67). Seven other case series favor surgical fixation in this age group. There is also one case-control study by Lennarson et al.

(46) providing Class II medical evidence for surgical treatment of elderly patients. Ryan and Taylor (63) described 30 patients 60 years and older with Type II odontoid fractures. The fusion success rate in patients older than 60 years treated with external immobilization was only 23%. The authors thought that the high fracture nonunion rate was secondary to inadequate immobilization and delays in diagnosis in most cases. If these issues were eliminated, no significant difference in outcome between surgical and nonsurgical management would have been demonstrated. They concluded that surgical fixation and fusion for elderly patients with odontoid fractures should be reserved for unusual circumstances. Greene et al. (36) reported the largest series (120 patients) of retrospectively reviewed cases of traumatic odontoid Type II axis fractures. Patients with dens displacement of 6 mm or more in their experience had a nonunion rate of 86%, compared with a nonunion rate of 18% for patients with displacement of less than 6 mm. The authors reported no significant relationship between fracture nonunion and age using χ^2 analysis. It might be argued that statistical tests of association would be more appropriate in this circumstance, and age might have been shown to be a factor had it been used.

Andersson et al. (2) described 29 patients 65 years and older with odontoid fractures managed by surgical and nonsurgical means. In their series, six (86%) of seven patients achieved successful fusion after posterior cervical C1–C2 arthrodesis. Worse results were observed in patients treated with anterior odontoid screw fixation (20% fusion rate) and in patients managed with external immobilization alone (20% fusion rate). These authors favored posterior cervical fusion over other management options in elderly patients with Type II odontoid fractures. Pepin et al. (58) reported their experience with 41 acute odontoid fractures (1 Type I, 19 Type II, 21 Type III). The authors found that halo immobilization was poorly tolerated in patients 75 years and older. They suggested that early C1–C2 fixation and fusion was appropriate in this group. Hanigan et al. (41) described 19 patients 80 years and older with odontoid fractures (16 Type II, 3 Type III). Five patients with displacement of more than 5 mm were treated with posterior cervical fixation and fusion with good results. Three of the five had stable nonunions. The authors reported a mortality rate of 26% in patients managed conservatively with prolonged immobilization rather than surgical fixation and fusion. On the other hand, they noted that no patient treated with external immobilization alone developed clinically significant instability. Pitzen et al. (59) described their experience with surgical therapy in seven patients 70 years and older with odontoid fractures. Two patients died of related medical comorbidity. Five patients did well and were mobilized early. The authors concluded that early surgical fixation in this age group is the preferred management strategy. This view is shared by several other investigators, including Seybold and Bayley (67), Campanelli et al. (14), and Muller et al. (56). Bednar et al. (5) reported a prospective assessment of elderly patients with odontoid fractures managed with early operative stabilization and fusion. Eleven patients were included in their study. The authors found a 91% fusion rate (10 of 11 patients). One patient died of unrelated causes. The authors argued in favor of early surgical intervention for elderly patients with odontoid fractures. In 1997, Berleman and Schwarzenbach (7) offered a retrospective review of their experience with 19 patients 65 years and older with Type II odontoid fractures treated with anterior odontoid screw fixation. Radiographic fusion with nearly 5-year follow-up was obtained in 16 (85%) of 19 patients. The authors concluded that anterior odontoid screw fixation is a successful therapy for elderly patients with Type II odontoid fractures.

In the only case-control Class II evidence study published on this topic, Lennarson et al. (46) examined 33 patients with isolated Type II odontoid fractures treated with halo vest immobilization. The authors found that age older than 50 years was a significant factor for failure of fusion in a halo immobilization device. Patients 50 years and older had a risk for nonunion 21 times higher than that found for patients younger than 50 years. No significant effect on outcome was found attributable to other medical conditions, sex of the patient, degree of fracture displacement, direction of fracture displacement, length of hospital stay, or length of follow-up.

Traumatic spondylolisthesis of the axis (hangman's fracture)

Overview

Traumatic fractures of the posterior elements of the axis, often related to hyperextension injuries from motor vehicle accidents, diving, and falls, are reminiscent of the injury induced to the axis by judicial hangings (65, 78). A distinction has been made between the two fracture types because the mechanisms of injury are different. The mechanism of injury associated with judicial hanging is one of distraction and hyperextension. The more common hangman's fracture injury induced by motor vehicular trauma is typically a result of hyperextension, compression, and possible rebound flexion. The incidence of head injury is high with the latter hangman's fracture injury type.

Wood-Jones (78) described the cervical fracture-dislocation injury induced by hanging in 1913. Garber (32) used the term "traumatic spondylolisthesis" of the axis in 1964. He described eight patients with "pedicular" fractures of the axis after motor vehicle accidents. The term "hangman's fracture" has been attributed to Schneider (65), who described a series of eight patients and noted the similarity between the fracture of the posterior elements of the axis to the pattern of fracture injury induced by judicial hanging. Williams (77) documented four cases of hangman's fracture injury in 1975, noting that three occurred associated with motor vehicle accidents and the fourth with a fall. A number of authors have suggested that a more appropriate term for this axis injury type may be "traumatic spondylolisthesis of the axis" because of the differences in the mechanism of injury between hanging and the deceleration injuries of falls and motor vehicle accidents (28, 29). Most traumatic spondylolisthesis fractures of C2 caused by motor vehicle accidents seem to result from hyperextension and compression, rather than the hyperextension and distraction associated with hangings. These differences in the mechanism of injury, along with the wide range of neurological deficits identified with these injuries, prompted a series of investigators to attempt to better characterize and classify traumatic spondylolisthesis injuries of the axis.

Classification of hangman's fractures

In 1981, Pepin and Hawkins (57) published a two-type classification scheme for hangman's fractures. Type I was described as a nondisplaced fracture of the posterior elements alone. Type II was a displaced fracture involving the posterior elements and the body of C2. The authors successfully treated 42 patients without surgery using their scheme, which involved reduction (Type II injuries) and immobilization. They noted a low incidence of associated spinal cord injury, but a frequent association with head injury. Although simple and effective, Pepin and Hawkins' scheme has not gained popular acceptance and is not widely used. In the same year, Francis et al. (29) published a collaborative experience in treating 123 patients with traumatic spondylolisthesis of the axis. Injuries were divided into five grades based on displacement and angulation of C2 on C3. Grade I was defined as displacement of less than 3.5 mm and angulation of less than 11 degrees. Grade V was defined as complete C2–C3 disc disruption. Grade IV in their scheme had more than 3.5 mm of C2–C3 disruption, but less than half of C3 vertebral width with more than 11 degrees of C2–C3 angulation. Grades II and III were injury types graded between Grades I and IV.

Effendi et al. (25) described three types of fractures of the ring of the axis based on a series of 131 patients. Their classification scheme was based on the mechanism of injury: Type I, axial loading and hyperextension; Type II, hyperextension and rebound flexion; Type III, primary flexion and rebound extension. Type I fractures were defined as isolated hairline fractures of the ring of the axis with minimal displacement of the body of C2. Type II fractures were defined as displacement of the anterior fragment with disruption of the disc space below the axis. Type III fractures were defined as displacement of the anterior fragment with the body of the axis in a flexed position in conjunction with C2–C3 facet dislocation. This Type III fracture is associated with a flexed forward position of the axis body. The incidence of Type I, II, and III fracture injury in their series was 65, 28, and 7%, respectively. Levine and Edwards (47) modified Effendi's classification scheme in 1985. They added flexion-distraction as a mechanism of injury (Type IIA) and offered a tailored treatment strategy for each of the four injury types. In the largest series of axis fractures yet described, Greene et al. (36) used the classification schemes of both Effendi et al. and Francis et al. to characterize 74 hangman's fractures. The most common fracture pattern identified was the Effendi Type I (72%) and the Francis Grade I (65%). The investigators found a strong correlation between Effendi Types I and III and Francis Grades I and IV, respectively.

Not all authors think that all hangman's fractures fit into one or both of these classification schemes. In the review by Burke and Harris (13) of 165 acute injuries of the axis vertebra, 62 (38%) were traumatic spondylolisthesis of the axis, including 13 Effendi I, 35 Effendi II, and 3 Effendi III injuries. Eleven patients (18%) had a fracture pattern not previously described in which one or both fractures involved a portion of the posterior cortex of the body of the axis.

Incidence of traumatic spondylolisthesis and associated injuries

In Greene et al.'s (36) series of 1820 cervical fractures, 340 (19%) were fractures of the axis and 74 (4%) were hangman's type. In the series of acute fractures of the axis vertebra described by Burke and Harris (13), injuries of the axis were associated with other fractures of the cervical vertebra in 8% of cases. Ryan and Henderson (61) studied 657 patients with cervical spine fractures over a 13-year period. Hangman's-type fractures occurred as isolated fractures in 74% of their series. Only 9% were associated with fractures of C1. An additional 9% were associated with subaxial cervical spine fractures. In the series of Guiot and Fessler (37) of 10 complex combined atlantoaxial fractures, only one involved a hangman's injury. Although the incidence of spinal cord and nerve root injury as a result of a hangman's fracture is reportedly low, unstable hangman's injuries do occur with some frequency (12, 57). If the patient survives the initial injury, it has been proposed that the relatively spacious intracanicular diameter affords some protection against spinal cord compression (54). Starr and Eismont (68) described an atypical fracture pattern occurring through the posterior aspect of the vertebral body, with continuity of the posterior cortex or pedicle and narrowing of the spinal canal as a result of the associated subluxation. In their series of 19 patients, this hangman's fracture variant occurred in six patients, including two patients with resultant paralysis. In the series described by Francis et al. (29), 8 (6%) of 123 patients they managed had neurological deficits. Tan and Balanchandran's (70) retrospective series of 33 hangman's fractures included 14 patients with no neurological deficit at admission. The other 19 (57%) had neurological deficits ranging from quadriparesis to urinary retention. Twenty-eight patients (85%) had returned to employment at the 1-year follow-up. Mirvis et al.'s (53) series of 27 patients had associated neurological findings in 26% of patients with hangman's fractures. Combination fractures of C1 and C2 in association with a hangman's-type C2 injury seem to have a higher incidence of associated neurological injury, likely because of increased instability and a more severe traumatic injury pattern (23, 37).

Treatment

Most patients with traumatic hangman's fractures reported in the reviewed literature were treated with cervical immobilization with good results. The three largest experiences reported are the multi-institutional series of Effendi et al. (25) and Francis et al. (29) and the single institutional experience described by Greene et al. (36). Management strategies and surgical indications vary somewhat among investigators.

In the series reported by Effendi et al. (25) in 1981, there were 85 Type I fractures, 62 of which were managed with external immobilization. They reported 37 Type II fractures;

17 of the patients were treated with bracing and 15 with surgical fusion. Of the patients managed surgically, 4 were treated with a C2–C3 anterior fusion and 11 were treated with dorsal internal fixation and fusion. Nine patients had Effendi Type III fractures. Three died without definitive treatment, one was managed in a brace, and five were treated surgically with fusion, one anterior and four posterior. The authors concluded that most hangman's fractures were best managed nonoperatively. They commented that they might have overtreated patients early in their series, offering surgery when external immobilization might well have been successful. They decided that surgery should be reserved for unusual Type III fractures and those patients with failure of fusion despite 3 months of halo immobilization.

In Pepin and Hawkins' (57) series, also reported in 1981, all 42 patients with hangman's fractures they treated healed successfully with external immobilization alone. Francis et al. (29) described and classified hangman's fracture injuries in 123 patients from four institutions. Injuries were categorized into Grades I through V on the basis of displacement and angulation. There were 19 Grade I, 9 Grade II, 46 Grade III, 42 Grade IV, and 7 Grade V fractures. All patients were initially managed with traction with conversion to a halo orthosis or were treated in a halo vest without traction. Healing occurred in 116 patients (95%) with halo immobilization alone. Seven patients received surgical management with fusion for nonunion despite halo immobilization (four had an anterior C2–C3 fusion, two had a posterior C1–C3 fusion, and one had a posterior C2–C4 fusion). The authors assessed the injury type with respect to success with nonoperative management. Three (33%) of 9 Grade II injury patients and 2 (28%) of 7 Grade V injury patients developed nonunion despite halo management and required subsequent surgical treatment. Halo treatment failed in none of the Grade I and Grade III injury patients and in only one Grade IV injury patient. The authors concluded that primary surgical treatment for hangman's fracture injuries is not indicated. All patients should be provided late follow-up to assess for nonunion, particularly Grade II and Grade V injury patients. When surgical management is considered, the authors recommended an anterior C2–C3 fusion.

In Levine and Edwards' (47) series of 52 patients with hangman's fractures, all isolated Type I, II, and IIa injuries were managed nonoperatively. Three of five Type III patients underwent surgical stabilization and fusion for failure to obtain or maintain fracture reduction in a halo. The authors singled out the subgroup of the Effendi Type II fracture that significantly distracted with the application of craniocervical traction. They thought that Type II injuries were likely the result of flexion-distraction forces. The three patients with Type II fractures in their series were successfully treated with mild compression-extension in a halo vest under fluoroscopic control (47).

Greene et al. (36) noted a strong correlation between Effendi Type I and Francis Grade I hangman's injury and between Effendi Type III and Francis Grade IV fractures in their series of 74 patients. Sixty-five of 74 patients were treated nonoperatively with external immobilization for a median of 12 weeks. There were two early deaths. Seven patients required early surgical fixation and fusion for inability to maintain fracture alignment in a halo brace. All seven early surgical patients were either Effendi Grade II or III, and five of the seven were Francis Grade III or IV. Overall, 33% of patients with unstable Effendi Types II and III or 36% of Francis Grades III, IV, and V injuries required early surgical treatment. Eventually, all seven patients achieved solid fusion without evidence of instability. The authors compared their experiences with those of Effendi et al. and Francis et al. and concluded that conservative management (external immobilization) should be the initial treatment in virtually every patient with a hangman's fracture. Early surgical management should be reserved for unstable injuries that are ineffectively immobilized in a halo device.

In a combined clinical and cadaveric anatomic study, Mestdagh et al. (52) described their experience with 41 fractures of the posterior neural arch of the axis. Eleven cases were treated surgically with anterior C2–C3 interbody fusion, and 30 patients were treated with external immobilization. Thirty patients were available for follow-up. Cervical mobility was better in patients managed conservatively. Displacement of up to 5 mm at the hangman's fracture site in a cadaveric study was compatible with stability without disruption of the ligaments or the C2–C3 disc space. The authors concluded that conservative management was the ideal treatment for hangman's fractures, except in cases of marked instability or failure of union. Grady et al. (35) reported their experience with 27 patients with hangman's fractures. Sixteen were managed in a halo device, eight in a rigid collar, and three with bed rest only. All achieved fusion with no residual symptoms. The authors concluded that use of a Philadelphia collar alone for hangman's fractures is a reasonable alternative to halo immobilization, particularly for injuries with minimal C2–C3 displacement. In 1987, Govender and Charles (33) prospectively studied 39 patients with traumatic spondylolisthesis of the axis. Injuries were classified for stability by the criteria of White and Panjabi (76). All patients were successfully treated with collar immobilization regardless of assessment of stability. The authors argue against basing treatment on dynamic imaging, as advocated by Effendi et al. (25) and Levine and Edwards (47). A number of other reports favor nonoperative management of hangman's fractures (4, 11, 17, 27, 33, 47, 50, 52, 66, 71).

Surgical management

Surgical options for unstable hangman's fracture injuries, particularly those that fail to heal despite external immobilization, include anterior C2–C3 interbody fusion and dorsal C1–C3 fusion procedures. In the series of Effendi et al. (25), 42 of 131 patients with hangman's fractures were treated surgically. Ten were treated with an anterior C2–C3 fusion, and 32 underwent a posterior fusion. All were successfully stabilized at last follow-up. In the Francis et al. (29) series of 123 hangman's fracture patients, only 7 patients were treated surgically. Four underwent anterior C2–C3 fusion, two had posterior C1–C3 fusion, and one underwent posterior C2–C4 fusion. The authors noted that 6 of the 7 patients requiring fusion for nonunion had C2–C3 angulation of more than 11 degrees. All seven patients achieved bony stability.

A number of case series of hangman's fractures offer similar experiences with surgical management. McLaurin et al. (51) described their experience with early fusion in two patients with hangman's fractures to allow early mobilization. The authors acknowledged that both injuries would likely have healed with external immobilization alone. Salmon (64) described 20 patients with hangman's fractures treated with posterior interlaminar wiring and fusion with no morbidity. Verheggen and Jansen (73), in their 1998 report, argued strongly for surgical fixation and fusion of Effendi Type II and III hangman's fractures. In their opinion, the optimal management of these injuries remains controversial. They described 16 patients with hangman's fractures they treated with surgical fixation of the posterior arch of the axis with screw fixation. They found that this fixation technique resulted in superior functional results as compared with historical controls. They favor this management strategy in the setting of the Levine and Edwards (47) Type IIa fracture. The viewpoint of Verheggen and Jansen (73) is challenged by Sypert (69a) in his comments that accompany their article. Borne et al. (10), in 1984, published their approach to the management of pedicular fractures of the axis. They used a technique of bilateral posterior screw fixation. They described excellent results and a 100% fusion rate. Despite this, their technique has not gained widespread acceptance.

Fractures of the axis body

A number of authors have addressed the management of non-odontoid, non-hangman's fractures of the axis. They have been labeled as miscellaneous fractures of the axis, non-odontoid non-hangman's fractures, or simply axis body fractures (6, 31, 36, 40). Several attempts have been made to classify the various fracture types within this diverse group. Benzel et al. (6) reported on 15 patients with fracture of the axis body and divided them into three types: coronal, sagittal, and transverse oriented. The latter group was thought to represent the same group as the Anderson and D'Alonzo Type III odontoid fracture. The authors proposed that the Type III odontoid fracture classification be discarded because it is misleading (6). The original authors had the same thought (1). Benzel et al. (6) offered a mechanism of injury for each of the three fracture types they described. No treatment or outcome data were included in their report. Greene et al. (36) described 67 patients with miscellaneous axis fractures of all types. Of the 61 patients available for follow-up (median follow-up, 14 mo), all but one was successfully managed with a variety of nonoperative means. The authors note that this is a diverse injury group and describe a treatment algorithm based on features of fracture stability. Only one patient with a miscellaneous axis fracture required surgical intervention for delayed nonunion. Fujimura et al. (31) classified 31 axis body fractures on the basis of their radiographic injury pattern: avulsion, transverse, burst, or sagittal. In their series, all nine cases of avulsion fracture and the two cases of transverse fracture healed with external immobilization. Two of the three burst fractures were treated with C2–C3 anterior interbody fusion. Of the 17 sagittal fractures, 15 healed with nonoperative treatment. The remaining two patients required surgical fusion. The authors recommend initial nonoperative treatment for all non-odontoid, non-hangman's axis fractures. Craig and Hodgson (19) added nine cases of axis fractures involving the superior articular facet. In seven patients, there was an associated odontoid fracture. This fracture occurred in either the coronal or sagittal plane, resulting in shearing of the anterior or lateral portion of the facet complex. The lateral mass of the atlas was noted to occasionally sublux into the facet fracture. The authors recommended immobilization for nondisplaced fractures and the consideration of surgical reduction, fixation, and fusion for fractures that are difficult to reduce. Bohay et al. (8) described three unusual fractures of the posterior body of C2, all of which responded to nonoperative management. Jakim and Sweet (42) contributed a single case. Korres et al. (45) described 14 patients with avulsion fractures of the anteroinferior portion of the axis that they believed to be extension-type injuries. These cases represented only 3% of the cervical spine fractures they managed over a 12-year period. All 14 of these body fracture types were successfully managed with cervical immobilization (mean follow-up, 8.5 yr).

SUMMARY

Fractures of the odontoid

There is no Class I medical evidence addressing the issue of management of acute traumatic odontoid fractures. A single Class II evidence paper reviews the management of Type II odontoid fractures in halo immobilization devices. This study demonstrated a 21-fold increase in risk of nonunion with halo immobilization in patients older than 50 years. All other articles reviewed contain Class III evidence that supports several treatments.

Type II odontoid fractures in patients 50 years and older should be considered for surgical stabilization and fusion. Type I, Type II, and Type III fractures may be managed initially with external cervical immobilization. Type II and Type III odontoid fractures should be considered for surgical fixation in cases of dens displacement of 5 mm or more, comminution of the odontoid fracture (Type IIA), and/or inability to achieve or maintain fracture alignment with external immobilization. Isolated Type I and Type III odontoid fractures may be treated with cervical immobilization, resulting in fusion rates of 100 and 84%, respectively. Anterior surgical fixation of Type III fractures has been associated with a 100% fusion rate. Type II odontoid fractures may be treated with external immobilization or surgical fixation and fusion. Halo immobilization and posterior fixation have both been used successfully for these injuries. Anterior odontoid-screw fixation has been reported with an up to 90% fusion success rate, except in older patients. Treatment of Type II odontoid fracture with a cervical collar alone or traction and then cervical collar immobilization may also be undertaken, but these methods have lower success rates.

Traumatic spondylolisthesis of the axis

There is no Class I or Class II medical evidence addressing the management of traumatic spondylolisthesis of the axis. All articles reviewed contain Class III evidence that supports a variety of treatments. Most hangman's fractures heal with 12 weeks of cervical immobilization with either a rigid cervical collar or a halo immobilization device. Surgical stabilization is an option in cases of severe angulation (Francis Grade II and IV, Effendi Type II), disruption of the C2–C3 disc space (Francis Grade V, Effendi Type III), or the inability to establish or maintain fracture alignment with external immobilization.

Fractures of the axis body (miscellaneous axis fractures)

There is no Class I or Class II medical evidence addressing the management of traumatic fractures of the axis body. All articles reviewed contain Class III evidence that supports the use of external immobilization as the initial treatment strategy.

KEY ISSUES FOR FUTURE INVESTIGATION

More data are necessary to determine treatment standards and/or guidelines for the definitive management of odontoid fractures. For Type I and Type III fractures, the available Class III evidence suggests that a well-designed multicenter case-control study could provide sufficient evidence to define their appropriate management in the early postinjury period. For Type II fractures, the literature suggests that both operative and nonoperative management remain treatment options. A randomized or case-control study would be of benefit in establishing definitive treatment recommendations for this fracture type. Traumatic spondylolisthesis of the axis and miscellaneous axis fractures are treated successfully with external immobilization in most cases. A multicenter case-control study of patients with these injury types would help to define optimal treatment of each specific fracture subtype.

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