Management of Isolated Fractures of the Axis in Adults

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RECOMMENDATIONS

Fractures of the Odontoid

Level II:

- Consideration of surgical stabilization and fusion for type II odontoid fractures in patients ≥ 50 years of age is recommended.

Level III:

- Initial management of nondisplaced type I, type II, and type III odontoid fractures with external cervical immobilization is recommended, recognizing that a decreased rate of union (healing) has been reported with type II odontoid fractures compared with type I or type III odontoid fractures.
- Surgical stabilization and fusion of type II and type III odontoid fractures with dens displacement ≥ 5 mm, comminution of the odontoid fracture, and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.
- If surgical stabilization is elected, either anterior or posterior techniques are recommended.

Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Level III:

- External immobilization as the initial management of traumatic spondylolisthesis of the axis is recommended.
- Surgical stabilization and fusion for the treatment of Hangman fractures in cases of severe angulation of C2 on C3, disruption of the C2-3 disk space, and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.

Fractures of the Axis Body (Miscellaneous Fractures)

Level III:

- External immobilization for the treatment of isolated fractures of the axis body is recommended. Consideration of surgical stabilization and fusion in unusual situations of severe ligamentous disruption and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.
- In the presence of comminuted fracture of the axis body, evaluation for vertebral artery injury is recommended.

RATIONALE

The unique anatomy of the axis vertebra results in a variety of fracture patterns in the setting of significant cervical trauma. Fractures of the axis are often associated with other cervical fracture or ligamentous injuries. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons published a medical evidence-based guideline on this important topic[1] and subdivided axis fractures into 3 general subtypes: fractures of the odontoid process, traumatic spondylolisthesis of the axis (Hangman fractures), and miscellaneous nonodontoid non-Hangman fractures of the C2 vertebra. The previous guideline recommended that surgical stabilization of type II odontoid fractures in patients ≥ 50 years of age be considered on the basis of Class II medical evidence. All other recommendations for the treatment of all other isolated fractures of the axis were made at a lower level of medical evidence (Class III) and included both cervical immobilization and surgical fixation with fusion, depending on the fracture type and its radiographic features. It was recommended that type I, II, and III odontoid fractures be managed by immobilization alone. Surgical fixation and fusion were recommended for those cases with a dens displacement of ≥ 5 mm, comminution of the odontoid fracture (type IIA fractures), and/or the inability to maintain fracture alignment. It was recommended that traumatic spondylolisthesis of the axis be managed initially with external immobilization. However, consideration of surgical stabilization and fusion for Hangman fractures was recommended in cases of severe angulation of C2 on C3 (Francis grade II and IV, Effendi type II), disruption of the C2-3 disk space (Francis grade V, Effendi type III), or the inability to maintain alignment with external immobilization. Finally, it was recommended that fractures involving the axis body be treated with cervical immobilization. The purpose of this review is to update the medical evidence on the treatment of isolated axis fractures since the 2002 guidelines publication.[1]

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with "spinal cord injury": "axis," "vertebrae," "fracture," and "human." A total of 1181 articles were identified. Those articles focusing on the clinical management of acute traumatic axis fractures were selected for review. The bibliographies of these articles were scanned for additional references to confirm completeness of the literature review. Relevant articles addressing the mechanism of injury or the biomechanics and radiology of the C2 vertebra were considered for inclusion in the scientific foundation of this document.

Forty-six articles not previously included in the original guidelines document were identified, reviewed, and classified using established methodology. Thirty-one articles described the management of odontoid fractures; 10 articles were focused on traumatic spondylolisthesis of the axis; and 5 articles described the treatment of patients with miscellaneous axis fractures and are summarized in Evidentiary Table format.

SCIENTIFIC FOUNDATION

Odontoid Fractures

Classification of Odontoid Fractures

The classification of odontoid fractures into 3 types, as described by Anderson and D'Alonzo[2] in 1974, remains an accepted classification scheme for odontoid fracture injuries. The authors defined 3 odontoid fracture types based on their series of 49 patients. Type I fractures were described as oblique fractures through the upper portion of the odontoid process. Type II fractures were described as fractures across the base of the odontoid process near the junction with the axis body. Type III fractures were fractures that include the odontoid and extend into the body of the axis. This historic series includes 2 type I fractures (4%), 32 type II fractures (65%), and 15 type III fractures (31%). Hadley et al[3] modified this classification scheme in 1988, defining the type IIA odontoid fracture as a comminuted fracture of the base of the odontoid with associated free fracture fragments. This unique fracture was associated with severe instability in their series and represented 3 of the 62 type II odontoid fractures they treated. Further odontoid fracture classification modification was proposed by Grauer et al,[4] who described 3 subtypes of type II fractures. Type IIA was defined as a minimally or nondisplaced fracture with no comminution treated with external immobilization. Type IIB was defined as a displaced odontoid fracture that extends from anterior-superior to posterior-inferior, or a transverse fracture, amenable to anterior screw fixation if reducible, assuming adequate bone quality. Type IIC was defined as a fracture extending from anterior-inferior to posterior-superior or a fracture with significant comminution likely to be considered for posterior internal fixation and fusion. These modifications were introduced to specifically address the issue that the original Anderson-D'Alonzo scheme did not take into account the direction of the fracture across the dens, the presence of comminuted fragments, or the degree of displacement or angulation of the fractured odontoid process. In addition, the authors noted the difficulty in differentiating a low type II fracture from a high type III fracture. They applied their revised scheme to a series of 52 patients with odontoid fractures. Seven raters were asked to characterize the odontoid fracture injuries. There was agreement in 70% of the cases by at least 5 of 7 raters. The overall κ value for the modified system was 0.48, indicating moderate to good agreement. Other than this single study, none of these classification schemes (Table 1) have been subjected to rigorous validity and reliability evaluation.

Treatment

Numerous therapeutic strategies for odontoid fracture management have been described on the basis of a variety of factors, including the fracture type, degree of dens displacement, angulation of the dens with respect to the body of C2, interval between the fracture and treatment, and patient age. The medical evidence supporting the nonoperative management of odontoid fractures with external immobilization, including traction, a cervical collar, or the halo orthosis (including custom devices such as the suboccipital mandibular device and Minerva devices), and the surgical management of these fracture injuries, including posterior cervical fusion with or without supplemental screw fixation or anterior odontoid screw fixation, is the subject of this updated review.

Nonoperative Treatment

In 1985, the Cervical Spine Research Society published a multicenter review addressing the management of odontoid fractures. Their report included 18 patients with type II odontoid fractures and 3 patients with type III odontoid fractures who received no treatment. None of these patients achieved bony healing or fracture union. The authors concluded that no treatment was not a good option for patients with odontoid fractures.[5]

Traction. Evidence-based reviews by Traynelis[6] in 1997 and Julien et al[7] in 2000 include evidentiary tables that contain Class III medical evidence addressing the use of traction and subsequent immobilization in a cervical collar for patients with odontoid fractures. The combined radiographic union rates from these reports were as follows: type I, 100% (3 of 3); type II, 43% (42 of 97); and type III, 87% (55 of 63).

Cervical Collar. As described in the previous guideline publication, the treatment of the infrequent type I odontoid fracture with cervical collar immobilization has been reported to be successful in nearly 100% of cases (Class III medical evidence).[2,5,8] No new data of higher quality was identified in this review. Previous Class III medical evidence reports describing the outcome of type II fractures treated with a cervical collar alone resulted in union rates ranging from 53% to 57%.[9,10] The management of type III odontoid fractures with cervical collars results in union rates ranging from 50% to 65%, also based on Class III medical evidence.[5,10]

Halo Immobilization. In the largest reported series of axis fractures published in 1997, Greene et al[11] described the management of 199 patients with odontoid fractures: type I, n = 2; type II, n = 116; type IIA, n = 4; and type III, n = 77. Union rates for those treated with a halo orthosis were reported to be the following: for type I, 100% (2 of 2); for type II, 72% (68 of 95); and for type III, 99% (68 of 69). Analysis of the type II fractures with nonunion indicated that a dens displacement of ≥ 6 mm was associated with an increased rate of nonunion regardless of patient age, direction of displacement, or neurological deficit. The negative impact of dens displacement ranging from 2 to 6 mm on successful healing/union was confirmed in other reports.[5,12-14]

The evidenced-based review by Julien et al[7] included a total of 269 patients with odontoid fractures treated with rigid external fixation (halo orthosis or Minerva vest) for 8 to 12 weeks. Reported union rates were as follows: for type, I 100% (3 of 3); for type II, 65% (110 of 168); and for type III, 84% (67 of 80). The Class III medical evidence provided in these reports was the foundation for the option level/Level III recommendations for treatment of odontoid fractures published in the previous guideline.

Shears and Armitstead[15] in 2008 published a Cochrane Review of odontoid fracture management and concluded that no randomized medical evidence existed on this topic.

In 2007, Platzer and colleagues[16] reported their series of 90 patients with type II odontoid fractures. The authors prospectively studied the success of halo immobilization with union as the outcome of interest. The mean patient age in their series was 69 years. The reported union rate was 84% (76 of 90). Eighty-three percent of these patients (75 of 90) returned to their preinjury status. The authors identified the following risk factors for failure of halo immobilization ($P < .05$): older patients (cases, 77.2 years vs controls, 60.8 years; $P < .05$) and displaced fractures > 2 mm (cases, 11 of 14 [79%] vs controls, 16 of 76 [21%]). Two other factors had a significant effect on the multivariate regression analysis they performed: secondary loss of reduction and delay of treatment ($P < .05$). If 2 of these covariate risk factors were present, there was a 57% risk of nonunion. The likelihood of nonunion increased to 70% with 3 covariate risk factors and was 87% when all 4 risk factors were present. The authors concluded that halo immobilization provided satisfactory outcome with an 84% union rate. This publication supports the previous case-control study published by Lennarson et al[17] in which patient age was identified as a risk factor for nonunion, along with the degree of dens displacement, secondary loss of reduction, and delay of treatment. Although the authors described their analysis as a case-control study, with respect to treatment, it is a prospective cohort study. Because all of the patients were treated the same, there is no comparison group. Their study offers Class III medical evidence on this topic.

Kim et al[18] present a prospective cohort study of 20 patients with type II odontoid fractures to evaluate radiographic indicators for predicting failure of treatment with halo immobilization. Of 14 patients in a halo group, 4 patients developed nonunion. All 4 patients had a > 5° change of angulation in the dens fracture between supine and upright films at the 2-week time point. None of the patients in the successful union group demonstrated this radiographic finding.

In 2005, Kontautas et al[19] reported their prospective nonrandomized cohort study of 37 patients with type II odontoid fractures treated initially with traction to determine reducibility. Two groups were identified: group 1with dens displacement ≤ 5 mm and group 2 with dens displacement > 5 mm. The groups were equivalent by age, sex, neurological condition, and associated spinal fractures ($P > .05$). Eleven group 1 injuries (64%) and 13 Group 2 fractures were able to be reduced and treated in a halo device. The nonunion rate at 8 weeks for group 1 injuries was 0%. Fracture injuries had a 16.7% nonunion rate. Patients with fractures that could not be reduced and those who failed halo treatment were treated with posterior internal fixation and fusion. The authors concluded that when closed reduction of an odontoid fracture can be achieved, external immobilization with a halo-vest device will likely be effective.

Nourbakhsh et al[20] published a meta-analysis using a random-effects model to assess the effectiveness of nonoperative management of type II odontoid fractures. The authors identified a union rate > 80% for all patients < 55 years of age regardless of the mode of treatment. External immobilization (halo vest or collar) was equally effective with anterior displacement of the dens fracture and younger patients (< 55 years of age).

Müller et al[21] in 2003 reported a retrospective analysis of 26 "stable" type II and III fracture patients managed with collar immobilization. A stable fracture met the following criteria: fracture gap of < 2 mm, displacement of < 5 mm, and angulation of < 11°. Reported union fusion rates were 73.7% for type II fractures and 85.7% for type III fractures. In 4 patients (15%), a fibrous union was documented. Three of these patients were > 65 years of age. No correlation between clinical outcome and the radiological finding of a fibrous union was identified. Patients with a stable fibrous union were as pleased with their outcome as those patients with documented bony fusion. The authors concluded that stable type II and III fractures of the odontoid can be treated successfully with collar immobilization.

In 2010, Butler et al[22] reported their series of 66 patients with type II odontoid fractures treated with halo immobilization. The nonunion rate was 21% in patients > 65 years of age (compared with 2% for patients < 65 years of age). Age was associated with poorer functional outcomes. Similarly, Komadina et al[23] described a high rate of union for type II and III odontoid fractures managed in a halo immobilization device (86%). Sixty-five percent of their patients had complete symptom resolution at the 1-year follow-up.

Operative Treatment

Posterior Cervical Fixation. The previous guideline publication summarized the outcome of 177 patients with odontoid fractures treated with posterior cervical fixation and fusion. Fusion success after operative treatment was as follows: type I, 100% (1 of 1); type II, 87% (128 of 147); and type III, 100% (29 of 29). Of note, Maiman and Larson[24] reported a union rate at the fracture site of only 35% but a fusion rate of 100% at the posterior operative site. These patients were treated with an instrumented (wire or cable) posterior C1-2 arthrodesis followed by immobilization in a rigid orthosis. At the time of the previous guideline publication, transarticular screw fixation and fusion of C1-2 had been described,[25] particularly in patients with fracture nonunion after initial management, but the experience was limited.

Anterior Cervical Fixation. Screw fixation of odontoid fractures from an anterior approach, although technically challenging, has the potential to maintain rotational motion at the atlantoaxial joint, which is lost with posterior C1-2 fusion techniques. Anterior odontoid screw fixation is best suited for fractures that are either horizontal or oblique and posterior with an intact transverse atlantal ligament.[26-29] The previous guideline identified Class III medical evidence addressing the role of anterior odontoid screw fixation. Julien et al[7] described fusion rates of 89% (112 of 126) for type II fractures and 100% (20 of 20) for type III fractures. Subach et al[30] reported 1 failure resulting from inadequate reduction in their series of 26 type II fractures treated with anterior odontoid fixation (fusion rate, 96%). The success of anterior odontoid fixation has been reported to be similar with 1 vs 2 screws (81% vs 85%)[31] and greater when it is performed within 6 months of injury compared with 18 months after injury (88% vs 25%).[32]

Smith et al[33] examined a 20-year period to identify trends in the role of surgery for type II odontoid fractures. They found that the rate of surgical intervention for these injuries increased during the study period. A thorough report on the role of surgery for odontoid fractures was published recently by Nourbakhsh et al.[20] Their meta-analysis offers Class III medical evidence on this issue. The authors concluded that operative treatment of acute type II fractures (posterior C1-2 fixation or anterior screw fixation) increases the union/fusion success rate compared with external immobilization and is recommended for older patients, patients with posterior displacement of the dens fracture, and in cases with dens displacement > 4 to 6 mm.

A large number of case series without comparison groups (Class III medical evidence) have been published and support the safety and efficacy of anterior odontoid screw fixation in the treatment of type II and III odontoid fractures. Moon et al[34] treated 32 patients with type II or III odontoid fractures with anterior odontoid screw fixation followed by halo vest immobilization and reported a 100% fusion rate at 9 weeks. Fountas et al[35] in 2005 reported their results with anterior odontoid screw fixation in 31 patients with type II and "shallow" type III odontoid fractures. They identified an 87% fusion rate at long-term follow-up (mean, 58.4 months). Lee et al[36] described 48 patients with type II and III odontoid fractures treated with single anterior odontoid screw fixation. They reported a fusion rate of 96% and a failure rate of 10% (1 nonunion and 1 malposition). Bhanot et al[37] reviewed their experience with 17 type II odontoid fractures managed with ventral screw fixation. They reported fusion in 94% of patients (16 of 17) with 1 nonunion and 1 case of screw back-out. Chi et al[38] described 10 patients with type II and III odontoid fractures managed with a percutaneous anterior odontoid screw technique. They described fusion success in 9 of 10 patients. Song et al[39] described 16 patients with type II and III odontoid fractures treated with single anterior odontoid screw fixation. They found a 94% fusion rate. One patient required a subsequent posterior procedure. Cervical spine range of motion after treatment was reported as full in 12 patients and limited in 4 patients.

Odontoid Fracture Management in the Elderly Patient

The management of odontoid fractures in the elderly is controversial. The previous guideline publication identified 1 Class II medical evidence article favoring surgical fixation of type II odontoid fractures in patients > 50 years of age. Multiple Class III medical evidence articles offer conflicting evidence on this issue, although the majority of the case series previously reviewed support a role for surgery in elderly patients with type II odontoid fractures.

The case-control study by Lennarson et al[17] provides Class II medical evidence on the topic. The authors examined 33 patients with isolated type II odontoid fractures treated with halo vest immobilization. Patients were divided by age and outcome and by union or nonunion of their odontoid fracture. Patients ≥ 50 years of age had a risk of nonunion 21 times greater than patients < 50 years of age when treated with halo immobilization. Medical conditions, sex of the patient, degree of fracture displacement, direction of fracture displacement, length of hospital stay, and length of follow-up were not found to have a significant effect on outcome.

The ability of elderly patients to tolerate halo fixation immobilization has been questioned.[40] Mortality rates as high as 26% with the use of the halo device have been reported.[41] Reported union rates for odontoid fractures in elderly patients treated with halo immobilization vary between 20% and 100% in the literature.[2,41,42] Fusion rates reported for elderly patients treated with surgery are generally higher.[2,43,44] The majority of published papers on this topic favor consideration of surgery in the elderly patient with an odontoid fracture.[25,45-47] Multiple Class III medical evidence articles and the single Class II medical evidence citation formed the basis for the previous guideline recommendations on the management of odontoid fractures. The current review identified 12 citations on the management of elderly patients with odontoid fractures published since 2002. All provide Class III medical evidence.

Börm et al[48] reported their study of the effect of age on outcome in 27 patients with type II odontoid fractures treated with anterior odontoid screw fixation. The patients were evaluated in 2 groups. Group 1 contained patients ≥ 70 years of age, and group 2 contained patients < 70 years of age. The groups were equivalent in terms of demographics. There was no significant difference between the 2 groups with respect to fusion success rate (73% vs 75%), the need for subsequent posterior operative procedures (13% vs 17%), or the incidence of complications (20% vs 8%). This article provides Class III medical evidence that age alone does not have a negative impact on outcome after anterior odontoid screw fixation.

Dailey et al[49] retrospectively reviewed 57 type II odontoid patients > 70 years of age whom they treated with anterior odontoid screw fixation. Postoperative stability was reported in 81% of the patients. In patients treated with 2 screws, stability was 96% compared with 56% for 1-screw fixation. They reported a 25% incidence of significant dysphagia and a 19% rate of aspiration pneumonia in their series.

Platzer et al[50] in 2007 published their series of patients with type II odontoid fractures (n = 110) managed with anterior screw fixation. They examined the effect of age on nonunion. The overall fusion rate was 93%. They identified an increased rate of nonunion in older patients (12% vs 4%; $P < 0.05$). The authors concluded that anterior screw fixation was a safe and effective option for the treatment of type II odontoid fractures in patients of all ages.

Smith et al[51] published a retrospective cohort analysis of older patients with type II odontoid fractures (≥ 80 years of age) and compared operative (n = 32) and nonoperative (n = 20) treatment strategies. The length of acute hospital stay was longer in the operative treatment patients (mean, 22.8 vs 11.2 days; $P < .05$). Significant complications were greater in the operative group compared with the nonoperative group (62% vs 35%; $P < .05$). The mortality rate was similar in the 2 groups (12.5% vs 15%; $P > .05$) The authors concluded that type II odontoid fractures in the octogenarian population are associated with significant morbidity and mortality regardless of management. They found that nonoperative management was associated with fewer complications and outcomes similar to those from operative management. This retrospective comparative cohort study offers Class III medical evidence on this topic.

White et al[52] published a systematic review of the literature from 1990 through 2010 on the role of surgery for odontoid fractures in the elderly. Fourteen articles met their criteria for analysis. They identified a postoperative mortality rate of 10.1% (in-hospital, 6.2%; after discharge, 8.8%). There was no difference in postoperative mortality on the basis of operative approach, anterior vs posterior. The incidence of postoperative complications in this patient group was airway compromise (17%), pneumonia (9.9%), respiratory failure (7.7%), cardiac failure (6.8%), deep vein thrombosis (3.2%), stroke (3.2%), liver failure (6.7%), and severe infection (3.2%).

Koech et al[53] evaluated the effectiveness of nonoperative management of type II odontoid fractures in 42 elderly patients treated with either collar (n = 10) or halo (n = 32) immobilization. They found bony fusion rates of 50% and 37.5%, respectively. They described radiographic stability rates of 90% and 100%, respectively. They found no difference in clinical outcome between bony fusion, fibrous union, and radiographic stability. The authors suggested that fibrous union with radiographic stability may be a suitable outcome in elderly patients.

Majercik et al[54] compared patient age and outcome with treatment in a halo immobilization device (not specifically odontoid fracture patients) and found a mortality rate of 21% in patients ≥ 66 years of age compared with 5% in patients < 66 years of age ($P < .05$). These authors strongly recommended against halo vest immobilization in the treatment of cervical fracture injuries in elderly patients if other treatment alternatives were available.

Similarly, Tashjian et al[55] reported the morbidity and mortality of halo immobilization compared with collar and/or operative treatment in a cohort of 78 patients with type II, type III, and combination atlas-axis fractures in patients with a mean age of 81 years. All patients were > 65 years of age. There were 24 deaths during the initial hospitalization (31%). Of those treated in a halo device, 42% died. Major complications were twice as likely with a halo device, 66% vs 36% ($P = .003$). The authors concluded that odontoid fractures are associated with significant morbidity and mortality in the elderly. Both appear to increase significantly when treated in a halo immobilization device.

In 2010, Fagin et al[56] published a retrospective review of 108 patients with odontoid fractures whom they managed. Sixty-nine patients were managed nonoperatively; 17 were treated with an immediate operation; and 23 were treated with a delayed operation. The mean age of the nonoperative group was older, 82.4 years, compared with 77.4 and 76.4 years, respectively ($P = .006$). The mortality rate was not significantly different between the 3 groups (17.6%, 11.7%, and 8.7%, respectively; $P > .05$). The need for tracheostomy or gastrostomy and the development of urinary tract infection or pneumonia were equivalent in all groups. The incidence of deep vein thrombosis was lower in the nonoperative group compared with the early surgery group (3% compared to 18%; $P = .02$). The length of stay was less for nonoperative patients compared with operated patients (8.5 compared to 13.9 days; $P < .001$). The authors recommended that nonoperative treatment be strongly considered for elderly patients with odontoid fractures.

In 2009, Omeis et al[57] described 24 elderly patients with type II odontoid fractures treated surgically. They found a 7% incidence of central cord syndrome at presentation. Perioperative

TABLE 1. Initial Management of Isolated Axis Fracture in the Adult

Fracture Type	Treatment Options
Odontoid fracture	
Type I	Collar immobilization
Type II	Consider for early surgery, age ≥ 50 y; Halo immobilization, age ≤ 50 y
Type IIA (Hadley), type IIC (Gauer)	Consider for early surgery
Type III	Collar or Halo immobilization, surgical fusion
Traumatic spondylolisthesis of the axis (Hangman fracture)	
Stable (Effendi type I; Francis type I, II)	Halo immobilization, collar
Unstable (Effendi type II, III; Francis type III, IV, V)	Halo immobilization, consider surgical stabilization and fusion
Miscellaneous axis fractures	External immobilization in a collar or halo device

complications were identified in 10.3% of patients, including 1 perioperative death caused by a myocardial infarction. Sixteen patients underwent anterior odontoid screw fixation, and 13 underwent posterior fixation and fusion. Ultimately, 86.2% of patients treated surgically returned to their previous level of activity. The authors concluded that the elderly patient with a type II odontoid fracture can be treated with surgical fixation and fusion with acceptable morbidity and a relatively high expectation of returning to their preinjury status.

Frangen et al[58] published a retrospective review of elderly patients (median age, 85.5 years) with type II odontoid fractures treated with posterior C1-2 fusion. Their 2010 publication described a 22% perioperative mortality rate. Survivors in their series had a 95% rate of fusion with minimal operative complications. The authors concluded that compared with historical control subjects described in the literature, their fusion rate was high. They concluded that posterior surgery is recommended for the treatment of type II odontoid fractures in the elderly, but they recognized the relatively high mortality rate in this age group.

Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Classification of Hangman Fractures

Historically, the classification schemes for traumatic spondylolisthesis of the axis proposed by Effendi et al[59] and Francis et al[60] (with modification by Levine and Edwards[61]) have been the most widely used. The Francis classification[60] recognizes 5 injury grades of increasing severity based on displacement and angulation of C2 on C3:

- Grade I: fractures with 0- to 3.5-mm displacement and/or C2-3 angulation up to 11°
- Grade II: fractures with displacement < 3.5 mm and angulation > 11°
- Grade III: fractures with displacement > 3.5 mm but less than half of C3 vertebral width < 0.5 and angulation < 11°
- Grade IV: fractures with displacement > 3.5 mm but less than half of C3 vertebral width with > 11° angulation
- Grade V: fractures with complete C2-3 disk disruption.

The classification scheme proposed by Effendi et al[59] defines 3 types of fractures of the ring of the axis based on the mechanism of injury:

- Type I: isolated hairline fracture of the ring of the axis with minimal displacement of the body of C2 associated with axial loading and hyperextension
- Type II: fractures of the ring of the axis with displacement of the anterior fragment with disruption of the disk space below the axis associated with hyperextension and rebound flexion
- Type III: fractures of the ring of the axis with displacement of the body of the axis in a flexed forward position (angulation), in conjunction with C2-3 facet dislocation associated with primary flexion and rebound extension.

The incidence of type I, II, and III fracture injuries in the Effendi et al[59] original series of 131 patients was 65%, 28%, and 7%, respectively.

The modification of the Effendi classification scheme proposed by Levine and Edwards[61] added flexion-distraction as a mechanism of injury (type IIA), with 4 injury types:

- Type I: nondisplaced fractures and all fractures with < 3-mm displacement of C2 on C3 associated with hyperextension and axial loading.
- Type II: fractures with significant displacement (> 3 mm) and angulation > 11° defined as displacement of the anterior fragment with disruption of the C2-3 disk space associated with hyperextension and secondary flexion-compression.
- Type IIA: fractures with a minimum degree of C2-3 displacement but severe angulation associated with flexion-distraction
- Type III: fractures with unilateral or bilateral C2-3 facet dislocation in addition to fracture of the posterior elements associated with flexion-compression.

Greene et al[11] applied the Francis and Effendi classification schemes to 74 patients with Hangman fractures. They noted a strong correlation between Francis grade I and Effendi type I injuries and between Francis grade IV and Effendi type III injuries. The most common fracture types in their series were Effendi type I (72%) and Francis grade I (65%). Burke and Harris[62] applied the Effendi classification scheme to their series of 65 patients with Hangman fractures; 11% of the fracture injuries in their series were not accurately described by the Effendi scheme.

TABLE 2. Evidentiary Table: Axis Fractures: Odontoid Fracture

Reference	Description of Study	Evidence Class	Conclusions
Butler et al,[22] *European Spine Journal*, 2010	Retrospective review of 66 type II odontoid fractures treated with external immobilization	III	Nonoperative treatment was successful.
			Advancing age associated with significantly poorer long-term functional outcomes.
Dailey et al,[49] *Journal of Neurosurgery: Spine*, 2010	Retrospective review of 57 patients with type II odontoid fractures > 70 y of age treated with anterior odontoid screws	III	Higher stabilization rates with 2 screws.
			Anterior approach associated with dysphagia.
Fagin et al,[56] *Journal of Trauma*, 2010	Retrospective review of 108 odontoid fractures evaluating operative vs nonoperative management by age; age ≥ 60 y compared with < 60 y	III	Nonoperative management should be strongly considered in the elderly population.
White et al,[52] *Spine*, 2010	Systematic review addressing role of 14 articles discussing the role of surgery for odontoid fracture in the elderly	III	Morbidity is increased but acceptable in the elderly.
Nourbakhsh et al,[20] *Journal of Neurosurgery: Spine*, 2009	Meta-analysis of the role of surgery in type II odontoid fractures	III	Operative treatment increases fusion rate and is recommended in older patients, posterior displacement, and displacement > 4 mm.
			Nonoperative management equally effective with anterior displacement of the fracture and younger patients.
Omeis et al,[57] *Journal of Spinal Disorders and Techniques*, 2009	Retrospective review of 24 type II odontoid fractures treated surgically	III	Odontoid fractures in the elderly can be treated surgically with acceptable morbidity and mortality.
			The majority return to their preinjury levels of activity.
Collins and Min,[82] *Journal of Trauma*, 2008	Retrospective review of 15 elderly patients with type IIB (Grauer) odontoid fractures	III	Fusion rate was 77%.
			The results of anterior odontoid screw fixation in the elderly are satisfactory.
Kim et al,[18] *Spine Journal*, 2008	Prospective cohort study of 20 patients with type II odontoid fractures to identify radiographic indicators of potential failure of immobilization	III	Fracture angulation between supine and upright lateral x-ray films ≥ 5° associated with failure of external immobilization.
			Class III because there are no comparative treatment groups.
Koech et al,[53] *Spine*, 2008	Retrospective review of 42 elderly patients with type II odontoid fracture managed nonoperatively	III	No difference in outcome between fusion and stable fibrous union.
			Fibrous union may be an adequate outcome in the elderly.
Shears and Armitstead,[15] *Cochrane Database System Review*, 2008	Cochrane Review of odontoid fracture management; no studies fitting criteria identified	III	Appropriately designed clinical trials are recommended.
Smith et al,[33] *Orthopedics*, 2008	Retrospective review of type II odontoid fracture management trends over a 20-y period	III	The rate of surgical intervention increased during the study period.
Chi et al,[38] *European Spine Journal*, 2007	Retrospective review of 10 patients treated with percutaneous anterior odontoid screw fixation	III	Fusion rate 90%.
			Percutaneous screw fixation for odontoid fracture is effective.

(Continues)

TABLE 2. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
Frangen et al,[58] *Journal of Trauma*, 2007	Retrospective review of 27 patients with isolated unstable type II odontoid fractures	III	Posterior surgical stabilization and fusion was superior to halo-vest immobilization.
Platzer et al,[16] *Neurosurgery*, 2007	Retrospective comparative study of risk factors in 90 patients with type II odontoid fractures treated nonoperatively	III	Risk factors for failure of external immobilization include age and displacement > 2 mm, loss of reduction, and delay in treatment.
			Nonoperative management was successful.
			Class III because there is no comparative treatment group.
Platzer et al,[50] *Spine*, 2007	Retrospective review of 110 patients with Type II odontoid fractures treated with anterior screw fixation.	III	Fusion rate 93%.
			Anterior screw fixation is successful.
			Younger patients have higher fusion rates.
Song et al,[39] *Journal of Clinical Neuroscience*, 2007	Retrospective review of 16 patients with odontoid fractures using single anterior screw fixation	III	Fusion rate was 94%.
			No major complications.
			Single screw fixation was successful.
Bhanot et al,[37] *Journal of Surgical Orthopaedic Advances*, 2006	Retrospective review of 17 patients with type II odontoid fractures treated with anterior screw fixation	III	Fusion rate was 94%.
			Anterior odontoid screw fixation is safe and effective and maintains motion.
Moon et al,[34] *Bulletin of the Hospital for Joint Diseases Orthopaedic Institute*, 2006	Retrospective review of 32 odontoid fractures treated with anterior screw fixation	III	Fusion rate was 100%.
			No complications.
			No difference between 1 and 2 screws.
			Anterior odontoid screw fixation is safe and effective and maintains motion.
Tashjian et al,[55] *Journal of Trauma*, 2006	Retrospective review of type II (n = 50) or III odontoid fractures (n = 17) or combined (C1/C2) (n = 11)	III	Odontoid fractures are associated with significant morbidity and mortality in the elderly and appear worse with the use of a halo device.
Fountas et al,[35] *Spine*, 2005	Retrospective review of 32 patients with type II and "shallow" type III odontoid fractures with anterior screw fixation	III	Anterior odontoid screw fixation safe with high stability and low mechanical failure rates after long-term follow-up.
Grauer et al,[4] *Spine Journal*, 2005	Proposal of a modified classification system for odontoid fractures	III	κ Value was 0.48.
	52 Odontoid fractures were classified by 4 attending spine surgeons and 3 spine fellows		Downgraded to Class III because no validation group.
Kontautas et al,[19] *Medicina*, 2005	Prospective comparative study of outcomes with different amounts of displacement of 37 patients with type II odontoid fractures treated with traction followed by halo	III	Displacement of > 5.0 mm is associated with an increased rate of failure with external immobilization.
			Class II because it does not have a comparative treatment group.
Majercik et al,[54] *Journal of Trauma*, 2005	Retrospective review of nonoperative management in odontoid fracture with respect to age	III	Age > 65 y is associated with a significant increase in failure rate of external immobilization.

(Continues)

TABLE 2. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
Lee et al,[36] *Journal of Clinical Neuroscience*, 2004	Retrospective review of 48 patients with type II and III odontoid fractures treated with single odontoid screw fixation	III	Fusion rate was 96%.
			Complication rate of 10% (malposition rate, 6%; nonunion rate, 4%).
			Sagittally oblique type II fractures had an increased rate of fusion failure.
Börm et al,[48] *Neurosurgery*, 2003	Retrospective review of 27 patients with type II odontoid fractures treated with anterior odontoid double-screw fixation with respect to age	III	Outcome after anterior odontoid screw fixation is not affected by patient age.
			The authors describe this as a case-control trial. Classified as Class III for treatment because there is no comparative treatment group.
Komadina et al,[23] *Archives of Orthopaedic and Trauma Surgery*, 2003	Retrospective review of 14 type II and III odontoid fractures treated with halo immobilization	III	Radiographic fusion rate was 85.7%.
			External immobilization was successful.
Müller et al,[21] *European Spine Journal*, 2003	Retrospective review of 26 type II and III minimally displaced odontoid fractures treated with nonrigid immobilization	III	Minimally displaced type II and III fractures of the odontoid can be successfully treated with nonrigid immobilization.
Andersson et al,[26] *European Spine Journal*, 2000	Retrospective review of 29 patients with odontoid fractures $>$ 65 y of age managed with posterior fusion, anterior odontoid fixation, or immobilization	III	Posterior fusion was most successful.
Apfelbaum et al,[32] *Journal of Neurosurgery*, 2000	Retrospective review of 147 odontoid fractures; 2-institution experience with anterior odontoid screw fixation	III	Fusion rate up to 88%.
			Fractures oriented in the horizontal or posterior oblique planes had best fusion rates.
Dai et al,[28] *European Spine Journal*, 2000	Retrospective review of 57 cases of failed management for odontoid fracture	III	Both occipitocervical fusion and atlantoaxial fusion used with success.
Lennarson et al,[17] *Spine*, 2000	Case-control study of 33 patients with isolated type II odontoid fracture treated with halo vest immobilization; cases defined as nonunions in halo and controls defined as unions	II	Patients $\geq$ 50 y of age had a risk for failure 21 times higher than for those $<$ 50 y of age.
Julien et al,[7] *Neurosurgery Focus*, 2000	Systematic review of odontoid fracture management	III	Type I and III odontoid fractures can be managed initially with external immobilization.
			Type II fractures can be managed initially with external immobilization or surgery.
Müller et al,[83] *European Spine Journal*, 2000	Retrospective review of 28 cases of anterior screw fixation for odontoid fracture	III	Procedure is technically demanding.
Campanelli et al,[25] *Surgical Neurology*, 2000	Retrospective review of 7 patients with displaced type II odontoid treated with posterior transarticular screw fixation	III	Fusion rate 86%.
			One vertebral artery injury.
Müller et al,[45] *European Spine Journal*, 1999	Retrospective review of 23 patients $>$ 70 y of age with odontoid fractures	III	Elderly patients are at high risk for morbidity and mortality.

(Continues)

TABLE 2. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
Morandi et al,[29] *Surgical Neurology*, 1999	Retrospective review of 17 cases of anterior odontoid screw fixation	III	Fusion rate was 94%. Anterior fixation based on the orientation of the fracture line.
Subach et al,[30] *Neurosurgery*, 1999	Retrospective review of 26 patients (mean age, 35 y) with type II fractures treated with anterior odontoid screw fixation (single screw)	III	Fusion rate was 96%.
Seybold and Bayley,[47] *Spine*, 1998	Retrospective review of 37 type II and 20 type III odontoid fractures divided into age groups: < 60 and > 60 y	III	Fusion rates did not differ significantly between the 2 groups.
			Elderly patients had a decreased tolerance for halo immobilization.
Müller et al,[84] *Unfallchirurgie*, 1998	Retrospective review of 10 cases of nonunion pseudoarthrosis after immobilization for type II odontoid fractures	III	The authors favor surgical fixation.
Jenkins et al,[31] *Journal of Neurosurgery*, 1998	Retrospective review of 42 patients with type II odontoid fractures treated with anterior screw fixation comparing 1 and 2 screws	III	No difference in fusion rate with 1 vs 2 screws.
Berlemann and Schwarzenbach,[44] *Acta Orthopaedica Scandinavica*, 1997	Retrospective review of 19 patients with type II odontoid fractures > 65 y of age treated with anterior odontoid screw fixation	III	Fusion rate was 84%.
			Anterior fixation was successful.
Traynelis,[6] *Clinical Neurosurgery*, 1997	Systematic review of type II odontoid fractures	III	First evidence-based report on odontoid fracture management. Four treatment options for type II odontoid fractures: traction followed by immobilization, immobilization with halo or Minerva, posterior cervical fusion, or anterior screw fixation. Higher fusion rate reported with anterior screw fixation might be offset by its higher complication rate and learning curve.
Greene et al,[11] *Spine*, 1997	Retrospective review of 340 cases of axis fractures, including 199 odontoid fractures	III	The highest nonunion rate was observed in type II odontoid displaced ≥ 6 mm.
			Surgery recommended for instability despite external immobilization, transverse ligament disruption, or type II odontoid fracture with > 6-mm displacement.
Polin et al,[9] *Neurosurgery*, 1996	Retrospective review of 36 type II fractures treated with halo or collar	III	Lower rate of fusion with collar.
Chiba et al,[8] *Journal of Spinal Disorders*, 1996	Retrospective review of 104 patients with odontoid fractures:	III	Type I fractures can generally be managed nonoperatively.
	Type I, 2 patients		Anterior screw fixation recommended for most type II and unstable type III fractures. Type III fractures can be treated with halo immobilization or anterior screw fixation.
	Type II, 62 patients		Established nonunions and irreducible fractures should be treated with posterior fusion.
	Type III, 32 patients		
Bednar et al,[43] *Journal of Spinal Disorders*, 1995	Prospective cohort study of 11 geriatric patients with odontoid fractures treated with surgical stabilization	III	Mortality can be reduced by surgical intervention and avoiding the use of halo immobilization.

(Continues)

TABLE 2. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
			Class III because there is no comparative group.
Dickman et al,[85] *Journal of Neurosurgery*, 1995	Retrospective review of 16 cases of atlantoaxial instability undergoing salvage surgical management including 2 type II odontoid fractures	III	Failed fusion can be successfully salvaged with a secondary procedure.
Hanigan et al,[41] *Journal of Neurosurgery*, 1993	Retrospective review of 19 patients > 80 y of age with odontoid fractures	III	Displacement > 5 mm required posterior surgical fixation with good results.
			The mortality rate in the conservative treatment group was 27%.
Ryan and Taylor,[42] *Journal of Spinal Disorders*, 1993	Retrospective review of 30 patients with type II fractures > 60 y of age	III	Patients treated with surgery had a higher fusion rate.
Hadley et al,[3] *Neurosurgery*, 1988	Retrospective review of 62 patients with type II odontoid fractures, including 3 with comminution at the base	III	Type IIA odontoid fracture defined as a type II with comminution at the base of the dens with a high risk of nonunion with external immobilization.
Govender and Charles,[64] *Injury*, 1988	Retrospective review of 41 patients with type II and III odontoid fractures treated with a rigid collar or halo	III	Fusion rate for type II was 73% and for type III was 100%.
			External immobilization was successful.
Fujii et al,[86] *Spine*, 1987	Retrospective review of 52 patients with odontoid fractures treated with immobilization or surgery	III	Both immobilization and surgery were successful, although the fusion rate was lowest for type II fractures treated with immobilization.
Lind et al,[14] *Spine*, 1987	Retrospective review of 14 patients with odontoid fractures treated with halo immobilization	III	Fusion rate was 91%.
			External immobilization was successful.
Dunn and Seljeskog,[12] *Neurosurgery*, 1986	Retrospective review of 74 patients with odontoid fractures treated primarily with rigid bracing	III	Fusion rate was 68%.
			Immobilization in a cervical collar resulted in a reasonable rate of fusion.
Clark and White,[5] *Journal of Bone and Joint Surgery: American Volume*, 1985	Retrospective review of multicenter data including 144 patients managed by 27 different surgeons	III	Surgical management, either anterior or posterior, had the highest rate of fusion, approaching 100%.
Pepin et al,[40] *Clinical Orthopaedics and Related Research*, 1985	Retrospective review of 41 patients with odontoid fractures including 26 treated conservatively with tongs, 4-poster brace, collars, and/or halo vests	III	Fusion rate with halo for type II fractures was 46%.
			Fusion rate with surgery was 100%. Immobilization was poorly tolerated in patients > 75 y of age.
Wang et al,[10] *Spine*, 1984	Retrospective review of 25 patients with odontoid fractures treated with a variety of cervical immobilization techniques	III	Fusion rate for type II fractures treated with a collar only was 57% and 80% with a halo.
Böhler,[87] *Surgery Annual*, 1982	Retrospective review of 15 patients with odontoid fractures treated with anterior screw fixation	III	Fusion rate was 100%.
			Anterior surgery was successful.
Maiman and Larson,[24] *Neurosurgery*, 1982	Retrospective review of 49 cases of odontoid fracture, including 34 type II fractures treated with posterior wire/graft stabilization	III	Fusion rate of 35% is lowest reported.

(Continues)

TABLE 2. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
Ryan and Taylor,[96] *J Bone Joint Surg Br*, 1982	Retrospective review of 23 patients with odontoid fractures treated nonoperatively	III	Fusion rate for type I and III was 100% and for type II was 60%.
			External immobilization was successful.
Ekong et al,[13] *Neurosurgery*, 1981	Retrospective review of 22 cases of odontoid fracture treated nonoperatively	III	Fusion rate for type II was 50% and for type III was 80%.
			External immobilization was successful.
Marar and Tay,[88] *Australian and New Zealand Journal of Surgery*, 1976	Retrospective review of 26 cases of odontoid fractures treated with traction	III	Fusion rate for type II 37.5% and for type III was 100%.
Anderson and D'Alonzo,[2] *Journal of Bone and Joint Surgery: American Volume*, 1974	Retrospective review of 49 patients with odontoid fractures managed nonoperatively and operatively	III	Fusion rates were higher in the operative patients.

Treatment

The initial management of Hangman fractures has typically been nonsurgical, and high success rates have been reported. Early surgical stabilization and fusion of Hangman fractures have been reserved for situations of severe C2-C3 instability. The series described by Effendi et al,[59] Francis et al,[60] and Greene et al[11] reported that the majority of patients with Hangman fractures were effectively treated with external immobilization. These authors recommended that surgical internal fixation and fusion be reserved for Effendi type III fractures and for nonunion of other Hangman fractures after 3 months of halo immobilization.

In the Levine and Edwards[61] series of 52 patients with Hangman fractures, all isolated Effendi type I, II, and IIa injuries were successfully managed nonoperatively (n = 47 combined). Three of the 5 type III injury patients (60%) required surgical stabilization for failure to obtain or to maintain fracture reduction with a halo orthosis.

The Francis et al[60] series of 123 patients with Hangman fractures, from which their classification scheme was developed, reported that nonoperative management (traction followed by conversion to halo fixation) was successful in 95% of patients (116 of 123). Three of 9 grade II injury patients (33%) and 2 of 7 grade V injury patients (28%) developed nonunion despite halo management and required subsequent surgical treatment. Greene et al[11] successfully treated 65 of 74 patients (87%) with Hangman fractures nonoperatively with external immobilization for a median of 12 weeks. Of patients with either Effendi type II or III injuries, 7 (33%) required early surgical treatment because of failure of external immobilization. The authors concurred with Effendi et al and Francis et al that conservative management (external immobilization) should be the initial treatment in virtually every patient with a Hangman fracture. They concluded that early surgical management of Hangman fractures should be reserved for unstable injuries ineffectively immobilized in a halo device. Reports of smaller case series have described 100% successful fracture union with halo immobilization (42 patients)[63] or cervical collar immobilization alone (39 and 8 patients[64,65a]) regardless of C2-3 displacement or angulation. Class III medical evidence describing the nonoperative management for Hangman fractures is found in Table 3.

The current updated literature search on the management of Hangman fractures identified additional Class III medical evidence in support of initial nonoperative management for these injuries. To be fair, halo immobilization does not always achieve or maintain fracture reduction, as evidenced by the occasional need for surgical fixation in the larger series reported previously.[11,59,60] Halo immobilization is associated with a number of known complications, including but not limited to pin loosening, infection, cranial fracture, pressure sores, poor patient compliance, pulmonary issues, pneumonia, and restricted patient mobility.[54] Although treatment over and above fracture immobilization may not be necessary, there may be significant management advantages in avoiding the potential complications associated with halo vest use by performing early surgery to stabilize and fuse the C2-C3 vertebral segments.

In their review of axis fractures, Suchomel and Hradil[65b] presented their argument in favor of early surgical fixation: "A fracture-dislocation of the C3/4 level in an otherwise healthy person would be treated by anterior surgery and fusion today. It becomes very hard to find a reasonable argument against the use of the same principle for C2/3 intervertebral space."

Li et al[65a] in 2006 performed a systematic review to address the issue of the operative vs the nonoperative management of Hangman fractures. The authors indicated that the classification scheme by Effendi et al as modified by Levine and Edwards was preferred. Thirty-one of the 32 articles they included in their review (97%) advocated nonsurgical management for Hangman fractures. The authors summarized the literature and made the following recommendations for the treatment of Hangman fractures:

TABLE 3. Evidentiary Table: Axis Fractures: Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Reference	Description of Study	Evidence Class	Conclusions
ElMiligui et al,[73] *European Spine Journal*, 2010	Prospective multicenter study (n = 15) of consecutive patients with displaced type II (Effendi) traumatic spondylolisthesis of the axis treated with direct transpedicular screw fixation	III	Fusion rate was 100% with no limitation in range of motion.
			Transpedicular screw fixation through the C2 pedicles is safe and effective.
			Class III because there is no comparative group.
Xu et al,[71] *International Orthopaedics*, 2010	Retrospective review of 28 patients with Hangman fracture treated with anterior diskectomy and fusion	III	Fusion rate 100%.
			No complications.
			Anterior diskectomy can be used successfully in the treatment of unstable Hangman fracture.
Dalbayrak et al,[74] *Turkish Neurosurgery*, 2009	Retrospective review of 4 patients with Hangman fracture type II (Levine Edwards) treated with direct C2 pars fixation	III	Successful fusion 100%.
			Screw fixation through the pars is safe and effective.
Ying et al,[72] *Spine*, 2008	Retrospective review of 30 patients with Hangman fractures treated with anterior cervical diskectomy and fusion	III	Fusion rate was 100%.
			Anterior cervical diskectomy at C2-C3 can be used success fully for unstable Hangman fracture.
Li et al,[65a] *European Spine Journal*, 2006	Systematic review to address operative vs nonoperative management of Hangman fracture	III	The classification system proposed by Effendi et al and modified by Levine and Edwards provided a clinically reasonable guideline for successful management of Hangman fractures.
	32 relevant articles included.		Class III because all included studies were Class III.
Watanabe et al,[66] *Journal of Spinal Disorders and Techniques*, 2005	Retrospective review of 9 patients with Hangman fracture treated nonoperatively	III	Angulation was associated with poorer healing.
Boullosa et al,[75] *Arquivos de Neuro-Psiquiatria*, 2004	Retrospective review of 10 patients with Hangman fracture not candidates for halo placement treated with transpedicular C2 fixation	III	Fusion rate was 100%.
			Transpedicular C2 fixation can be used successfully in cases when halo placement is not an option.
Vaccaro et al,[68] *Spine*, 2002	Retrospective review of 31 patients with Hangman fracture treated with traction reduction and early halo immobilization	III	Traction reduction and early halo immobilization are an effective treatment for Hangman fractures.
			Angulation of 12° appears to have a higher risk of failure.
Moon et al,[34] *Bulletin of the Hospital for Joint Diseases Orthopaedic Institute*, 2001	Retrospective review of 42 patients with Hangman fracture	III	Fusion 100%.

(Continues)

TABLE 3. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
	Stable fractures were treated nonoperatively (n = 20), unstable fractures were treated surgically (n = 22)		No reported complications.
			Stable Hangman fracture can be successfully treated with reduction and external immobilization.
			Unstable Hangman fracture can be successfully treated with surgical stabilization.
Barros et al,[89] *Spinal Cord*, 1999	Case report of surgical fixation in Hangman fracture	III	Surgical treatment for Hangman fracture is an option.
Verheggen and Jansen,[90] *Surgical Neurology*, 1998	Retrospective study of 16 patients treated with early posterior screw fixation of the neural arch following Hangman fracture	III	Posterior stabilization and fusion is effective for Edwards and Levine (Effendi) type II and III fractures.
Greene et al,[11] *Spine*, 1997	Retrospective review of 72 patients with traumatic spondylolisthesis of the axis	III	Immobilization is generally sufficient treatment.
			Surgery may be considered for severe Francis- or Effendi-type Hangman fractures.
Corric,[97] *Journal of Neurosurgery*, 1996	Retrospective review of 39 patients with nondisplaced Hangman fracture including nondisplaced treated with nonrigid immobilization	III	Fusion rate 100%.
			Nonrigid immobilization successful.
Starr,[98] *Spine*, 1993	Retrospective 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	III	Neurological deficit is uncommon and occurs primarily with subluxation.
Tan,[99] *Paraplegia*, 1992	Retrospective review of 33 patients with Hangman fracture	III	Normal neurologic examination at admission in 77%.
			Complete recovery in 85% at 1 year.
			Neurologic deficit is uncommon and long-term outcome is good.
Torreman,[100] *Nederlands Tijdschrift Voor Geneeskunde*, 1990	Retrospective review of 23 patients with Hangman fractures treated with immobilization with long term follow-up	III	Fusion rate was 100%.
			Nonoperative management was successful.
Govendor,[101] *Injury*, 1987	Prospective study of 39 patients with Hangman fracture	III	Nonoperative management was successful.
Grady,[102] *Neurosurgery*, 1986	Retrospective review of 27 patients including 16 managed with halo, 8 with a collar, and 3 with bed rest	III	Nonoperative management was successful.
Levine and Edwards,[61] *Journal of Bone and Joint Surgery: American Volume*, 1985	Retrospective review of 52 patients with traumatic spondylolisthesis of the axis; this study updates the Effendi classification by adding the type IIA fracture	III	Nonoperative management was successful for nondisplaced fractures.
			Surgery was successful for Effendi type II, and III fractures and for Levine and Edwards type IIA fractures.
Borne et al,[70] *Journal of Neurosurgery*, 1984	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 resulted in 100% fusion rate.

(Continues)

TABLE 3. *Continued*

Reference	Description of Study	Evidence Class	Conclusions
Francis et al,[60] *Journal of Bone and Joint Surgery: British Volume*, 1981	Retrospective review of 123 Hangman fractures	III	A classification is described based on the amount of C2-3 displacement and angulation.
Pepin and Hawkins,[63] *Clinical Orthopaedics and Related Research*, 1981	Retrospective review of 42 Hangman fractures	III	Defines a classification scheme for Hangman fracture based on displacement of posterior elements.
Effendi et al,[59] *Journal of Bone and Joint Surgery: British Volume*, 1981	Retrospective review of 131 Hangman fractures	III	Defines the most popular classification system based on mechanism of injury, displacement, and stability.
			Nonoperative management is successful in the majority of cases.
Brashear,[103] *Journal of Bone and Joint Surgery: American Volume*, 1975	Retrospective review of 29 Hangman fractures	III	No case of neurologic deficit.
			Nonoperative management was successful.

- Levine-Edwards type I and II injuries: nonrigid external fixation was sufficient.
- Effendi type I and II and Levine-Edwards type II fractures: traction followed by external immobilization.
- Levine-Edwards type IIa and III and Effendi type III fractures (significant dislocation): rigid immobilization; consider surgical fixation and fusion.

Watanabe et al[66] reported 9 patients with Hangman fractures treated with halo immobilization. They observed that those patients with angulation and C2-3 translation caused by fracture of the inferior C2 facet joint had a worse outcome and should be considered for surgical fixation and fusion rather than halo immobilization.

In 2001, Moon et al[67] described a series of 42 patients with Hangman fractures. Patients without displacement or angulation were considered stable (n = 20) and were treated with traction followed by a cervical orthosis with 100% fusion success. Patients with C2-3 angulation or displacement with ligamentous disruption were considered unstable and were treated with anterior C2-3 interbody fusion. They described a 100% fusion rate and reported no complications.

Vaccaro et al[68] described their experience with early halo immobilization in a series of 31 patients with Hangman fractures (type II, n = 27; type IIA, n = 4). All the type IIA patients achieved bony union and 21 of 27 of the patients with type II injuries (78%) achieved successful union. Six patients with type II injuries (22%) failed initial attempts at closed reduction/immobilization and had to be replaced in traction, which was followed by surgical fixation and fusion. All 6 patients (100%) had an initial fracture angulation of 12° or greater.

A number of investigators have advocated early surgical intervention for patients with more severe Hangman fracture injuries, particularly those patients with significant displacement and angulation at the C2-C3 level. The reported advantages of surgical treatment include improved fracture alignment, reduction in hospitalization and treatment times, faster patient mobilization, and potentially an improved quality of life. Surgical options for unstable Hangman fracture injuries, particularly those that fail to heal despite external immobilization, include anterior C2-3 interbody fusion,[59] dorsal C1-C3 fusion procedures,[69] direct pars fixation,[70] or combinations of these approaches. Class III medical evidence addressing surgery for Hangman fractures is found in Table 3.

Anterior surgical approaches to C2-C3 have the advantage of being safe and familiar to surgeons. Xu et al[71] retrospectively reviewed their series of 28 patients with Effendi type II and III Hangman fractures treated with C2-3 anterior discectomy and fusion. Fusion was obtained in 100% of cases, and complete recovery was reported. Ying et al[72] reported 30 patients with Effendi type II and III Hangman fractures treated with anterior cervical discectomy and fusion. They described 100% fusion success at 6 months with 1 transient complication (dysphagia).

Posterior surgical approaches have the advantage of allowing direct access to the C2-3 facets for reduction (Effendi type III). The additional muscle dissection required with this approach may be a disadvantage for patients with less severe Hangman injuries. A posterior approach for reduction and stabilization coupled with anterior C2-3 fusion has been reported for severe C2-3 instability. Direct pars fixation has been described as an alternative for Hangman fractures with limited disk and ligamentous injury but may be the most technically challenging procedure. As with any posterior C2 screw fixation technique, there is concern for vertebral artery injury. ElMiligui et al[73] described their operative experience with 15 type II Hangman fractures treated with transpedicular screw fixation. They reported a fusion rate of 100% with minimal complications

TABLE 4. Evidentiary Table: Axis Fractures: Fractures of the Axis Body (Miscellaneous Fractures)

Reference	Description of Study	Evidence Class	Conclusions
Ding et al,[77] *Spine*, 2010	Retrospective review of C2 fractures (n = 100), 18 (17.8%) with vertebral artery injury	III	No correlation between C2 fracture type and vertebral artery injury.
			Vertebral artery injury correlated with communition fracture (*P* = .03) fragment(s) in foramen transversarium (*P* = .008).
Aydin and Cokluk, *Turkish Neurosurgery*,[78] 2007	Case report of C2 unilateral pars interarticularis fracture treated with cervical collar	III	Nonoperative treatment was successful.
German et al,[79] *Neurosurgery*, 2005	Retrospective review of 21 vertical axis fractures	III	Nonoperative treatment was successful.
Korres et al,[80] *Spine*, 2005	Retrospective review of 674 cervical fractures	III	Incidence of horizontal (Chance-type) fractures of the axis, 2/674 (0.05%).
			Nonoperative treatment was successful.
Korres et al,[81] *Orthopedics*, 2004[77]	Retrospective review of 674 cervical fractures	III	Incidence of multiple fractures involving the axis was 9/674 (1%).
			Nonoperative treatment was successful.
Greene et al,[11] *Spine*, 1997	Retrospective review of 61 miscellaneous C2 fractures	III	Nonoperative treatment was successful in 98%.
Fujimura et al,[91] *Journal of Orthopaedic Trauma*, 1996	Retrospective report of 31 C2 fractures categorized with radiographic imaging	III	4 Types: avulsion (9/9 fused with immobilization), transverse (2/2 healed with immobilization), burst (2/3 treated with C2-3 fusion), and sagittal fractures (15/17 healed with immobilization).
Benzel et al,[76] *Journal of Neurosurgery*, 1994	Retrospective report of 15 patients described with fractures of the axis body	III	Classified into type 1, (coronal) most common; type 2 (sagittal); type 3 (oblique); and type 3, equivalent to the type III odontoid fracture.
Korres et al,[92] *European Spine Journal*, 1994	Retrospective review of 14 cases of avulsion fracture of the anterior inferior portion of the axis	III	Nonoperative treatment was successful.
Bohay et al,[93] *Journal of Orthopaedic Trauma*, 1992	Retrospective review of 3 cases of vertical fractures of the axis	III	Nonoperative treatment was successful.
Craig and Hodgson,[94] *Spine*, 1991	Retrospective review of 9 cases of superior facet fracture of the axis vertebra	III	Nonoperative treatment was successful in 5 patients but 3 patients required open reduction and posterior fusion.
Burke and Harris,[62] *Skeletal Radiology*, 1989	Retrospective review 31 miscellaneous C2 body fractures	III	Nonoperative treatment was successful.
Jakim and Sweet,[95] *Journal of Bone and Joint Surgery: British Volume*, 1988	Case report of a transverse fracture of the axis	III	Nonoperative treatment was successful.

and preservation of postoperative range of motion. In 2009, Dalbayrak et al[74] described 4 patients with Levine-Edwards type II Hangman fractures treated with C2 pars fixation. All 4 patients had successful union. Boullosa et al[75] reported 10 Hangman fracture patients successfully treated with transpedicular C2 fixation in whom external immobilization had failed or a halo device was contraindicated. They described a 100% fusion success rate. Ninety percent of their patients experienced complete resolution of symptoms.

Fractures of the Axis Body

The treatment of miscellaneous fractures of the axis body remains challenging because of their diversity and relative infrequency. The majority of clinical reports cited in the literature describe successful fracture union with nonoperative techniques. The most comprehensive attempt at classifying these fractures remains the report of Benzel et al.[76] They characterized C2 body fractures into 3 anatomical subtypes: type I, coronal; type II, sagittal; and type III, transverse. The Greene et al[11] series included 61 patients with miscellaneous axis fractures. Ninety-nine percent were treated successfully with nonoperative techniques. Only 1 patient with a miscellaneous axis fracture required surgical intervention for delayed nonunion. Class III medical evidence studies on the treatment of miscellaneous fractures of the axis described in the previous guideline on this subject are compiled in Table 4. Of the 119 patients included in these reports, 117 were successfully treated nonoperatively (99%). The present updated review of this topic identified 5 additional citations. All provide Class III medical evidence and are summarized in Table 4.

In 2010, Ding et al[77] published a retrospective review of 102 patients with axis fractures of all types and found that comminuted fractures of any type with fragments of bone within the foramen transversarium were associated with an increased risk of vertebral artery injury. Many miscellaneous axis fractures involve the transverse foramen; therefore, a high level of suspicion for potential vertebral artery injury should be maintained when these patients are evaluated. Aydin and Cokluk[78] described an axis pars interarticularis fracture that they successfully treated with a cervical collar. German et al[79] described their series of 21 patients with vertical C2 body fractures. Sixteen were coronally oriented type I vertical C2 body fractures, and 5 were sagitally oriented type II C2 body fractures. Three patients died of associated injuries. All 18 surviving patients (100%) were successfully treated nonoperatively. Korres et al[80] reported 2 separate observations after review of their database of 674 cervical fractures. The first[80] described the incidence of horizontal (Chance-type) fractures of the atlas, identified in 2 of 674 injuries that they managed (0.05%). Both were treated nonsurgically with success at the long-term follow-up. The second observation[81] described the occurrence of multiple fractures of the atlas, an injury that occurred in 9 of their 674 patients (1%). The most common multiple fracture patterns were a teardrop fracture of the axis body associated with a traumatic spondylolisthesis or the combination of a traumatic spondylolisthesis of the axis with an odontoid fracture. The authors recommended computed tomography as the imaging modality of choice for patients with C2 fractures.

SUMMARY

A summary of the recommendations for the acute management of axis fractures is provided in Table 1 and the data supporting the recommendations in this section are provided in Table 2.

Fractures of the Odontoid

There is no Class I medical evidence on the management of patients with acute traumatic odontoid fractures. Class II medical evidence exists indicating that the risk of nonunion of a type II odontoid fracture in patients ≥ 50 years of age is 21 times greater than the incidence of nonunion for younger patients with a similar type II odontoid fracture. Therefore, consideration of surgical stabilization and fusion for type II odontoid fractures in patients ≥ 50 years of age is recommended. Type I, II, and III odontoid fractures are often effectively managed with external cervical immobilization, with the understanding that the failure of external immobilization is significantly higher for type II odontoid fractures. Treatment of type II odontoid fractures with a cervical collar alone or traction followed by cervical collar immobilization may be undertaken but is associated with lower fracture union rates. Class III medical evidence indicates that factors associated with nonunion of type II fractures include age, fracture displacement, secondary loss of reduction, and delays in treatment. Similarly, Class III medical evidence suggests that a change in angulation of the type II odontoid fracture of ≥ 5° on lateral radiography taken at 2 weeks after immobilization in a halo device is associated with failure of fusion. Closed reduction of displaced type II odontoid fractures is associated with successful treatment with halo immobilization. Type II and III odontoid fractures should be considered for surgical fixation in patients with dens displacement of ≥ 5 mm, comminution of the odontoid fracture (type IIA), and/or inability to achieve or maintain fracture alignment with external immobilization. The treatment of isolated type I odontoid fractures with cervical immobilization is recommended, resulting in fusion rates approaching 100%. Anterior and posterior surgical fixation and fusion of type II and III odontoid fractures have been reported with fusion rates exceeding 90% with low morbidity. The management of odontoid fractures in elderly patients is associated with increased failure rates, and higher rates of morbidity and mortality irrespective of the treatment offered.

Traumatic Spondylolisthesis of the Axis

There is no Class I or Class II medical evidence in the literature addressing the management of traumatic spondylolisthesis of the axis. Class III medical evidence supports a variety of treatments for these injuries. The majority of Hangman 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 the treatment of Hangman fractures and is typically reserved for cases of severe angulation, disruption of the C2-3 disk space, or 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 in the literature addressing the management of traumatic fractures of the axis body. Class III medical evidence supports the use of external immobilization as the initial treatment strategy for the variety of traumatic fractures of the C2 body.

KEY ISSUES FOR FUTURE INVESTIGATION

More data are necessary to determine the definitive management of odontoid fractures. For type I and III fractures, a well-designed multicenter case-control study could provide Class II medical evidence to define their appropriate management in the early postinjury period. For type II fractures, the literature suggests that both operative management and nonoperative management remain treatment options. A randomized analysis or a 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 the majority of cases. A multicenter case-control study of patients with these injury types would help to define optimal treatments for each specific fracture subtype.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Isolated fractures of the axis in adults. In: Guidelines for the management of acute cervical spine and spinal cord injuries. *Neurosurgery*. 2002;50(3 suppl):S125-S139.
2. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am.* 1974;56(8):1663-1674.
3. Hadley MN, Browner CM, Liu SS, Sonntag VK. New subtype of acute odontoid fractures (type IIA). *Neurosurgery*. 1988;22(1 pt 1):67-71.
4. 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.
5. Clark CR, White AA 3rd. Fractures of the dens: a multicenter study. *J Bone Joint Surg Am.* 1985;67(9):1340-1348.
6. Traynelis VC. Evidence-based management of type II odontoid fractures. *Clin Neurosurg.* 1997;44:41-49.
7. Julien TD, Frankel B, Traynelis VC, Ryken TC. Evidence-based analysis of odontoid fracture management. *Neurosurg Focus.* 2000;8(6):e1.
8. Chiba K, Fujimura Y, Toyama Y, Fujii E, Nakanishi T, Hirabayashi K. Treatment protocol for fractures of the odontoid process. *J Spinal Disord.* 1996;9(4):267-276.
9. Polin RS, Szabo T, Bogaev CA, Replogle RE, Jane JA. Nonoperative management of types II and III odontoid fractures: the Philadelphia collar versus the halo vest. *Neurosurgery*. 1996;38(3):450-456; discussion 456-457.
10. Wang GJ, Mabie KN, Whitehill R, Stamp WG. The nonsurgical management of odontoid fractures in adults. *Spine (Phila Pa 1976)*. 1984;9(3):229-230.
11. Greene KA, Dickman CA, Marciano FF, Drabier JB, Hadley MN, Sonntag VK. Acute axis fractures: analysis of management and outcome in 340 consecutive cases. *Spine (Phila Pa 1976)*. 1997;22(16):1843-1852.
12. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. *Neurosurgery*. 1986;18(3):306-310.
13. Ekong CE, Schwartz ML, Tator CH, Rowed DW, Edmonds VE. Odontoid fracture: management with early mobilization using the halo device. *Neurosurgery*. 1981;9(6):631-637.
14. Lind B, Nordwall A, Sihlbom H. Odontoid fractures treated with halo-vest. *Spine (Phila Pa 1976)*. 1987;12(2):173-177.
15. Shears E, Armitstead CP. Surgical versus conservative management for odontoid fractures. *Cochrane Database Syst Rev.* 2008(4):CD005078.
16. Platzer P, Thalhammer G, Sarahrudi K, et al. Nonoperative management of odontoid fractures using a halothoracic vest. *Neurosurgery*. 2007;61(3):522-529; discussion 529-530.
17. Lennarson PJ, Mostafavi H, Traynelis VC, Walters BC. Management of type II dens fractures: a case-control study. *Spine (Phila Pa 1976)*. 2000;25(10):1234-1237.
18. Kim DH, Vaccaro AR, Affonso J, Jenis L, Hilibrand AS, Albert TJ. Early predictive value of supine and upright X-ray films of odontoid fractures treated with halo-vest immobilization. *Spine J.* 2008;8(4):612-618.
19. Kontautas E, Ambrozaitis KV, Spakauskas B, Kalesinskas RJ. The treatment of odontoid fractures with a significant displacement. *Medicina (Kaunas)*. 2005;41(1):23-29.
20. Nourbakhsh A, Shi R, Vannemreddy P, Nanda A. Operative versus nonoperative management of acute odontoid type II fractures: a meta-analysis. *J Neurosurg Spine.* 2009;11(6):651-658.
21. Müller EJ, Schwinnen I, Fischer K, Wick M, Muhr G. Non-rigid immobilisation of odontoid fractures. *Eur Spine J.* 2003;12(5):522-525.
22. Butler JS, Dolan RT, Burbridge M, et al. The long-term functional outcome of type II odontoid fractures managed non-operatively. *Eur Spine J.* 2010;19(10):1635-1642.
23. Komadina R, Brilej D, Kosanović M, Vlaovic M. Halo jacket in odontoid fractures type II and III. *Arch Orthop Trauma Surg.* 2003;123(2-3):64-67.
24. Maiman DJ, Larson SJ. Management of odontoid fractures. *Neurosurgery*. 1982;11(6):820.
25. Campanelli M, Kattner KA, Stroink A, Gupta K, West S. Posterior C1-C2 transarticular screw fixation in the treatment of displaced type II odontoid fractures in the geriatric population: review of seven cases. *Surg Neurol.* 1999;51(6):596-600; discussion 600-601.
26. Andersson S, Rodrigues M, Olerud C. Odontoid fractures: high complication rate associated with anterior screw fixation in the elderly. *Eur Spine J.* 2000;9(1):56-59.
27. Anselmetti GC, Regge D, Sardo E, et al. Minimally invasive treatment of C2 odontoid traumatic fracture with transoral percutaneous vertebroplasty. *Eur Radiol.* 2007;17(3):850-851.
28. Dai LY, Yuan W, Ni B, et al. Surgical treatment of nonunited fractures of the odontoid process, with special reference to occipitocervical fusion for unreducible atlantoaxial subluxation or instability. *Eur Spine J.* 2000;9(2):118-122.
29. Morandi X, Hanna A, Hamlat A, Brassier G. Anterior screw fixation of odontoid fractures. *Surg Neurol.* 1999;51(3):236-240.
30. 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; discussion 819-820.
31. Jenkins JD, Coric D, Branch CL Jr. A clinical comparison of one- and two-screw odontoid fixation. *J Neurosurg.* 1998;89(3):366-370.
32. Apfelbaum RI, Lonser RR, Veres R, Casey A. Direct anterior screw fixation for recent and remote odontoid fractures. *J Neurosurg.* 2000;93(2 suppl):227-236.
33. Smith HE, Vaccaro AR, Maltenfort M, et al. Trends in surgical management for type II odontoid fracture: 20 years of experience at a regional spinal cord injury center. *Orthopedics*. 2008;31(7):650.
34. Moon MS, Moon JL, Sun DH, Moon YW. Treatment of dens fracture in adults: a report of thirty-two cases. *Bull Hosp Jt Dis.* 2006;63(3-4):108-112.
35. Fountas KN, Kapsalaki EZ, Karampelas I, et al. Results of long-term follow-up in patients undergoing anterior screw fixation for type II and rostral type III odontoid fractures. *Spine (Phila Pa 1976)*. 2005;30(6):661-669.
36. Lee SC, Chen JF, Lee ST. Management of acute odontoid fractures with single anterior screw fixation. *J Clin Neurosci.* 2004;11(8):890-895.
37. Bhanot A, Sawhney G, Kaushal R, Aggarwal AK, Bahadur R. Management of odontoid fractures with anterior screw fixation. *J Surg Orthop Adv.* 2006;15(1):38-42.
38. Chi YL, Wang XY, Xu HZ, et al. Management of odontoid fractures with percutaneous anterior odontoid screw fixation. *Eur Spine J.* 2007;16(8):1157-1164.
39. Song KJ, Lee KB, Kim KN. Treatment of odontoid fractures with single anterior screw fixation. *J Clin Neurosci.* 2007;14(9):824-830.
40. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. *Clin Orthop Relat Res.* 1985;193:178-183.
41. Hanigan WC, Powell FC, Elwood PW, Henderson JP. Odontoid fractures in elderly patients. *J Neurosurg.* 1993;78(1):32-35.
42. Ryan MD, Taylor TK. Odontoid fractures in the elderly. *J Spinal Disord.* 1993;6(5):397-401.
43. 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.
44. Berlemann U, Schwarzenbach O. Dens fractures in the elderly: results of anterior screw fixation in 19 elderly patients. *Acta Orthop Scand.* 1997;68(4):319-324.
45. Müller EJ, Wick M, Russe O, Muhr G. Management of odontoid fractures in the elderly. *Eur Spine J.* 1999;8(5):360-365.
46. Pitzen T, Caspar W, Steudel WI, Barbier D. Dens fracture in elderly patients and surgical management [in German]. *Aktuelle Traumatol.* 1994;24(2):56-59.
47. Seybold EA, Bayley JC. Functional outcome of surgically and conservatively managed dens fractures. *Spine (Phila Pa 1976)*. 1998;23(17):1837-1845; discussion 1845-1846.
48. Börm W, Kast E, Richter HP, Mohr K. Anterior screw fixation in type II odontoid fractures: is there a difference in outcome between age groups? *Neurosurgery*. 2003;52(5):1089-1092; discussion 1092-1094.
49. Dailey AT, Hart D, Finn MA, Schmidt MH, Apfelbaum RI. Anterior fixation of odontoid fractures in an elderly population. *J Neurosurg Spine.* 2010;12(1):1-8.
50. Platzer P, Thalhammer G, Ostermann R, Wieland T, Vécsei V, Gaebler C. Anterior screw fixation of odontoid fractures comparing younger and elderly patients. *Spine (Phila Pa 1976)*. 2007;32(16):1714-1720.
51. Smith HE, Kerr SM, Maltenfort M, et al. Early complications of surgical versus conservative treatment of isolated type II odontoid fractures in octogenarians: a retrospective cohort study. *J Spinal Disord Tech.* 2008;21(8):535-539.

52. White AP, Hashimoto R, Norvell DC, Vaccaro AR. Morbidity and mortality related to odontoid fracture surgery in the elderly population. *Spine (Phila Pa 1976)*. 2010;35(9 suppl):S146-S157.
53. Koech F, Ackland HM, Varma DK, Williamson OD, Malham GM. Nonoperative management of type II odontoid fractures in the elderly. *Spine (Phila Pa 1976)*. 2008;33(26):2881-2886.
54. Majercik S, Tashjian RZ, Biffl WL, Harrington DT, Cioffi WG. Halo vest immobilization in the elderly: a death sentence? *J Trauma.* 2005;59(2):350-356; discussion 356-358.
55. 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.
56. Fagin AM, Cipolle MD, Barraco RD, et al. Odontoid fractures in the elderly: should we operate? *J Trauma.* 2010;68(3):583-586.
57. Omeis I, Duggal N, Rubano J, et al. Surgical treatment of C2 fractures in the elderly: a multicenter retrospective analysis. *J Spinal Disord Tech.* 2009;22(2):91-95.
58. 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.
59. Effendi B, Roy D, Cornish B, Dussault RG, Laurin CA. Fractures of the ring of the axis: a classification based on the analysis of 131 cases. *J Bone Joint Surg Br.* 1981;63-B(3):319-327.
60. Francis WR, Fielding JW, Hawkins RJ, Pepin J, Hensinger R. Traumatic spondylolisthesis of the axis. *J Bone Joint Surg Br.* 1981;63-B(3):313-318.
61. Levine AM, Edwards CC. The management of traumatic spondylolisthesis of the axis. *J Bone Joint Surg Am.* 1985;67(2):217-226.
62. Burke JT, Harris JH Jr. Acute injuries of the axis vertebra. *Skeletal Radiol.* 1989;18(5):335-346.
63. Pepin JW, Hawkins RJ. Traumatic spondylolisthesis of the axis: Hangman's fracture. *Clin Orthop Relat Res.* 1981;157:133-138.
64. Govender S, Charles RW. Traumatic spondylolisthesis of the axis. *Injury*. 1987;18(5):333-335.
65a. Li XF, Dai LY, Lu H, Chen XD. A systematic review of the management of Hangman's fractures. *Eur Spine J.* 2006;15(3):257-269.
65b. Suchomel P, Hradil J, Barsa P, et al. Surgical treatment of fracture of the ring of axis - "hangman's fracture" [in Czech]. *Acta Chir Orthop Traumatol Cech.* 2006;73(5):321-328.
66. Watanabe M, Nomura T, Toh E, Sato M, Mochida J. Residual neck pain after traumatic spondylolisthesis of the axis. *J Spinal Disord Tech.* 2005;18(2):148-151.
67. Moon MS, Moon JL, Moon YW, Sun DH, Choi WT. Traumatic spondylolisthesis of the axis: 42 cases. *Bull Hosp Jt Dis.* 2001;60(2):61-66.
68. Vaccaro AR, Madigan L, Bauerle WB, Blescia A, Cotler JM. Early halo immobilization of displaced traumatic spondylolisthesis of the axis. *Spine (Phila Pa 1976)*. 2002;27(20):2229-2233.
69. Salmon JH. Fractures of the second cervical vertebra: Internal fixation by interlaminar wiring. *Neurosurgery*. 1977;1(2):125-127.
70. Borne GM, Bedou GL, Pinaudeau M. Treatment of pedicular fractures of the axis: a clinical study and screw fixation technique. *J Neurosurg.* 1984;60(1):88-93.
71. Xu H, Zhao J, Yuan J, Wang C. Anterior discectomy and fusion with internal fixation for unstable Hangman's fracture. *Int Orthop.* 2010;34(1):85-88.
72. Ying Z, Wen Y, Xinwei W, et al. Anterior cervical discectomy and fusion for unstable traumatic spondylolisthesis of the axis. *Spine (Phila Pa 1976)*. 2008;33(3):255-258.
73. ElMiligui Y, Koptan W, Emran I. Transpedicular screw fixation for type II Hangman's fracture: a motion preserving procedure. *Eur Spine J.* 2010;19(8):1299-1305.
74. Dalbayrak S, Yilmaz M, Firidin M, Naderi S. Traumatic spondylolisthesis of the axis treated with direct C2 pars screw. *Turk Neurosurg.* 2009;19(2):163-167.
75. Boullosa JL, Colli BO, Carlotti CG Jr, Tanaka K, dos Santos MB. Surgical management of axis' traumatic spondylolisthesis (Hangman's fracture). *Arq Neuropsiquiatr.* 2004;62(3B):821-826.
76. Benzel EC, Hart BL, Ball PA, Baldwin NG, Orrison WW, Espinosa M. Fractures of the C-2 vertebral body. *J Neurosurg.* 1994;81(2):206-212.
77. Ding T, Maltenfort M, Yang H, et al. Correlation of C2 fractures and vertebral artery injury. *Spine (Phila Pa 1976)*. 2010;35(12):E520-E524.
78. Aydin K, Cokluk C. A fracture of unilateral pars interarticularis of the axis: a case report. *Turk Neurosurg.* 2007;17(2):155-157.
79. German JW, Hart BL, Benzel EC. Nonoperative management of vertical C2 body fractures. *Neurosurgery*. 2005;56(3):516-521; discussion 516-521.
80. Korres DS, Papagelopoulos PJ, Mavrogenis AF, Benetos IS, Kyriazopoulos P, Psycharis I. Chance-type fractures of the axis. *Spine (Phila Pa 1976)*. 2005;30(17):E517-E520.
81. Korres DS, Papagelopoulos PJ, Mavrogenis AF, et al. Multiple fractures of the axis. *Orthopedics*. 2004;27(10):1096-1099.
82. Collins I, Min WK. Anterior screw fixation of type II odontoid fractures in the elderly. *J Trauma.* 2008;65(5):1083-1087.
83. Müller EJ, Wick M, Russe OJ, Palta M, Muhr G. Anterior screw fixation for odontoid fractures [in German]. *Unfallchirurgie*. 2000;103(1):38-43.
84. Müller EJ, Wick M, Russe O, Muhr G. Accident-induced pseudarthroses of the dens axis: etiology, follow-up and therapy [in German]. *Unfallchirurgie*. 1998;101(10):750-754.
85. Dickman CA, Sonntag VK. Surgical management of atlantoaxial nonunions. *J Neurosurg.* 1995;83(2):248-253.
86. Fujii E, Kobayashi K, Hirabayashi K. Treatment in fractures of the odontoid process. *Spine (Phila Pa 1976)*. 1988;13(6):604-609.
87. Böhler J. An approach to non-union of fractures. *Surg Annu.* 1982;14:299-315.
88. Marar BC, Tay CK. Fracture of the odontoid process. *Aust N Z J Surg.* 1976;46(3):231-236.
89. Barros TE, Bohlman HH, Capen DA, et al. Traumatic spondylolisthesis of the axis: analysis of management. *Spinal Cord*. 1999;37(3):166-171.
90. Verheggen R, Jansen J. Hangman's fracture: arguments in favor of surgical therapy for type II and III according to Edwards and Levine. *Surg Neurol.* 1998;49(3):253-261; discussion 261-262.
91. Fujimura Y, Nishi Y, Kobayashi K. Classification and treatment of axis body fractures. *J Orthop Trauma.* 1996;10(8):536-540.
92. Korres DS, Zoubos AB, Kavadias K, Babis GC, Balalis K. The "tear drop" (or avulsed) fracture of the anterior inferior angle of the axis. *Eur Spine J.* 1994;3(3):151-154.
93. Bohay D, Gosselin RA, Contreras DM. The vertical axis fracture: a report on three cases. *J Orthop Trauma.* 1992;6(4):416-419.
94. Craig JB, Hodgson BF. Superior facet fractures of the axis vertebra. *Spine (Phila Pa 1976)*. 1991;16(8):875-877.
95. Jakim I, Sweet MB. Transverse fracture through the body of the axis. *J Bone Joint Surg Br.* 1988;70(5):728-729.
96. Ryan MD, Taylor TK. Odontoid fractures. A rational approach to treatment. *J Bone Joint Surg Br.* 1982;64(4):416-421.
97. Coric D, Wilson JA, Kelly DL Jr. Treatment of traumatic spondylolisthesis of the axis with nonrigid immobilization: a review of 64 cases. *J Neurosurg.* 1996;85(4):550-554.
98. Starr JK, Eismont FJ. Atypical hangman's fractures. *Spine (Phila Pa 1976)*. 1993;18(14):1954-1957.
99. Tan ES, Balachandran N. Hangman's fracture in Singapore (1975-1988). *Paraplegia.* 1992;30(3):160-164.
100. Torreman M. Long-term prognosis of the hangman's fracture [in Dutch]. *Ned Tijdschr Geneeskd.* 1990;134(24):1173-1176.
101. Govender S, Charles RW. Traumatic spondylolisthesis of the axis. *Injury*. 1987;18(5):333-335.
102. Grady MS, Howard MA, Jane JA, Persing JA. Use of the Philadelphia collar as an alternative to the halo vest in patients with C-2, C-3 fractures. *Neurosurgery*. 1986;18(2):151-156.
103. Brashear R, Venters G, Preston ET. Fractures of the neural arch of the axis. A report of twenty-nine cases. *J Bone Joint Surg Am.* 1975;57(7):879-887.