ISOLATED FRACTURES OF THE AXIS IN ADULTS

RECOMMENDATIONS:

Fractures of the Odontoid

Standards: There is insufficient evidence to support treatment standards.

Guidelines: Type II Odontoid fractures in patients 50 years of age and older should be considered for surgical stabilization and fusion.

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

Traumatic Spondylolisthesis of the Axis (Hangman's fracture)

Standards: There is insufficient evidence to support treatment standards.

Guidelines: There is insufficient evidence to support treatment guidelines.

Options: Traumatic spondylolisthesis of the axis may be managed initially with external immobilization in the majority of cases. Surgical stabilization should be considered in cases of severe angulation of C2 on C3, (Francis Grade II and IV, Effendi Type II), disruption of the C2-3 disc space, (Francis Grade V, Effendi Type III) or inability to establish or maintain alignment with external immobilization.

Fractures of the Axis Body (Miscellaneous Fractures)

Standards: There is insufficient evidence to support treatment standards.

Guidelines: There is insufficient evidence to support treatment standards.

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

RATIONALE

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

SEARCH CRITERIA

A National Library of Medicine computerized literature search from 1966 to 2001 was undertaken using Medical Subject Headings in combination with "spinal cord injury": "axis", "vertebrae", "fracture" and "human". Seven hundred and eleven articles were identified. Those manuscripts focusing on the clinical management of acute traumatic axis fractures were selected for review. The bibliographies of these papers were scanned for additional references to confirm completeness of the literature review. Relevant papers addressing the mechanism of injury or the biomechanics and radiology of the C2 vertebra were included.

The articles were reviewed and classified using established methodology. Thirty-eight articles for odontoid fracture, 17 for traumatic spondylolisthesis and eight for miscellaneous axis fractures comprised the basis for the scientific foundation of this guideline. Data from articles describing axis fractures and/or their management were categorized and are provided in Evidentiary Table format. Fifteen additional articles are referenced for supporting information.

SCIENTIFIC FOUNDATION

Odontoid Fractures:

Overview

The most common traumatic axis injury is fracture through the odontoid process, either through the tip of the dens (Type I), through its base (Type II) or involving the odontoid but extending into the C2 body (Type III). (1,6,41)

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

Prior publications utilizing evidence-based methodology for evaluating the literature on odontoid fracture management have focused on fusion as the primary outcome criterion with a minimum follow-up of 18 months.(45,72) Articles on odontoid fractures containing this information were included. While it has been argued that the radiographic determination of fusion may be difficult and subject to observer variability, it appears to be the most appropriate outcome measure and is described in the majority of clinical articles addressing odontoid fractures. It is recognized that outcome measures incorporating patient satisfaction, quality of life measures, and function would perhaps be superior, however, this information is sparse and less objective than the fusion criteria described in the literature.

Classification of Odontoid Fractures:

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

In 1988 Hadley et al added another fracture subtype to this classification scheme.(40) They described the Type IIA odontoid fracture as a comminuted fracture involving the base of the dens with associated free fracture fragments. The incidence of a Type IIA fracture was estimated at 5% of all Type II fractures, (three of 62 Type II fractures in their series) and was associated with severe instability and inability to obtain and maintain fracture reduction and realignment. The authors proposed that Type IIA odontoid fractures be managed with early posterior surgical fixation and fusion of C1-C2.

Treatment

A variety of treatment strategies have been proposed for odontoid fractures based on the fracture type, the degree of initial dens displacement, the extent of angulation of the dens with respect to the body of C2, and the age of the patient. These include non-operative and operative methods.**(**1,15,16,31,35,39-41,45,51,58,72**)** Patients with odontoid fracture injuries have been treated with external immobilization using a variety of orthoses with varying results.**(**1,15,16,31,35,39-41,45,51,58,72**)** Surgical options include posterior cervical fusion with or without transarticular screw fixation or anterior odontoid screw fixation techniques.

Non-operative Treatment

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

Traction: Reviews by Traynelis and Julien et al include evidentiary tables describing seven articles containing Class III medical evidence addressing the treatment of odontoid fractures with traction and subsequent immobilization in a cervical collar.(1,15,16,31,35,45,51,58,72) All patients with Type I odontoid fractures achieved radiographic fusion (three of three). Eighty-seven percent of patients with Type III fractures achieved fusion (55 of 63 patients). The failure rate for patients with Type II fractures treated in this fashion was 43% (42 of 97). Fifty-seven percent achieved bony union. It appears that traction followed by cervical collar immobilization may be considered a management option for patients with odontoid fractures, particularly those with Type I and Type III fractures. The low fusion success rate reported for Type II odontoid fractures managed with traction and collar immobilization (57%) implies that perhaps collar immobilization is not the ideal strategy for Type II fracture patients.

Cervical collar: Several authors have proposed treatment of odontoid fractures with cervical collars. Polin et al in 1996 describes a series of 36 Type II fractures treated with either a Philadelphia collar or halo vest immobilization.(24) The fusion rate was lower in the patients treated with collars (53%) compared to 74% for patients managed in halos. An earlier report from the same institution described a similar rate of fusion (57%) in a study including seven Type II fractures treated with a collar alone. (75)

The infrequent Type I odontoid fracture appears to have an acceptable rate of fusion with rigid cervical collar immobilization, approaching 100% in one study.(1,15,16) Type III odontoid fractures have been treated with cervical collars as well but have a less favorable union rate with fusion rates ranging from 50% to 65% in small series. (16,75)

Halo Immobilization: In a series of publications resulting in the largest institutional series of axis fractures published to date, 340 cases of axis fractures were reviewed including 199 odontoid fractures (Type I - two, Type II – 116, Type IIA - four, Type III - 77. (37,39,41) Excellent results were obtained with rigid external immobilization in the Type I and Type III fracture patients (two of two and 68 of 69 with successful fusion). Of the Type II patients, 95 were treated with external immobilization for a median of 13 weeks. The authors reported a 28% failure rate. Seven failures were successfully treated with additional external immobilization and 18 patients underwent subsequent posterior C1-C2 fusion. The authors found that a displacement of the dens six millimeters or greater was associated with a high non-union rate, irrespective of patient age, direction of displacement, or neurological deficit (86% failure rate, chi square 33.74, $p < .001$). The degree of dens displacement and a negative correlation with fusion was noted by at least four other investigators.(16,25,27,49) The amount of odontoid displacement observed ranged from two to six millimeters in their studies.

Julien et al reviewed nine articles that dealt with treatment of odontoid fractures (total 269 patients) using halo/Minerva fixation for 8-12 weeks.(12,15,16,25,27,31,45,49,58,63) All patients with Type I odontoid fractures were found to have successful fusion (three of three). (15,31,63) One hundred and sixty-eight patients with Type II odontoid fractures were treated with halo immobilization. One hundred ten had successful fusion (65%). There was a 30% non-union rate (50 of 168 patients). Eight patients were described as having a malunion. Eighty-four percent of patients with Type III odontoid fractures (67 of 80) achieved a solid fusion. There was an 8% failure rate (6 of 80 patients) and seven cases were described as malunions. The authors of these series generally concluded that rigid external immobilization can be considered a viable treatment option for Type I, Type II, and Type III odontoid fractures. Rigid external immobilization appears to be most successful for patients with Type I, Type III and nondisplaced Type II odontoid fractures but should be considered with caution in elderly patients.

Operative Treatment

Posterior Cervical Fixation: Posterior cervical fixation and fusion has been successfully utilized in the treatment of acute traumatic odontoid fractures. Although no criteria defining the indications for surgical fixation have been established, a number of retrospective case series suggest treatment options. (15,16,18,25,31,50,58,74) These papers describe a total of 147 patients who underwent posterior cervical fixation and fusion for Type II odontoid fractures and 29 patients treated similarly for Type III fractures. One patient with a Type I fracture was treated successfully with posterior fusion. The overall fusion rates for Type II and Type III fractures managed with surgical fixation and fusion were 87% and 100% respectively in these series. The report of Maiman and Larson described a fusion rate across the fracture line of only 35%, but a fusion rate of 100% at the posterior operative site. (50)

The aforementioned series typically describe an instrumented (wire or cable) posterior C1-2 arthrodesis followed by cervical immobilization in a rigid orthosis. More recently, transarticular screw fixation and fusion of C1-2 has been employed for traumatic odontoid fractures, particularly in cases of failed fusion following initial management (14,44). The reported surgical morbidity and mortality is 2% to 4%, and includes failure of fracture reduction, vertebral artery injury, and the new onset of neurological deficit. Loss of motion at the atlantoaxial joint following posterior C1-2 fusion results from of dorsal C1-C2 arthrodesis. Despite this, several authors favor posterior C1-2 fusion rather than anterior odontoid screw fixation as ideal treatment of unstable odontoid fractures. (2,14,57)

Anterior Cervical Fixation: Anterior single and double screw fixation of odontoid fractures has been accomplished with success. The technical challenges associated with this procedure have limited widespread application. If successful, this technique has the potential to maintain rotational motion at the atlanto-axial joint. It has been suggested that this is an appropriate strategy when the odontoid fracture line is either horizontal or oblique and posterior, and that it is contraindicated in situations where the fracture line is oblique and anterior.(2,3,20,56) In cases of transverse atlantal ligament disruption, anterior screw fixation can result in an unsatisfactory outcome despite union of the odontoid fracture due to persistent transverse atlantal ligament incompetence. Julien et al summarized a series of articles that describe retrospective experiences with anterior screw fixation for odontoid fractures.(9,15,22,31,44,45) The combined fusion rate of Type II fractures treated in these reports is 89% (112 of 126 patients). Patients with type III odontoid fractures achieved radiographic fusion in 20 of 20 patients (100%). In a recent series reported by Subach et al, 26 patients with Type II fractures (mean age 35) underwent anterior odontoid fixation with single screw followed by immobilization in a cervical collar (median 7.2 weeks). (69) Twenty-five of 26 patients achieved successful fusion (96%). The one failure was attributed to inadequate fracture reduction. That patient required subsequent posterior C1-C2 fusion. Jenkins, Corric and Branch in 1998 described a retrospective non-randomized series of 42 patients undergoing anterior screw fixation for Type II odontoid fractures. They compared single-screw versus two-screw techniques.(44) The fusion rate in their experience was similar for single-screw fixation (81%) compared to two-screw fixation (85%). Use of lag screws to achieve anterior odontoid fixation is recommended. Complications of the procedure include retropharyngeal wall injury, screw fracture, infection, and screw misplacement with injury to surrounding vascular and neural structures.(9,22,31) Attempts at anterior odontoid fixation utilizing a transoral approach was associated with multiple significant complications.(15)

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

Odontoid Fracture Management in the Elderly Patient

One of the controversial issues in the management of odontoid fractures is the influence of age on treatment selection. A number of studies have examined the circumstance of acute odontoid fracture in the older patient. Three case series argue against surgical fixation in the elderly patient.(37,63,67) Seven other case series favor surgical fixation in this age group. There is also one case-control study by Lennarson et al providing Class II medical evidence for surgical treatment of elderly patients.(47)

Ryan et al described 30 patients over 60 years of age with Type II odontoid fractures. The fusion success rate in patients over age 60 treated with external immobilization was only 23%.(61) The authors felt that the high fracture nonunion rate was secondary to inadequate immobilization and delays in diagnosis in the majority of cases. If these issues were eliminated, no significant difference in outcome between surgical and non-surgical management would have been demonstrated. They concluded that surgical fixation and fusion for elderly patients with odontoid fractures should be reserved for unusual circumstances.

Greene et al reported the largest series (120 patients) of retrospectively reviewed cases of traumatic odontoid Type II axis fractures.(37) Patients with dens displacement of six millimeters or greater in their experience had a non-union rate of 86%, compared to a non-union rate of 18% for patients with displacement less than six millimeters. The authors reported no significant relationship between fracture non-union and age using chi square analysis. It might be argued that statistical tests of association would be more appropriate in this circumstance and age may have been shown to be a factor had they been used.

Andersson et al described 29 patients age 65 and older with odontoid fractures managed with surgical and non-surgical means.(2) In their series, six of seven patients (86%) achieved successful fusion following posterior cervical C1-C2 arthrodesis. Worse results were observed in patients treated with anterior odontoid screw fixation (20% fusion rate) and in patients managed with external immobilization alone (20% fusion rate). These authors favored posterior cervical fusion over other management options in elderly patients with Type II odontoid fractures.

Pepin et al reported their experience with 41 acute odontoid fractures (Type I - one, Type II - 19, Type III - 21).(58) The authors found that halo immobilization was poorly tolerated in patients over 75 years of age. They suggested that early C1-2 fixation and fusion was appropriate in this group.

Hanigan et al described 19 patients over 80 years of age with odontoid fractures (Type II - 16, Type III - three).(42) Five patients with displacement greater than five mm were treated with posterior cervical fixation and fusion with good results. Three of the five had stable non-unions. They reported a mortality rate of 26% in patients managed conservatively with prolonged immobilization rather than surgical fixation and fusion. On the other hand, they noted that no patient treated with external immobilization alone developed clinically significant instability.

Pitzen and colleagues described their experience with surgical therapy in seven patients with odontoid fractures over 70 years of age.(60) Two patients died of related medical co-morbidity. Five patients did well and were mobilized early. The authors concluded that early surgical fixation in this age group is the preferred management strategy. This view is shared by several other investigators including Seybold et al, Campanelli et al, and Muller et al (14,57,67).

Bednar et al reported a prospective assessment of elderly patients with odontoid fractures managed with early operative stabilization and fusion.(5) Eleven patients were included in their study. The authors found a 91% fusion rate (10 of 11 patients). One patient died of unrelated causes. The authors argued in favor of early surgical intervention for elderly patients with odontoid fractures.

In 1997 Berleman et al offered a retrospective review of their experience with 19 patients over 65 years of age with Type II odontoid fractures treated with anterior odontoid screw fixation.(7) Radiographic fusion with nearly five-year follow-up was obtained in 16 of 19 patients (85%). The authors concluded that anterior odontoid screw fixation is a successful therapy for elderly patients with Type II odontoid fractures.

In the only case-control, Class II evidence study published on this topic, Lennarson et al examined 33 patients with isolated Type II odontoid fractures treated with halo vest immobilization.(47) Age greater than 50 was found to be a significant factor for failure of fusion in a halo immobilization device. Patients age 50 and greater had a risk for non-union 21 times higher than that found for patients under age 50 years. No significant effect on outcome was found due to other medical conditions, sex of the patient, degree of fracture displacement, direction of fracture displacement, length of hospital stay or length of follow-up.

Traumatic Spondylolisthesis of the Axis (Hangman's Fracture)

Overview

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

Wood-Jones described the cervical fracture-dislocation injury induced by hanging in 1913.(78) Garber used the term "traumatic spondylolisthesis" of the axis in 1964. He described eight patients with "pedicular" fractures of the axis following motor vehicle accidents.(33) The term "Hangman's Fracture" has been attributed to Schneider et al who described a series of eight patients and noted the similarity between the fracture of the posterior elements of the axis to the pattern of fracture injury induced by judicial hanging.(65) Williams documented four cases of Hangman's fracture injury in 1975, noting that three occurred due to motor vehicle accidents and the fourth due to a fall.(77) A variety of authors have suggested that a more appropriate term for describing this axis injury type may be "traumatic spondylolisthesis of the axis" due to the differences in mechanism of injury between hanging and the deceleration injuries of falls and motor vehicle accidents.(29,30) The majority of traumatic spondylolisthesis fractures of C2 due to motor vehicle accidents appear to result from hyperextension and compression, rather than the hyperextension and distraction associated with hangings. These differences in the mechanism of injury, along with the wide range of neurological deficits identified with these injuries prompted a series of investigators to attempt to better characterize and classify traumatic spondylolisthesis injuries of the axis.

Classification of Hangman's Fractures

In 1981 Pepin and Hawkins published a two-type classification scheme for Hangman's fractures. Type I was described as a non-displaced fracture of the posterior elements alone. Type II was a displaced fracture involving the posterior elements and the body of C2.(59) They successfully treated 42 patients without surgery using their scheme, which involved reduction (Type II injuries) and immobilization. They noted a low incidence of associated spinal cord injury but a frequent association with head injury. Although simple and effective, Pepin and Hawkins' scheme has not gained popular acceptance and is not widely used.

In the same year Francis, Pepin, Hawkins and others published a collaborative experience with 123 patients with traumatic spondylolisthesis of the axis. Injuries were divided into one of five grades based on displacement and angulation of C2 on C3.(30) Grade I was defined as displacement less than 3.5 mm and angulation less than 11 degrees. Grade V was defined as complete C2-3 disc disruption. Grade IV in their scheme had greater than 3.5 mm of C2-3 disruption but less than half of C3 vertebral width with greater than 11 degrees of C2-3 angulation. Grades II and III were injury types graded between Grades I and IV.

Effendi et al described three types of fractures of the ring of the axis based on a series of 131 patients.(26) Their classification scheme was based on the mechanism of injury: Type I Axial loading and hyperextension, Type II Hyperextension and rebound flexion, Type III Primary flexion and rebound extension. Type I fractures were defined as isolated hairline fractures of the ring of the axis with minimal displacement of the body of C2. Type II fractures were defined as displacement of the anterior fragment with disruption of the disc space below the axis. Type III fractures were defined as displacement of the anterior fragment with the body of the axis in a flexed position in conjunction with C2-3 facet dislocation. This Type III fracture is associated with a flexed forward position of the axis body. The incidence of Type I, II and III fracture injury in their series was 65%, 28% and 7% respectively.

Levine and Edwards modified Effendi's classification scheme in 1985.(48) They added flexion-distraction as a mechanism of injury (Type IIA) and offered a tailored treatment strategy for each of the four injury types.

In the largest series of axis fractures yet described, both the classification schemes of Effendi et al and that of Francis et al were utilized to characterize 74 Hangman's fractures.(37) The most common fracture pattern identified was the Effendi Type I (72%) and the Francis Grade I (65%). The investigators found a strong correlation between Effendi Types I and III and Francis Grades I and IV, respectively.

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

Incidence of Traumatic Spondylolisthesis and Associated Injuries

In Greene's series of 1,820 cervical fractures, 340 (19%) were of the axis and 74 (4%) were Hangman's type.(37) In the series of acute fractures of the axis vertebra described by Burke et al, injuries of the axis were associated with other fractures of the cervical vertebra in 8% of cases.(13) Ryan and Henderson studied 657 patients with cervical spine fractures over a 13-year period. Hangman's type fractures occurred as isolated fractures in 74% of their series.(62) Only nine percent were associated with fractures of C1. An additional nine percent were associated with subaxial cervical spine fractures. In the series of Guiot et al of ten complex combined atlantoaxial fractures only one involved a Hangman's injury.(38)

Although the incidence of spinal cord and nerve root injury as a result of a Hangman's fracture is reportedly low, unstable Hangman's injuries do occur with some frequency.(12,59) If the patient survives the initial injury, it has been proposed that the relatively spacious intracanicular diameter affords some protection against spinal cord compression.(55) Starr et al described an atypical fracture pattern occurring through the posterior aspect of the vertebral body with continuity of the posterior cortex or pedicle with narrowing of the spinal canal due to the associated subluxation.(68) In their series of 19 patients, this Hangman's fracture variant occurred in six patients including two patients with resultant paralysis. In the series described by Francis et al, eight of 123 patients they managed had neurological deficits (6%).(30) Tan's retrospective series of 33 Hangman's fractures included 14 patients with no neurological deficit on admission.(70) The other 19 (57%) had neurological deficits ranging from quadriparesis to urinary retention. Twenty-eight patients (85%) returned to employment at one-year follow-up.

Mirvis' series of 27 patients had associated neurological findings in 26 % of patients with Hangman's fractures.(54)

Combination fractures of C1 and C2 in association with a Hangman's type C2 injury appear to have a higher incidence of associated neurological injury, likely due to increased instability and a more severe traumatic injury pattern. (23, 38)

Treatment

The majority of patients with traumatic Hangman's fractures reported in all the literature reviewed was treated with cervical immobilization with good results. The three largest experiences reported are the multi-institutional series of Effendi et al, Francis et al, and the single institutional experience described by Greene et al.(26,30,37) Management strategies and surgical indications vary somewhat between investigators.

In the series reported by Effendi et al in 1981 there were 85 Type I fractures, sixty-two of which were managed with external immobilization. They reported thirty-seven Type II fractures; seventeen of the patients were treated with bracing and fifteen with surgical fusion. Of the patients managed surgically, four patients were treated with a C2-3 anterior fusion and eleven were treated with dorsal internal fixation and fusion. Nine patients had Effendi Type III fractures. Three died without definitive treatment, one was managed in a brace and five were treated surgically with fusion, one anterior and four posterior. The authors concluded that the majority of Hangman's fractures were best managed non-operatively. They commented that they may have over-treated patients early in their series offering surgery when external immobilization may well have been successful.(26) They decided that surgery should be reserved for unusual Type III fractures and those patients with failure of fusion despite three months of halo immobilization.

In Pepin's series also reported in 1981, all 42 patients with Hangman’s fractures they treated healed successfully with external immobilization alone.(59) Francis et al described and classified Hangman’s fracture injuries in 123 patients from four institutions.(30) Injuries were categorized into Grades I through V based on displacement and angulation. There were 19 Grade I, nine Grade II, 46 Grade III, 42 Grade IV and seven Grade V fractures. All patients were initially managed with traction with conversion to a halo orthosis, or were treated in a halo vest without traction. Healing occurred in 116 patients (95%) with halo immobilization alone. Seven patients received surgical management with fusion for non-union despite halo immobilization (four had an anterior C2-3 fusion, two had a posterior C1-3 fusion, and one had a posterior C2-4 fusion). The authors assessed the injury type with respect to success with non-operative management. Three of nine Grade II injury patients (33%) and two of seven Grade V injury patients (28%) developed non-union despite halo management and required subsequent surgical treatment. No Grade I or Grade III injury patients and only one Grade IV injury patient failed halo treatment. The authors concluded that primary surgical treatment for Hangman’s fracture injuries is not indicated. All patients should be provided late follow-up to assess for non-union, particularly Grade II and Grade V injury patients. When surgical management is considered, the authors recommend an anterior C2-3 fusion.

In Levine and Edwards series of 52 patients with Hangman’s fractures, all isolated Type I, II and IIa injuries were managed non-operatively.(48) Three of five Type III patients underwent surgical stabilization and fusion for failure to obtain or maintain fracture reduction in a halo. The authors singled out the subgroup of the Effendi Type II fracture that significantly distracted with the application of craniocervical traction. They felt Type II injuries were likely the result of flexion-distraction forces. The three patients with Type II fractures in their series were successfully treated with "mild compression - extension in a halo vest under fluoroscopic control".

Greene et al noted a strong correlation between Effendi Type I and Francis Grade I Hangman's injury and between Effendi Type III and Francis Grade IV fractures in their series of 74 patients.(37) Sixty-five of 74 patients were treated non-operatively with external immobilization for a median of 12 weeks. There were two early deaths. Seven patients required early surgical fixation and fusion for inability to maintain fracture alignment in a halo brace. All seven early surgical patients were either Effendi Grade II or III and five of the seven were Francis Grade III or IV. Overall, 33% of patients with unstable Effendi Types II and III or 36% of Francis Grade III, IV and V injuries required early surgical treatment. Eventually all seven achieved solid fusion without evidence of instability. The authors compared their experiences with those of Effendi et al and Francis et al, and concluded that conservative management (external immobilization) should be the initial treatment in virtually every patient with a Hangman's fracture. Early surgical management should be reserved for unstable injuries ineffectively immobilized in a halo device.

In a combined clinical and cadaveric anatomic study, Mestdagh et al described their experience with 41 fractures of the posterior neural arch of the axis.(53) Eleven cases were treated surgically with anterior C2-3 interbody fusion and thirty patients were treated with external immobilization. Thirty patients were available for follow-up. Cervical mobility was better in patients managed conservatively. Displacement of up to five mm at the Hangman's fracture site in a cadaveric study was compatible with stability without disruption of the ligaments or the C2-C3 disc space. The authors concluded that conservative management was the ideal treatment for Hangman's fractures except in cases of marked instability or failure of union.

Grady et al reported their experience with 27 patients with Hangman's fractures. Sixteen were managed in a halo device, eight in a rigid collar and three with bed rest only.(36) All achieved fusion with no residual symptoms. The authors concluded that use of a Philadelphia collar alone for Hangman's fractures is a reasonable alternative to halo immobilization particularly for injuries with minimal C2-C3 displacement.

In 1987, Govendor and Charles prospectively studied 39 patients with traumatic spondylolisthesis of the axis.(34) Injuries were classified for stability based on the criteria of White and Panjabi.(76) All patients were successfully treated with collar immobilization regardless of assessment of stability. The authors argue against basing treatment on dynamic imaging as advocated by Effendi et al and Levine and Edwards. (26,48)

A variety of other reports favor non-operative management of Hangman's fractures.(4,11,17,28,34,48,51,53,66,71)

Surgical Management

Surgical options for unstable Hangman's fracture injuries, particularly those that fail to heal despite external immobilization, include anterior C2-3 interbody fusion and dorsal C1-C3 fusion procedures.

In the series of Effendi et al forty-two of 131 patients with Hangman's fractures were treated surgically.(26) Ten were treated with an anterior C2-3 fusion and 32 underwent a posterior fusion. All were successfully stabilized at last follow-up.

In the Francis et al series of 123 Hangman's fracture patients, only seven patients were treated surgically. Four underwent anterior C2-3 fusion, two had a posterior C1-3 fusion, and one underwent posterior C2-C4 fusion.(30) The authors noted that six out of the seven patients requiring fusion for non-union had C2-C3 angulation greater than 11 degrees. All seven patients achieved bony stability.

A number of case-series of Hangman's fractures offer similar experiences with surgical management. McLaurin et al described their experience with early fusion in two patients with Hangman's fractures in order to allow early mobilization. The authors acknowledged that both injuries would likely have healed with external immobilization alone.(52) Salmon described 20 patients with Hangman's fractures treated with posterior interlaminar wiring and fusion with no morbidity. (64)

Verheggen et al, in their 1998 report, argued strongly for surgical fixation and fusion of Effendi Type II and III Hangman's fractures. In their opinion the optimal management of these injuries remains controversial. They described 16 patients with Hangman's fractures they treated with surgical fixation of the posterior arch of the axis with screw fixation. They found that this fixation technique resulted in superior functional results as compared to historical controls.(73) They favor this management strategy in the setting of the Levine and Edwards type IIa fracture.(48) Their viewpoint is challenged by Sypert in his comments which accompany their article.(73)

Borne et al in 1984 published their approach to the management of pedicular fractures of the axis.(10) They utilized a technique of bilateral posterior screw fixation. They described excellent results and a 100% fusion rate. Despite this, their technique has not gained widespread acceptance.

Fractures of the Axis Body

A number of authors have addressed the management of non-odontoid, non-Hangman's fractures of the axis. They have been labeled as miscellaneous fractures of the axis, non-odontoid non-Hangman fractures, or simply axis body fractures.(6,32,37,41) There have been several attempts at classifying the various fracture types within this diverse group.

Benzel et al reported on 15 patients with fracture of the axis body and divided them into three types: coronal, sagittal and transverse oriented.(6) The latter group was felt to represent the same group as the Anderson and D'Alonzo Type III odontoid fracture. The authors proposed that the Type III odontoid fracture classification be discarded since it is misleading. The original authors had the same thought. Benzel and colleagues offered a mechanism of injury for each of the three fracture types they described. No treatment or outcome data was included in their report.

Greene et al described 67 patients with miscellaneous axis fractures of all types.(37) Of the 61 patients available for follow-up (median follow-up 14 months), all but one was successfully managed with a variety of non-operative means. The authors note that this is a diverse injury group and describe a treatment algorithm based on features of fracture stability. Only one patient with a miscellaneous axis fracture required surgical intervention for delayed non-union.

Fujimara et al classified 31 axis body fractures based on radiographic injury pattern: avulsion, transverse, burst or sagittal.(32) All nine cases of avulsion fracture and the two cases of transverse fracture healed with external immobilization. Two of the three burst fractures were treated with C2-3 anterior interbody fusion. Of the 17 sagittal fractures, 15 healed with non-operative treatment. The remaining two patients required surgical fusion. The authors recommend initial non-operative treatment for all non-odontoid, non-Hangman's axis fractures.

Craig et al added nine cases of axis fractures involving the superior articular facet.(19) In seven patients there was an associated odontoid fracture. This fracture occurred in either the coronal or sagittal plane resulting in shearing of the anterior or lateral portion of the facet complex. The lateral mass of the atlas was noted to occasionally sublux into the facet fracture. The authors recommended immobilization for non-displaced fractures and the consideration of surgical reduction, fixation and fusion for difficult to reduce fractures.

Bohay et al described three unusual fractures of the posterior body of C2, all of which responded to non-operative management.(8) Jakim and Sweet contributed a single case.(43)

Korres et al described fourteen patients with avulsion fractures of the anterior inferior portion of the axis that they believed to be extension-type injuries.(46) These cases represented only 3% of the cervical spine fractures they managed over a 12-year period. All fourteen of these body fracture types were successfully managed with cervical immobilization (mean follow-up of 8.5 years).

SUMMARY

Fractures of the Odontoid

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

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

Traumatic Spondylolisthesis of the Axis

There is no Class I or Class II medical evidence addressing the management of traumatic spondylolisthesis of the axis. All articles reviewed contain Class III evidence that supports a variety of treatments. The majority of Hangman's fractures heal with 12 weeks of cervical immobilization either with a rigid cervical collar or a halo immobilization device. Surgical stabilization is an option in cases of severe angulation (Francis Grade II and IV, Effendi Type II), disruption of the C2-3 disc space (Francis Grade V, Effendi Type III), or the inability to establish or maintain fracture alignment with external immobilization.

Fractures of the Axis Body (Miscellaneous Axis Fractures)

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

Table I: Initial Management of Isolated Axis Fracture in the Adult

Fracture Type	Treatment Options
Odontoid fracture	
Type I	Collar, halo
Type II	Consider for early surgery or halo, collar
Type IIA	Consider for early surgery or halo
Type III	Collar, halo, surgical fusion
Traumatic Spondylolisthesis of the Axis (Hangman's Fracture)	
Stable	
Effendi Type I, Francis Type I, II	Halo, collar
Unstable	
Effendi Type II, III, Francis Type III, IV, V	Halo, consider surgical stabilization
Miscellaneous Axis Fractures	Collar or halo

KEY ISSUES FOR FUTURE INVESTIGATION

More data are necessary to determine treatment standards and/or guidelines for the definitive management of odontoid fractures. For Type I and Type III fractures the available Class III evidence suggests that a well-designed multicenter case-control study could provide sufficient evidence to define their appropriate management in the early post-injury period. For Type II fractures, the literature suggests that both operative and nonoperative management remain treatment options. A randomized or case-control study would be of benefit in establishing definitive treatment recommendations for this fracture type.

Traumatic spondylolisthesis of the axis and miscellaneous axis fractures are treated successfully with external immobilization in the majority of case. A multicenter case-controlled study of patients with these injury types would help to define optimal treatments of each specific fracture subtype.

EVIDENTIARY TABLE one - Odontoid Fracture

Author / Year	Study Design	Data Class	Comments
Anderson S et al , *Eur Spine J*, 2000	Retrospective non-randomized report of 29 patients with odontoid fractures over age 65 managed with posterior fusion, anterior odontoid fixation or immobilization.	III	Posterior fusion resulted in 7/7 fused (100 %). Anterior odontoid screw resulted in three / 11 fused (27%) and Halo immobilization resulted in three /10 fused (30%). The authors argue for posterior fusion in the elderly patient with an odontoid fracture.
Apfelbaum RI et al, *,J Neurosurg,* 2000	Retrospective review of two institution experience with anterior odontoid screw fixation. 147 odontoid fractures (Type II n = 138, Type III n = 9) divided into recent (within six months, 129 patients) and remote (greater than six months from injury, 18 patients) groups.	III	The fusion rate was significantly higher in the recent group comparing fusion rates of 88 % versus 25 % ($p < 0.05$) with a mean follow-up of 18 months. A positive correlation was seen between fusion and fractures oriented in the horizontal or posterior oblique planes. No effect of age, sex, number of screws placed or displacement was demonstrated.
Dai LY et al,*Eur Spine J* , 2000	Review of 57 cases of failed management for odontoid fracture	III	50 treated with occipitocervical fusion and seven with atlantoaxial fusion. Two cases of non-union after atlantoaxial fusion alone. 38 achieved an excellent result.
Lennarson PJ et al, *Spine* , 2000	33 patients with isolated Type II odontoid fracture treated with halo vest immobilization. Cases defined as non-unions in halo and controls defined as unions.	II Case-control	Patients 50 years or older had a risk for failure 21 times higher than age under 50. No significant difference in medical conditions, sex, amount of fracture displacement, direction of fracture displacement, length of hospital stay, length of follow-up between groups.
Julien T et al, *Neurosurg Focus,* 2000	Evidence-based review of management of odontoid fractures	III	Authors conclude there is insufficient evidence for standards or guidelines. Type I and III odontoid fractures can be managed with external immobilization (100 % and 84 % fusion respectively). Anterior fixation for Type III odontoid fractures appears to improve the fusion rate to nearly 100 %. Type II fractures can be managed with external immobilization with an expected fusion rate of approximately 65%. Surgical instrumentation and fusion appears to improve the fusion rate and include posterior cervical fusion (74 %) or anterior odontoid screw fixation (90 %) with acceptable morbidity.
Campanelli M et al, *Surg Neurol,* 2000	7 patients with displaced Type II odontoid fractures underwent posterior transarticular screw fixation.	III	6 / seven (86%) achieved rigid immobilization. One vertebral injury. The authors conclude that this is a reasonable option.

Author / Year	Study Design	Data Class	Comments
Muller EJ et al, *Eur Spine J,* 1999	Retrospective review of 23 patients over 70 years of age with odontoid fractures.	III	Complication rate significantly increased in the elderly group (52 versus 33 %) primarily due to non-union after non-operative treatment. The authors suggest that the elderly patient is at high-risk for morbidity and mortality and suggest early halo fixation or primary stabilization.
Morandi X et al, *Surg Neurol,* 1999	17 cases of odontoid screw fixation	III	Fusion in 16 of 17 (94%). The authors suggest patient selection for anterior fixation be based on the orientation of the fracture line.
Subach BR et al, *Neurosurg*, 1999	26 patients (mean age 35) with Type II fractures treated with anterior odontoid screw fixation (single screw) plus collar (median 7.2 weeks).	III	25/26 fusion (96%). One patient required posterior fusion for inadequate reduction.
Seybold EA and Bayley JC, *Spine,* 1998	Retrospective review of 37 Type II and 20 Type III odontoid fractures divided into age groups. Age less than 60 and greater than 60.	III	Under age 60: Type II, 7/12 fused (58%) Over age 60: Type II, 8/11 fused (73%) Type III – all treated with halo, 95% fusion regardless of type Fusion rates did not differ significantly between the two groups. The authors noted a decreased tolerance in the elderly patient for halo immobilization and as a result favor surgery in select cases.
Jenkins JD et al, *J Neurosurg,* 1998	Comparison of one versus two screws in non-selected patients with Type II odontoid fractures divided into two groups: 20 (single screw) versus 22 (two screws). Follow up nine months.	III	The difference in fusion rate, 81% (one screw) versus 85%(two screws), was not significant.
Berlemann U and Schwarzenbach O, *Acta Orthop Scand,* 1997	19 patients with Type II odontoid fractures over 65 years treated with anterior odontoid screw fixation with a followup of 4.5 years.	III	Bony fusion in 16/19 (84%) and 15 / 19 (79%) were asymptomatic. The authors favor anterior fixation in this age group.
Traynelis VC, *Clin Neurosurg,* 1997	Evidence based review of Type II odontoid fractures.	III	First evidence based report on odontoid fracture management. Indicated that insufficient data was available for standards or guidelines and that four treatment options for Type II odontoid fractures were available including: traction followed by immobilization, immobilization with Halo or Minerva, posterior cervical fusion or anterior screw fixation. The author notes that the higher fusion rate reported with anterior screw fixation might be offset by its higher complication rate and learning curve.

Author / Year	Study Design	Data Class	Comments
Greene KA et al, *Spine,* 1997	Retrospective review of 340 cases of axis fractures, including 199 odontoid fractures.	III	Type I: two patients, 2/2 healed with Halo immobilization (12 weeks) Type II: 120 patients, 20 treated with early surgery - eight had Type II with greater than six mm, four Type IIA with instability despite external immobilization (one Type IIA treated successfully with a halo), seven patients underwent surgical fusion to avoid halo immobilization 95 treated with external immobilization (median of 13 weeks) - 88 available for followup - solid fusion failed in 25 (28.4 %) - seven successfully treated with additional immobilization and 18 successfully treated with posterior fusion (late surgery) - significant factors dens displacement greater than six mm (chi square 33.74, p <. 0001) giving an 86 % failure rate in the halo treatment group 5 died Type III: 77 patients, 69 managed non-operatively with external immobilization - 68 fused (median 12 weeks) - the one that failed also had a C1 posterior arch fracture and required posterior fusion 6 patients were treated with early surgery - five because the halo failed to maintain alignment and one because of a combined C2-3 subluxation - two had concomitant lateral mass fractures of the atlas with avulsion of the ligamentous insertion on the tubercle 2 died Conclusions: The highest non-union rate was observed in Type II odontoid displaced six mm or more. Surgery recommended for 1). Acute fracture instability despite external immobilization, 2). Transverse ligament disruption and 3). Type II odontoid fracture with greater than six mm displacement.
Polin RS et al, *Neurosurgery*, 1996	Retrospective review of 36 Type II fractures treated with Philadelphia collar (16) or Halo vest immobilization (20).	III	Type II 54 % fused with collar 74 % fused with Halo

Author / Year	Study Design	Data Class	Comments
Chiba K et al, *J Spinal Disord,* 1996	104 pts., with odontoid fractures: Type I - two pts. Type II -62 pts. Type III - 32 pts. 2 groups: Fresh group, 72 pts. whose fractures were identified within three weeks of traumatic event Old group, 32 pts. who had an extended period before definitive treatment 32 pts. 1 type I, 21 type II, and eight type III.	III	Type I: two patients, Collar 2/2, Both fused (100 %) Type II (62 patients), Immobilization 10/62 Surgery 52/62 In fresh fracture group treated with surgery 31/32 fused (97%). In delayed fracture group treated with surgery 13/19 fused (68 %). Type III (32 patients), Surgery 15 /32 (47%) fused Immobilization 17 /32 (53%) fused, ten /15 (66%) treated with surgery fused 11 / 17 (65%) treated with immobilization fused (Every patient treated with a halo fused 5/ five 100 %) Surgical Procedures (66 patients) *Posterior cervical fusion*, (10) Patients Type II: 9/9 successful fusions (100%) Type III: 1/1 successful fusions (100%) *Anterior screw fixation:* (46 patients). 36 type II, ten type III, 42/45 pts. achieved bony union (93.3%) *Transoral fusion*, (9 patients), 6/8 type II successful fusions (75%), 1/1 type III successful fusions (100%) The authors of this large series conclude: Type I fractures can generally be managed non-operatively. Anterior screw fixation recommended for most Type II and unstable Type III fractures. Contraindications include old established non-unions, irreducible fractures, caudal displacement, severe osteoporosis. Type III fractures can be treated with Halo immobilization or anterior screw fixation. Established non-unions and irreducible fractures should be treated with posterior fusion. Transoral fusion reserved for rare cases of anterior cord compression.
Bednar DA et al, *J Spinal Disord,* 1995	Prospective report of early surgical stabilization in 11 geriatric patients with odontoid fractures.	III	The authors suggest that mortality can be reduced by surgical intervention and avoiding the use of Halo immobilization.
Dickman C and Sontag V, *J Neurosurg,* 1995	14 pts. with either acute or subacute type II fractures treated with anterior odontoid screw fixation. Radiographic criteria for fusion- postoperative radiographs and CT scans.	III	Type II 14/14 successful fusions (100%).

Author / Year	Study Design	Data Class	Comments
Dickman CA et al, *J Neurosurg,* 1995	Describes salvage procedures for failed atlantoaxial non-unions.	III	Report includes two cases in which anterior atlantoaxial transarticular screws were used and eight cases of posterior transarticular screws.
Coyne TJ et al, *Neurosurg,* 1995	15 pts. treated with posterior wire fusion and immobilized postoperatively in either Philadelphia-collar or Halo. Minimum follow-up two years, mean 4.7 years Radiographic criteria for fusion- absence of C1-2 movt. on lateral flex./ext. radiographs and evidence of continuity of trabecular bone formation between C1 and C2 across the graft.	III	Type II: 13/14 successful fusions (93%) Type III: 2/2 successful fusion (100%)
Hanigan J et al, *J Neurosurg,* 1993	19 patients over 80 years of age with odontoid fractures (Type II - 16, Type III - 3).	III	Five patients with displacement greater than five mm required posterior surgical fixation with good results. There was a 27 % mortality in the conservative treatment group with prolonged immobilization noted as one of the contributing factors.
Waddell J and Reardon G, *Can J Surg,* 1993	24 patients with odontoid fracture: 20 type II and four type III fractures. 16 of the 20 type II fractures were treated with C 1-2 arthrodesis (Gallie procedure). All type III fractures were treated non-operatively.	III	Type II: 15/16 successful fusions (94%), one pt. was lost to follow-up Type III: 3/4 successful fusions (75%), 1/4 nonunion (25%)
Ryan M and Taylor T, *J Spinal Disord,* 1993	30 patients over 60 years of age with Type II fractures.	III	The fusion rate in the patients over age 60 treated with immobilization was only 7/29 (23 %). Despite the low fusion rate for this age group, the authors favor halo immobilization over surgical fixation..
Bucholz RW, *Clin Orthop,* 1989	26 pts. 0 type I, 17 type II, nine type III. Pts. were immobilized in Halo for a minimum of three months and if no movt. on flex./ext. radiographs, placed in a Philadelphia-collar for an additional four weeks. Radiographic criteria for fusion - no movt. or subluxation at the fracture site on flex./ext. radiograph.	III	Type II 15/17 successful fusions (88%) 2/17 nonunions (12%) Type III 9/9 successful fusions (100%) Three deaths: 2pts. had type II fractures while being treated in Halo and one pt. with type III fracture.

Author / Year	Study Design	Data Class	Comments
Hadley MN et al, *Neurosurg,* 1988	Retrospective study including 62 patients with Type II odontoid fractures, including three with comminution at the base.	III	The subgroup of Type II odontoid fracture with comminution at the base was defined as the Type IIA odontoid fracture. The clinical significance of this observation was that fracture fused poorly with immobilization and was considered for early surgery.
Govender S and Grootboom M, *Injury,* 1988	Review of 41 patients with odontoid fractures: 26 type II, 15 type III. One month in traction (2-4 Kg), then a rigid collar for 6-8 weeks, and assessed at three months. Radiographic criteria for fusion: bony continuity across fracture site and no movt. on flex./ext. tomograms	III	Type II - 19/26 successful fusions (73%) 2/26 fibrous unions (8%) 5/26 nonunions (19%) Type III - 15/15 successful fusions(100%) - No mortality - seven Halo pin site infections - three pts. had skin excoriation over chin secondary to halter traction.
Fujii E et al, *Spine,* 1987	Retrospective review of 52 pts. with odontoid fractures, including data on 24 treated with immobilization,10 treated with anterior screw fixation and seven treated with posterior fusion. Radiographic criteria for fusion- AP and lateral tomograms.	III	<u>Immobilization</u> Type I, 1/1 successful fusion (100%) Type II, 3/7 successful fusions (43%) Type III, 10/14 successful fusions (72%) <u>Posterior fusion</u> Type II, 7/7 successful fusions (100%) <u>Anterior screw fixation</u> 6/8 type II successful fusion (75%) 2/2 type III successful fusion(100%)
Lind B et al, *Spine,* 1987	Review of 14 pts. with odontoid fractures managed with Halo immobilization and evaluated at 12 weeks with flex/ext. radiographs. Included type nine type II and five type III fractures with a two year follow-up. Radiographic criteria for fusion - lateral flex./ext. radiographs.	III	10/11 successful fusions (91%) combined type II and type III fractures. Authors support the use of Halo immobilization as the initial treatment for Type II and III odontoid fractures.

Author / Year	Study Design	Data Class	Comments
Dunn ME ans Seljeskog EL, *Neurosurg,* 1986	Retrospective report of 80 pts. with odontoid fractures including data on 74 patients treated primarily with rigid bracing for 3-6 months followed by additional collar support for six weeks and 41 patients undergoing posterior cervical fusion. Minimum follow-up period was six months, 80% of the patients had follow-up longer than eight months. Radiographic criteria for fusion - lateral flex./ext. radiographs at 3-4 months.	III	Rigid immobilization Type II 40/59 successful fusions (68%) 19/59 nonunions (32%) Type III 15/15 successful fusions (100%) Posterior fusion 40/41 successful fusions (98%) for combined type II and type III fractures.
Clark CR and White AA, *J Bone Joint Surg Am* 1985	Multicenter review including 144 patients managed by 27 different surgeons. Fusion rates reported based on fracture type and treatment. Radiographic criteria for fusion-evidence of trabeculation across the fracture site and absence of movt. on lateral flex./ext. radiograph.	III	No treatment Type II: 0/18 successful fusions (0%) Type III: 0/3 successful fusions (0%) Collar Type II: 0/3 successful fusions (0 %) Type III: 5/10 successful fusions (50%) Traction Type II: 2/3 successful fusions (66%) Type III: 7/8 successful fusions (88%) Halo Type II: 25/38 successful fusions (66%) Type III: 13/16 successful fusions (81%) Anterior fusion Type II: 7/8 successful fusions (88%) Type III: 2/2 successful fusions (100%) Posterior fusion Type II: 25/26 successful fusions (96%) Type III: 4/4 successful fusions (100%)

Author / Year	Study Design	Data Class	Comments
Pepin JW et al, *Clin Orthop,* 1985	Retrospective review of 41 patients with odontoid fractures including 26 treated conservatively with tongs, four-poster brace, collars and/or Halo vests (0 type I, 13 type II, 13 type III). 12 patients underwent posterior cervical fusion (1 type I, four type II and seven type III). Radiographic criteria for fusion - union on plain radiograph and tomogram as well as lateral flex./ext. views. Nonunion was defined as movement of the dens fragment on lateral flex/ext. radiographs	III	<u>Halo/Traction</u> Type II: 6/13 successful fusions (46%) Type III: 11/13 successful fusions (85%) <u>Posterior cervical fusion</u> Type I: 1/1 successful fusions (100%) Type II: 4/4 successful fusions (100%) Type III: 7/7 successful fusions (100%) The authors noted that the Halo vests were poorly tolerated in patients over age 75.
Wang GJ et al, *Spine,* 1984	Retrospective review of 25 patients with odontoid fractures treated with a variety of cervical immobilization techniques.	III	Type I: 1/1 fused with Halo (100 %) Type II: 4/7 fused with collar (57 %) 4/5 fused in Halo (80 %) Type III: 2/2 fused with collar (100 %) 10/12 fused with Halo (83 %)
Bohler J, *Surg Annu,* 1982	15 pts. With odontoid fractures, both acute and chronic treated with anterior screw fixation followed by a period of cervical fixation in a plastic collar for a period of 4-16 weeks. Pt. distribution 0 type I, eight type II, and seven type III. Radiographic criteria for fusion- not given	III	Type II 8/8 successful fusions (100%) Type III 7/7 successful fusions (100%)

Author / Year	Study Design	Data Class	Comments
Maiman DJ and Larson SJ, *Neurosurg,* 1982	Retrospective review of 49 cases of odontoid fracture, including 34 type II fractures treated with early posterior wire/graft stabilization. Post-op immobilization with a Minerva for an average. of five weeks. Two type III fractures were included. Radiographic criteria for nonunion: tomographic evidence of avascular necrosis, gross instability with a demonstrable gap at the fracture line and no evidence of healing. Fusion results evaluated six months post-surgery	III	The authors observed a 100 % fusion rate at the posterior surgical site, but only a 35 % fusion rate across the fracture site.
Ryan MD and Taylor TK, *J Bone Joint Surg Br,* 1982	Retrospective review of 23 pts. with odontoid fractures over a ten year period including one type I, 16 type II and six type III. Radiographic criteria for fusion - no movement on lateral flex./ext. radiographs.	III	Halo/Minerva/ SOMI Type I: 1/1 successful fusion Type II: 9/15 successful fusions (60%) Type III: 6/6 successful fusions (100%)
Ekong CE et al, *Neurosurg,* 1981	Retrospective review of 22 cases of odontoid fracture treated with Halo immobilization for three months. Type I, - 0 Type II - 16 Type III - 6 Includes outcome on 17 patients with an average follow-up of 30 months. Radiographic criteria for fusion - lateral flex./ext. radiographs.	III	Type II: 6/12 successful fusions (50%) Type III: 4/5 successful fusions (80%)
Marar BC and Tay CK, *Aust NZ J Surg,* 1976	Review of 26 cases of odontoid fracture including. 24 type II and two type III treated with cervical traction for up to ten weeks. Radiographic criteria for fusion - fibrous union at fracture site.	III	Type II - 9/24 successful fusions (37.5%) Type III - 2/2 successful fusions (100%)

Author / Year	Study Design	Data Class	Comments
Anderson LD and D'Alonzo RT, *J Bone Joint Surg, Am,* 1974	Retrospective review of 49 patients with odontoid fractures classified into Type I, II and III based on fracture.	III	Non-operative treatment (37 patients) Type I: Collar / Brace, 2/2 successful fusions (100%) Type II: Halo, 14/22 successful fusions (64%) 8/22 nonunions (36%) Type III: Halo, 12/13 successful fusions (92%) 1/13 nonunion (8%) Operative treatment (12 patients) Type II: eight / ten successful fusions (80 %) Type III: 2/2 (100 %)

EVIDENTIARY TABLE two - Traumatic Spondylolisthesis of the Axis

Author/ Year	Study Design	Class	Comments
Barros TE et al, *Spinal Cord,* 1999	Case report of surgical fixation in Hangman's fracture	III	Surgical treatment for Hangman's fracture is an option.
Verheggen R and Janses J, *Surg Neurol,* 1998	Retrospective study of 16 patients treated with early posterior screw fixation of the neural arch following Hangman's fracture.	III	The authors suggest that this is the optimal therapy for Edwards and Levine (Effendi) Type II and III fractures describing excellent results in their series.
Greene KA et al, *Spine,* 1997	340 cases axis fractures, including 74 patients with traumatic spondylolisthesis of the axis. Followup available on 72.	III	Most common: Effendi Type I (72 %) Francis Grade I (65%) 65 treated successfully with immobilization (12 weeks) 7 required early surgery (posterior fusion) due to poor alignment in the halo. (Effendi II - six and Effendi III – 1, by Francis Grading one -I, 1-II, 2- III, 3-IV) 33 % of all Effendi types II and III and 36 % of all Francis types III, IV, V patients required surgery. Strong correlation observed between Effendi I and Francis I and Effendi III and Francis IV. Conclusions: Immobilization is generally sufficient treatment. Surgery may be considered for severe Francis or Effendi type Hangman's fractures.
Corric D et al, *J Neurosurg*, 1996	Retrospective review of Hangman's fracture including 39 non-displaced (less than six mm C2 on C3) treated with non- rigid immobilization (Philadelphia collar for and average of 12 weeks) and ten displaced (greater than six mm) treated with halo (3), collar (6) or surgery (1)	III	Non-displaced group 39 / 39 fused using collar alone. Displaced group also fused regardless of treatment. C1-3 fusion required in one patient for failure of closed reduction.
Starr JK et al, *Spine* ,1993	Review of 19 cases of axis fracture including six cases of a pattern occurring through the posterior aspect of the vertebral body continuity of the posterior cortex with subluxation resulting in narrowing of the spinal canal.	III	Occurred in six of 19 patients including two with spinal cord injury from the associated subluxation.
Tan ES and Balachandran N, *Paraplegia,* 1992	Retrospective study of 33 patients with Hangman's fracture. Classified by Effendi: Type I – 21, Type II – 11 and Type III – 1.	III	20 / 26 had no neurologic deficit on admission. 28 / 33 with complete recovery after one year.
Torreman M, *Ned Tijdschr Geneeskd,* 1990	Long term study of 23 patients with Hangman's fractures treated with immobilization. Average follow-up 9.6 years.	III	100 % long-term fusion rate with cervical immobilization.

Author/ Year	Study Design	Class	Comments
Govendor S and Grootboom M, *Injury*, 1987	Prospective study of 39 patients.	III	All patients successfully managed with traction and immobilization.
Grady MS et al, *Neurosurg,* 1986	Retrospective review of 27 patients including 16 managed with halo, eight with a collar and three with bedrest.	III	All achieved fusion with no residual symptoms. The authors recommend the use of a Philadelphia collar alone in fractures with minimal displacement.
Levine AM and Edwards CC, *J Bone Joint Surg Am,* 1985	Retrospective case series of 52 patients with traumatic spondylolisthesis of the axis classified using the Effendi criteria.	III	Isolated Type I, II and IIa were all managed non-operatively. three of five Type III patients underwent surgical stabilization for failure to obtain or maintain reduction in a halo. The authors identify the Type IIa subgroup of the Effendi Type II patients who distract significantly with the application of traction and note the mechanism of injury for this group is likely flexion-distraction. 3/3 Type IIa were treated with gentle extension and compression under fluoroscopic guidance followed with Halo immobilization.
Borne GM et al, *J Neurosurg,* 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 with 100 % fusion rate.
Mestdagh H et al, *Rev Clin Orthop Reparatrice Appar Mot,* 1984	Combined clinical and anatomic study describing 41 fractures of the posterior neural arch of the axis. Eleven cases treated with anterior C2-3 interbody fusion. 30 treated with traction and immobilization. Follow-up available on 30.	III	Cadaveric study demonstrated fractures with displacement of up to five mm were stable. Cervical mobility maintained better in the conservative management group. The authors recommend conservative measure except in cases of marked instability or non-union.
Francis WR et al, *J Bone Joint Surg Br,* 1981	Classification paper based on 123 cases of fractures of the posterior arch of the axis. Grade based on displacement and angulation.	III	Grade I (15% of total series) 0 % non-union with immobilization Grade II (7 %) 33 % non-union Grade III (37 %) 0 % non-union Grade IV (34 %) 2 % non-union Grade V (6 %) 28 % non-union
Bucholz RW, *Clin Orthop*,1981	Autopsy study of 170 cases of traumatic death.	III	38 had cervical spine fractures and eight /38 had traumatic spondylolisthesis of the axis.
Pepin JW and Hawkins RJ, *Clin Orthop* 1981	Defined an early classification scheme for Hangman's fracture based on 42 cases.	III	Type I - an non-displaced fracture of the posterior elements Type II - displaced fracture involving posterior and anterior structures. All 42 patients were successfully treated non-surgically.

Author/ Year	Study Design	Class	Comments
Effendi B et al, *J Bone Joint Surg Br,* 1981	Classification paper based on 131 cases patients with fractures of the ring of the axis. Fractures divided into three groups based on mechanism of injury, displacement and stability.	III	Type I (65 % of total group) Isolated hairline fractures of the ring of the axis with minimal displacement of the body of C2 caused by axial loading and hyperextension Type II (28 %) Displacement of anterior fragment with disruption of the disc space below the axis caused by hyperextension and rebound flexion Type III (7 %) Displacement of anterior fragment with C2-3 facet dislocation caused by primary flexion and rebound extension. Although five patients underwent surgery the authors conclude that the vast majority of these patients are best managed with cervical immobilization.
Brashear R et al, *J Bone Joint Surg Am,* 1975	29 patients with Hangman's fractures followed for an average of six years.	III	No case of neurologic deficit. 23/23 (100%) treated with immobilization achieved fusion. Supports non-operative management.

EVIDENTIARY TABLE three – Miscellaneous Axis Fractures

Author / Year	Study Design	Data Class	Comments
Greene KA et al, *Spine* 1997	340 cases axis fractures, including 67 non-odontoid, non-Hangman's fractures (miscellaneous) most involving the body of lateral masses.	III	60 / 61 (98 %) were successfully treated with external mobilization in all but one patient - (1.6 % non-fusion rate) Four died patients died and one underwent early surgery for five mm luxation C2 on C3.
FujimaraY et al, *J Orthop Trauma,* 1996	31 cases of axis body fractures categorized into four types based on radiographic imaging.	III	Four types: Avulsion: (9/9 fused with immobilization) Transverse: (2/2 healed with immobilization) Burst: (2/3 treated with C2-3 fusion) Sagittal fractures: (15/17 healed with immobilization). 8 sagittally oriented fracture patients still had pain despite a bony union.
Benzel EC et al, *J Neurosurg,* 1994	Retrospective report of 15 patients described with fractures of the axis body.	III	The authors propose classification into Type 1: (coronal, n = 12), Type 2: (sagittal, n = 3) Type 3: (oblique and equivalent to the Type III odontoid fracture).
Korres DS et al, *Eur Spine J,* 1994	14 cases of avulsion fracture of the anterior inferior portion of the axis secondary to an extension type injuries. Mean follow-up of 8.5 years.	III	3 % of the cervical spine trauma cases over a 12 year period. All patients treated successfully with cervical immobilization
Bohay D et al, *J Orthop Trauma*, 1992	Describes three cases of vertical fractures of the axis.	III	Notes this as an unusual variant fracture of the axis body. All treated with immobilization.
Craig JB and Hodgson BF, *Spine*, 1991	Describes nine cases of superior facet fracture of the axis vertebra	III	5 treated with reduction and immobilization. three required open reduction and posterior fusion.
Burke JT and Harris JH, *Skeletal Radiol,* 1989	Review of 165 patients with axis fractures. 31 miscellaneous body fractures identified and classified on mechanism of injury.	III	Identified 31 patients with axis body fractures. 21 / 38 (68 %) were extension teardrop and ten / 31 (32 %) were hyperextension.
Jakim I and Sweet MB, *J Bone Joint Surg Br,* 1988	Case report of a transverse fracture of the axis and literature review. A classification scheme is proposed.	III	Three types of axis body fractures were described: the Type III odontoid fracture of Anderson and De Alonzo, the transverse body fracture and the avulsion fracture.

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