

MANAGEMENT OF COMBINATION FRACTURES OF THE ATLAS AND AXIS IN ADULTS

RECOMMENDATIONS

Standards: There is insufficient evidence to support treatment standards.

Guidelines: There is insufficient evidence to support treatment guidelines.

Options: Treatment of atlas-axis combination fractures based primarily on the specific characteristics of the axis fracture is recommended. External immobilization of the majority of C1-C2 combination fractures is recommended. C1-Type II odontoid combination fractures with an ADI of five mm or greater and C1-Hangman's combination fractures with C2-C3 angulation of 11 degrees or greater should be considered for surgical stabilization and fusion. In some cases, the surgical technique must be modified as a result of the loss of the integrity of the ring of the atlas.

RATIONALE

Combined fractures of the atlas and axis often present management challenges due to the unique anatomy and biomechanics of the atlantoaxial complex and the untoward stresses applied to the atlanto-axial region during trauma. While the majority of isolated atlas and axis fractures have been managed with cervical immobilization, the occurrence of the two fractures in combination often implies a more significant structural and mechanical injury. Although reports of combination C1-C2 fractures are relatively infrequent, sufficient evidence exists to allow a review of the management of a variety of combinations of atlas and axis fractures. The purpose of this report is to examine the available literature to determine successful treatment strategies for individual C1-C2 combination fracture types.

SEARCH CRITERIA

A National Library of Medicine computerized literature search from 1966 to 2001 was undertaken using Medical Subject Headings in combination with “vertebral fracture”: “atlas”, “axis” and “human”. This strategy yielded 1,071 references. The abstracts were reviewed and articles focusing on clinical management and follow-up of combination fractures of the atlas and axis were selected for inclusion. The relative infrequency of these fractures, the small number of case series and the numerous case reports with pertinent information required rather broad inclusion criteria. Several papers addressing relevant biomechanics and radiology were included. The bibliographies of the selected papers were reviewed to provide additional references.

These efforts resulted in 48 manuscripts describing the clinical features and the management of acute traumatic atlas and axis combination fractures. They are summarized in Evidentiary Table format. No Class I or II evidence has been generated on the management of these fractures. Treatment options have been formulated based on Class III medical evidence.

SCIENTIFIC FOUNDATION

Overview

In 1920 Sir Geoffrey Jefferson reviewed 46 cases of atlas fractures.⁽³⁰⁾ While his paper is best known for the characterization of the C1 burst fracture or “Jefferson fracture”, Jefferson’s series included 19 fractures that were described as “combination fractures” of the atlas and the axis. He noted increased morbidity and mortality for combination injury patients. Eleven of the

19 patients he described with C1-C2 combination injuries suffered significant neurological injuries.

In 1986, Levine and Edwards reported their approach to the management of C1-C2 traumatic fracture injuries.(34) They suggested that if an atlas or axis injury was identified, that a careful search for other related injuries was indicated. They stressed that each patient and each injury needed to be evaluated independently. They described staged treatment for certain injuries to allow healing of one fracture (usually the atlas) before definitively managing the combination injury (typically the axis fracture). Several of their observations are worthy of consideration in the management of combination fracture injuries of the atlas and axis today.

Incidence

Combination fractures of the C1-C2 complex are relatively common. In reports focusing primarily on odontoid fractures, the occurrence of a concurrent C1 fracture in the presence of a Type II or Type III odontoid fracture has been reported in 5% to 53% of cases.(12,23,25,26,28,36,39,40,43-45,47,49)

Odontoid fractures have been identified in 24% to 53% of patients with atlas fractures. (18,32,35,45) In the presence of a Hangman's fracture, the reported incidence of a C1 fracture ranges from 6% to 26%.(13,17,33,38,41,45)

Greene et al reported on 340 axis fractures and found 48 concurrent atlas fractures (combination injuries) for an incidence of 14%.(23) Ryan et al reviewed 717 spine fractures and found combination atlas-axis fractures in 15% of odontoid fractures and in 9% of Hangman's fractures. (45)

Gleizes et al reviewed 784 patients with proximal cervical spine injuries in 2000. (21) One hundred sixteen patients had injuries to C1 and/or C2. Thirty-one patients had C1 fractures in association with a C2 fracture (combination injury) representing 4% of the total c-spine fracture population, and 27% of all C1-C2 fracture injuries.

Morbidity and Mortality

Various authors have suggested that the morbidity and mortality of C1-C2 combination fractures is greater than that associated with isolated fractures of either the atlas or the axis. (12,18,19,25,26,31,49) Fujimara et al observed neurological deficits in 82 of 247 patients (34%) with injuries to the C1-C2 complex.(19) Those patients suffering deficit had either burst fractures or fractures of the posterior arch of C1, or a fracture of the C2 body coupled with an odontoid or Hangman's fracture. Several authors have described a high mortality rate with combination fractures, in particular C1 fractures combined with Type II odontoid fractures.(18,25,26,49) Fowler et al found that six of seven patients (86%) with C1-Type II odontoid combination fractures died in the early treatment period.(18) Similarly, Hanssen et al observed that five of six patients (83%) with this same combination fracture pattern died within the first 40 days of injury.(26) Both Hanigan et al and Zavonne et al reported early deaths associated with C1-Type II odontoid fractures. (25,49)

In other reports on C1-C2 combination fractures, the description of morbidity and mortality has been less remarkable.(12,18) Dickman et al suggested a 12% incidence of neurological deficit for C1-C2 combination fractures, compared with a 0% (0 of 32) and a 2% incidence (two of 125) for isolated atlas and axis fractures, respectively.(12) Kesterson et al described four patients with C1-C2 combination fractures.(31) Only one patient had a

neurological deficit (25%). Irrespective of the author, the described incidence of morbidity and mortality associated with combination C1-C2 fractures appears to be more than that associated with isolated atlas and axis fractures.

Treatment

Since the original description of C1-C2 combination fracture injuries by Jefferson, nearly every series reviewing either isolated fractures of the atlas or the axis includes some mention of C1-C2 combination fractures. It is difficult to determine the specific treatment provided to and outcome for most of those patients. Several authors have focused their reports specifically on combination C1-C2 fractures and their management.(12,21,24)

In 1989 Dickman et al identified 25 cases of acute atlas-axis combination fractures in an overall series of 860 patients with acute cervical fracture injuries.(12) In their experience, C1-C2 combination fractures represented 3% of their total cervical fracture population. Combination injuries represented 43% of acute atlas fractures (25 of 58) and 16% of acute axis fractures (25 of 150). The fractures of C1 and C2 were identified using plain film radiographs in 76% and 92% of the cases respectively. Computed tomography characterized the combination fracture patterns in all cases. Twelve percent of patients (three of 25) had neurological deficits upon admission. Two patients had acute central cord syndrome and one patient had a complete neurological injury. The etiology of the injury was a motor vehicle accident in 60% of cases and a fall in 28%. Four main types of atlas-axis fracture combination were identified: C1-Type II odontoid (ten cases, 40%), C1 miscellaneous axis fracture (seven cases, 28%), C1-Type III odontoid (five cases, 20%) and C1- Hangman's type fracture (three cases, 12%). The distribution of the atlas fractures was reported as multiple ring fractures in 40%, posterior ring

fracture in 28%, unilateral ring fracture in 24% and lateral mass fracture in 8%. Non-operative therapy was the initial management strategy in 20 of 25 of patients (84%). Eighteen were placed in a halo orthosis and two in a SOMI brace, for a median duration of 12 weeks (range 10–22 weeks). Four patients were treated with early surgical stabilization and fusion based on an atlanto-axial interval of six mm or greater. Three were treated with posterior C1-C2 wiring and fusion. Follow-up was accomplished in 23 of 25 patients (92%). Nineteen of the 20 patients (95%) treated either with a halo or SOMI orthosis achieved stability and fusion. One patient with an initial atlanto-axial interval of five mm, failed halo immobilization and was treated with posterior C1-C2 fusion. All patients treated surgically achieved stability utilizing a posterior fusion technique, four early and one delayed (100%). No patient deteriorated during or as a result of treatment. Six patients complained of persistent neck pain or limitation of neck motion. The authors offered a treatment algorithm based on the type and displacement of the axis fracture. They believe every patient with a C1 or C2 fracture should be studied with CT to rule out a combination injury. When present, atlas fractures in combination with Type II or III odontoid fractures with an atlantoaxial interval of five mm or greater should be considered for early surgical management. They stressed that the integrity of the C1 ring must be assessed to determine if C1-C2 wiring techniques can be utilized. Their perspectives were offered prior to the popularization of C1-C2 transarticular screw fixation techniques.

Guiot et al in 1999 described a series of ten patients with combination atlas-axis fractures treated with surgical stabilization and fusion.(24) Fifty percent (five of ten) of these patients

had failed halo immobilization and were referred specifically for operative intervention. Ninety percent were patients with C1-Type II odontoid fractures and the remaining patient had a C1-Type III odontoid combination fracture injury. One patient died in the follow-up period of unrelated causes. There were no other significant complications with a follow-up period of 28.5 months. All nine other patients accomplished successful fusion, utilizing an odontoid screw alone in five patients, an odontoid screw plus C2 pedicle screws in one, posterior transarticular screws in two, and anterior transarticular screws in one patient. The authors' indications for surgery included patients with fractures that could not be reduced or maintained with external immobilization, and unstable fractures with a high likelihood of non-union (including evidence of disruption of the transverse atlantal ligament).

Treatment of C1-Type II odontoid combination fractures

The treatment of specific fracture combinations has been the subject of numerous reports. The C1-Type II odontoid fracture combination appears to be the most frequent and the subject of the most variability in treatment strategy. As noted with the management of isolated Type II odontoid fractures, optimal treatment remains controversial (see Management of Isolated Axis Fractures in Adults). Management techniques for C1-Type II odontoid combination fractures include semi-rigid immobilization (collar), traction followed by mobilization in a brace, rigid immobilization (halo, Minerva, SOMI), posterior fusion with and without instrumentation and anterior odontoid screw fixation.

While Esses et al describes a single cases of C1-Type II odontoid combination fracture managed successfully in a cervical collar,(16) the lower fusion rate described for Type II odontoid fractures managed in a collar alone should be considered when electing this treatment

option (see Management of Isolated Axis Fractures in Adults). Sherk and Nicholson described a single patient successfully treated with traction reduction followed by immobilization in a Minerva brace.(48) Segal et al treated two patients with traction followed by rigid immobilization.(46) A variety of authors have described the treatment of C1-Type II odontoid combination fractures with rigid immobilization (halo, SOMI, Minerva).(8,12,14,26,32,36,46) Dickman et al described five of six patients successfully treated in this way (83% success rate).(12) All six patients had an atlanto-axial interval of less than six mm. One patient with an atlantoaxial interval of 5mm failed halo immobilization and required posterior C1-C2 fusion at 12 weeks post-injury. Segal et al described three cases of C1-Type II odontoid combination fracture successfully treated with halo immobilization.(46) Andersson et al described two patients with this combination fracture injury over age 65 successfully treated with a halo device.(2) Seybold et al added two more patients treated with a halo resulting in successful union.(47) Additional single cases managed with halo immobilization have been described. (8,14,26,32,36,43)

The C1-Type II odontoid combination fracture has been successfully managed with surgical stabilization and fusion. Dickman et al treated four patients with C1-Type II odontoid combination fractures with early surgical fusion based on an atlanto-axial interval of six mm or greater.(12) Three patients had posterior C1-C2 fusion and one patient underwent occipital-cervical fusion for multiple fractures of the posterior atlantal arch. Andersson et al treated one patient with C1-Type II odontoid combination fracture with posterior C1-C2 fusion in a series of elderly patients.(2) Coyne et al also treated one patient with this injury pattern with a C1-C2 posterior fusion.(10) Several authors have suggested that the C1 arch fracture be allowed to heal prior to undertaking definitive atlantoaxial arthrodesis for this sub-type of combination fractures.

Others have suggested using onlay bone graft for C1-C2 fusion followed by halo immobilization in the setting of posterior C1 arch incompetence.(29,34,37) Lee et al described the surgical management of two patients with C1-Type II odontoid combination fractures in whom posterior C1-C2 fusion was performed.(32) Guiot et al described two patients with this combination injury pattern treated posteriorly with C1-C2 transarticular screw fixation and fusion.(24)

Multiple investigators have utilized anterior odontoid screw fixation in the treatment of C1-Type II odontoid combination fractures. Montesano et al described four cases in 1991 successfully managed in this fashion.(39) Berlemann and Schwazenbach published an additional four cases.(5) The report by Guiot et al included six patients in which odontoid screw fixation was accomplished.(24) These authors added anterior transarticular fixation in one patient. In 1999 Henry et al described a fusion success rate of 90% in ten patients with C1-Type II odontoid combination fractures treated with anterior odontoid screw fixation.(28) Apostolides et al described a single case in which three screws were placed all from an anterior trajectory to stabilize the C1-C2 (bilaterally) articulation and the odontoid fracture.(3)

Occipito-cervical fusion has been reported in the management of C1-Type II odontoid combination fractures.(1,2,12,27,31,42) It appears this approach is reserved for patients with disruption of the C1 arch and gross C1-C2 instability.

In summary, a variety of treatment options have been effective in C1 – Type II odontoid combination fractures. External orthoses have been successfully used in the management of the majority of these injuries. Combination fractures of this subtype with C1-C2 instability as defined by atlantal-dens interval of five mm or greater have a high failure rate with external immobilization alone and have been successfully managed with operative reduction, internal fixation, and fusion.

Treatment of C1- Type III odontoid combination fractures

Dickman et al described five patients with C1-Type III odontoid combination fractures.(12) All were successfully treated with halo immobilization for an average of 12 weeks. Ekong et al identified two similar cases.(14) One was managed successfully in a halo. The second failed halo immobilization and required a delayed posterior C1-C2 fusion. Guiot et al reported a patient with a C1-Type III odontoid-Hangman's combination fracture they successfully treated with ventral odontoid screw fixation followed by posterior pedicle screw fixation and fusion.(24) It appears external immobilization is effective in the management of these injuries in the majority of patients.

Treatment of C1-Hangman's combination fractures

Most reported combination injuries of the atlas and the posterior elements of the axis have been successfully managed with semi-rigid or rigid external immobilization (+/- initial traction).(7,9,12,15,32,46,49) Coric et al and Lee et al described the successful treatment of nine total patients with this combination fracture type with a cervical collar only.(9,32) Dickman et al reported three patients with C1-Hangman's combination fractures successfully treated with either a halo or SOMI immobilization device.(12) The reports of Elliot et al, Brashear et al, Segal et al, Govendor and Charles, and Zavanone et al each describe patients with similar injuries successfully treated with non-operative techniques.(7,15,22,46,49) As with an isolated unstable Hangman's fracture, surgical fixation may be an option. The report by Fielding et al included 15 patients with C1-Hangman's combination fractures.(17) These authors recommended that fractures with angulation between C2 and C3 of 11 degrees or greater be treated surgically.

These combination fractures with angulation greater than 11 degrees were associated with an 85 % non-union rate with non-operative management in their experience. This combination injury subtype appears to be managed effectively with external immobilization alone. Unstable injuries, as defined by C2-C3 angulation of 11 degrees or greater, may require surgical management.

Treatment of C1-Miscellaneous C2 body combination fractures

Combination fractures of the atlas associated with miscellaneous axis body fractures have been treated with both rigid and non-rigid immobilization.(6,11,12,20,32,44) Dickman et al reported seven cases of this combination fracture subtype treated successfully with either a halo or SOMI brace.(12) The cases described by Fujimara et al, Lee et al, Craig et al and Bohay et al were all managed successfully with a cervical collar alone.(6,11,20,32) A single case described by Polin et al was treated with traction and subsequent halo immobilization.(44) Non-operative management of this combination injury subtype is effective.

SUMMARY

Combination fractures involving fractures of both the atlas and axis occur relatively frequently. A higher incidence of neurological deficit is associated with C1-C2 combination fractures compared to either C1 or C2 fractures in isolation. The C1-Type II odontoid combination fracture appears to be the most common combination injury subtype, followed by C1-miscellaneous axis, C1-Type III odontoid and C1-Hangman's combination fractures.

No Class I or Class II evidence addressing the management of patients with combination atlas and axis fractures is available. All of the articles reviewed describe case series or case

reports containing Class III evidence supporting a variety of treatment strategies for these unique fracture injuries.

In most circumstances, the specifics of the axis fracture will dictate the most appropriate management of the combination fracture injury. As reported for isolated atlas and axis fractures, the majority of atlas-axis combination fractures can be effectively treated with rigid external immobilization. Combination atlas-axis fractures with an atlanto-axial interval of five mm or greater or angulation of C2-C3 of 11 degrees or greater may be considered for surgical fixation and fusion. The integrity of the ring of the atlas must often be taken into account when planning a specific surgical strategy utilizing instrumentation and fusion techniques. If the posterior arch of C1 is inadequate, both incorporation of the occiput into the fusion construct (occipitocervical fusion) and posterior C1-C2 transarticular screw fixation and fusion have been successful.

Table I:

Combination Fracture Type	Treatment Options
C1-Type II odontoid fracture Stable Unstable (ADI = five mm or greater)	Collar, Halo, surgical fixation/fusion Halo, Surgical fixation/fusion
C1-Type III odontoid fracture	Halo
C1-miscellaneous axis	Collar, Halo
C1-Hangman's fracture Stable Unstable (C2-C3 angulation 11 degrees or greater)	Collar, Halo Halo, Surgical fixation/fusion

KEY ISSUES FOR FUTURE INVESTIGATION

The identification of which of the atlas-axis combination fracture sub-types are at greatest risk for non-union and subsequent instability would be useful in determining appropriate management for combination fracture injuries. A uniform and clinically useful definition of cranial, C1, and C2 instability in association with these fractures would be of benefit. Prospective data collection and case-control studies at multiple institutions would provide meaningful data addressing these issues. The relative infrequency of combined atlas-axis fractures would make a randomized study difficult. Patients with a C1-Type II odontoid combination fracture should be studied comparing operative and non-operative management and should be evaluated in terms of management morbidity, long-term success, economic benefit, patient satisfaction and return to pre-injury activities.

VII. EVIDENTIARY TABLES

First Author Reference	Description of Study	Data Class	Conclusions
Andersson S et al, 2000, <i>J Bone Joint Surg</i>	Case series of patients over 65 with odontoid fractures	Class III	Includes three patients with C1-Type II odontoid fractures. Treatment: Halo – 2 Posterior cervical fusion – 1
Gleizes V et al, 2000, <i>Eur Spine J</i>	Retrospective epidemiological review of coincidence of fractures in the upper cervical spine	Class III	784 cervical spine injuries 116 upper cervical spine injuries (C1-C2) (15%) 31/116 (26 %) combination of C1 and C2 70 % of all atlas fractures occurred in combination with another fracture 30 % of all Hangman's and odontoid fractures occurred in combination with another fracture 41.9 % of patients with combination fractures of the upper cervical spine underwent surgical fixation versus 21.7 % of those with isolated injuries
Muller EJ et al, 2000, <i>Eur Spine J</i>	Case series of 39 cases of Hangman's fractures.	Class III	Included two with C1 ring fractures (5.1 %)
Guiot B and Fessler R, 1999, <i>J Neurosurg</i>	Retrospective review of ten patients undergoing surgical fixation for combination C1-C2 fractures 5/10 referred specifically for surgical fixation after failed external immobilization Average followup 28.5 months	Class III	Type: C1-Type II odontoid – nine (90%) C1-Type III odontoid and Hangman's – one (10%) Technique: Odontoid screw – six (60 %) Odontoid screw plus C2 pedicle screws one (10 %) C1-C2 Transarticular screws (posterior) two (20%) C1-C2 Transarticular screws (anterior) one (10%) Outcome: One unrelated death All others fused successfully without other complication.
Henry AD et al, 1999, <i>J Bone Joint Surg</i>	Case series of 61 cases of Type II odontoid fractures treated with anterior screw fixation in which followup was available.	Class III	Includes ten combination fractures of C1-C2 (16 %) C1 burst (Jefferson) – Type II odontoid – three (5 %) C1 anterior arch – Type II odontoid – three (5 %) C1 posterior arch – Type II odontoid – four (6 %) All patients in the series were treated with anterior odontoid screw fixation with a 92 % success rate. No problems attributed directly to the presence of the atlas fracture.
Morandi X et al, 1999, <i>Surg Neurol</i>	Case series including 17 odontoid fractures treated with anterior screw fixation.	Class III	Included two cases of C1-posterior arch fracture plus a posteriorly displaced Type II odontoid.

First Author Reference	Description of Study	Data Class	Conclusions
Lee TT et al, 1998, <i>Spine</i>	Retrospective review of 16 cases of atlas fracture	Class III	Includes eight patients with combination C1 and C2 fractures C1-Type II odontoid – two cases One treated with halo immobilization Two treated with posterior C1-C2 fusion C1-Hangman’s – two cases Both treated with cervical collar C1-C2 body fracture – three cases All three treated with cervical collar Authors conclude that the management of the combination fracture should be based on the C2 fracture and that halo immobilization is not always required
Seybold EA and Bayley JC, 1998, <i>Spine</i>	Case series of 57 odontoid fractures.	Class III	Includes three cases of C1 ring fracture plus Type II odontoid. The authors successfully managed two patients with a halo. One patient treated in a collar with a “poor” result. The overall fusion rate for the Type II odontoid fractures in this series was 65 %. No specific effect from the C1 fracture was noted.
Apostolides P et al, 1997, <i>J Neurosurgery</i>	Case report	Class III	Patient with anterior ring of C1 fracture and a Type II odontoid failed halo immobilization Treated successfully with anterior C1-C2 transarticular fixation and an odontoid screw
Berlemann U and Schwarzenbach O, 1997, <i>Acta Orthop Scand</i>	Retrospective review of 19 patients over age 65 with odontoid fractures	Class III	Includes four patients with C1 fractures and Type II odontoid fractures all treated with anterior odontoid screw fixation
Greene KA et al, 1997, <i>Spine</i>	Large review of 340 axis fractures.	Class III	48 patients with an axis fracture also had an atlas fracture (14 %). Specifics on management are not presented but the authors indicate that the management in these cases was based on the C2 fracture.
Castillo M and Mukherji SK, 1996, <i>Am J Neuroradiol</i>	Case report	Class III	Includes one case of Jefferson fracture plus Type II odontoid treated with halo
Coric D et al, 1996, <i>J Neurosurg</i>	Case series of 57 patients with Hangman’s fractures.	Class III	Includes seven cases of combination fracture (C1 –Hangman’s). All were treated based on degree of displacement. If less than six mm, were treated with non-rigid immobilization.
Fujimara Y et al, 1996, <i>Paraplegia</i>	Case series of axis body fractures	Class III	Describes three patients with C1- miscellaneous body fracture all treated with cervical immobilization. Authors recommend non-operative treatment except in cases of severe angulation. Philadelphia collar used if minimal angulation.
Polin RS et al, 1996, <i>Neurosurgery</i>	Case series of 62 patients with odontoid fractures.	Class III	Includes five cases of combination C1-C2 fracture (8 %) C1-Jefferson – Type II odontoid - four C1-Misc C2 body fracture – 1 All patients in series managed with either halo or collar.
Coyne TJ et al, 1995, <i>Spine</i>	Retrospective review of 32 patients with odontoid fractures includes one combination fracture	Class III	One case of Jefferson- Type II odontoid treated with Gallie fusion

First Author Reference	Description of Study	Data Class	Conclusions
Fujimara Y et al, 1995, <i>Paraplegia</i>	Retrospective review of 247 admissions with upper cervical spine fractures - focuses on 82 patients with neurological deficit	Class III	In patients with combined injury of C1 and two neurological deficit occurred in patients with posterior arch fracture, burst fracture of the atlas or body fracture of the axis associated with either an odontoid fracture or Hangman's
Benzel E et al, 1994, <i>J Neurosurg</i>	Case series	Class III	Includes one case of C1- vertically oriented C2 miscellaneous body fracture (treatment not described). The author discusses the possible mechanism included hyperextension and axial loading.
Pederson AK and Kostuik JP, 1994, <i>J Spinal Disord</i>	Case report of 70 year old man with fracture dislocation of C1-C2 with 20 mm atlantoaxial displacement	Class III	Successfully treated with O-C4 decompression and posterior fusion with complete recovery.
Hanigan WC et al, 1993, <i>J Neurosurg</i>	Case series of 19 patients over 80 years of age with odontoid fractures.	Class III	Included two patients with a C1-Jefferson – Type II odontoid. One died in the hospital after being placed in traction. One with a stable fibrous non-union following treatment in a halo.
Bohay D et al, 1992, <i>J Orthop Trauma</i>	Case series	Class III	Includes a case of a C1 burst fracture plus a vertical C2 body fracture successfully treated in a cervical collar alone.
Hays MB and Bernhang AM, 1992, <i>Spine</i>	Case series of unusual fractures of the atlas	Class III	Includes two cases of combination fractures. C1 (anterior arch)-Type II odontoid fracture failed halo treatment resulting in an O-C2 fusion.
Jeanneret B and Magerl F, 1992, <i>J Spinal Disord</i>	Case series of 59 patients with odontoid fractures 30 of which were treated surgically.	Class III	Includes two cases in which the posterior arch of C1 was not intact. C1-Jefferson – Type II odontoid - 1 C1 – posterior arch – Type III odontoid - 1 Authors feel strongly that if the posterior arch of C1 is not intact that C1-C2 transarticular fixation is indicated. In the comment following the article, the point is made that an onlay graft between C1 and C2 posteriorly without wiring of C1 followed by halo immobilization has been used in this situation.
Ryan MD and Henderson JJ, 1992, <i>Injury</i>	Epidemiological report of 717 spine fractures	Class III	Atlas fractures occurred with odontoid fractures (53%) and with Hangman's (24 %) Odontoid fractures occurred with atlas fractures (15%) Hangman's fracture occurred with atlas fracture (9%)
Craig JB and Hodgson BF, 1991, <i>Spine</i>	Case report	Class III	Jefferson plus superior facet of axis treated with collar.

First Author Reference	Description of Study	Data Class	Conclusions
Esses SI and Bednar DA, 1991, <i>Spine</i>	Case report - atlas and odontoid fracture	Class III	Jefferson plus type II odontoid in a 34-year-old male - treated successfully with collar only (seen after a one month delay in diagnosis)
Kesterson L et al, 1991, <i>J Neurosurg</i>	Case series, retrospective review	Class III	Includes four patients with combination fracture of the atlas and type II odontoid treated with O-C2 fusion One of these four patients had a significant neurological deficit (25%) The authors suggest surgery if unstable and define instability as atlantoaxial interval of greater than five mm or lateral mass displacement greater than seven mm
Levine AM and Edwards CC 1991, <i>J Bone Joint Surg</i>	Case series of 34 patients with atlas fractures.	Class III	Includes 15 patients with a combination C1-C2 fracture (44%) C1- TII or TIII odontoid – eight (24 %) C1- Hangman's – seven (21%) Describes two cases in the C1-odontoid fracture group in which the posterior C1 arch altered the treatment plan. In one case a Gallie fusion failed and the second no wiring was used, just onlay bone graft.
Montesano PX et al, 1991, <i>Spine</i>	Case series of 14 Type II odontoid fractures treated with anterior odontoid screw fixation. Follow-up 24 months.	Class III	Seven had a C1 fracture (50%) The overall fusion rate was 93 %. No problems attributed directly to the C1 fracture.
Zavonne M et al, 1991, <i>J Neurosurg Sci</i>	Case series of 23 C1-C2 fractures.	Class III	Included two combination fracture (9%) C1-Type II odontoid – patient died C1- Hangman's – treated successfully with traction reduction and Minerva
Fowler JL et al, 1990, <i>J Spinal Disord</i>	Case series of 48 atlas fractures from series of 867 C-spine fractures (5.5 %).	Class III	Included 18 cases with a combination C1-C2 fracture (38 % of total series) C1 burst (Jefferson) –Type II odontoid – six (33 %) C1 burst (Jefferson) -Type III odontoid – one (6 %) C1 burst (Jefferson) - Miscellaneous axis – two (11 %) C1 burst (Jefferson) – Hangman's – 0 (0 %) C1 arch –Type II odontoid – eight (44 %) C1 arch -Type III odontoid – one (6%) C1 arch - Miscellaneous axis – one (6 %) C1 arch – Hangman's – three (16 %) These authors present data supporting the increased mortality associated with combination C1-C2 fractures. Six of the seven early deaths (86 %) had a C1 fracture associated with either a Type II or Type III odontoid fracture.

First Author Reference	Description of Study	Data Class	Conclusions
Dickman C et al, 1989, <i>J Neurosurg</i>	Retrospective review of 25 patients with fractures of both C1 and C2 Comprises three % of the overall cervical spine injury cohort (25 of 860)	Class III	Four Types Noted: C1 –Type II odontoid – ten (40 %) C1- Miscellaneous axis – seven (28 %) C1-Type III odontoid – five (20%) C1 – Hangman’s – three (12 %) Neurological deficit in three / 25 (12 %) Treatment determined by type of C2 fracture Non-operative (84 %) Halo – 18 SOMI – 2 One of the C1-Type II patients failed halo and required C1-C2 fusion Operative (initial management) C1-Type II odontoid with six mm displacement – three patients treated with posterior C1-C2 fusion – one patient treated with O-C2 fusion because of multiple fractures in C1
Fielding JW et al, 1989, <i>Clin Orthop</i>	Case series of 123 Hangman’s fractures	Class III	Included: C1 arch – Hangman’s – ten cases (8 %) C1 burst (Jefferson) – Hangman’s – two (2%) C1 lateral mass – Hangman’s – three (3%) Specifics not given for each subtype but overall the authors recommend treatment based on the C2 fracture despite the presence of the C1 fracture. Regardless of the C1 fracture, the authors favored an anterior C2-3 fusion for those patients with angulation greater than 11 degrees as this group had an 85% non-union rate with cervical immobilization.
Govendor S and Charles RW, 1987, <i>Injury</i>	Cases series of upper cervical fractures.	Class III	Includes two cases of combination C1 posterior arch fracture – Hangman’s fracture – treated successfully with a cervical collar (non-rigid cervical immobilization)
Hanssen AD and Cabanela ME, 1987, <i>J Trauma</i>	Case series of 42 odontoid fractures.	Class III	Includes seven combination fractures (17 %). C1- Jefferson – Type II odontoid – 6 five of six (83 %) died within first 40 days 1of six developed a stable non-union C1- posterior arch – Type II odontoid – 1 Healed with halo immobilization
Lind B et al, 1987, <i>Spine</i>	Case series of 14 odontoid fractures managed in a halo orthoses.	Class III	Includes one case of C1-Jefferson- Type II odontoid managed in a halo vest for 12 weeks.
Mirvis SE et al, 1987, <i>Radiology</i>	Radiographic review 27 C2 fractures.	Class III	Noted nine associated C1 fractures (26 %).
Segal LS et al, 1987, <i>J Bone Joint Surg</i>	Case series of 18 patients with atlas fractures.	Class III	Six cases were combination C1-C2 fractures. C1-Jefferson – odontoid fracture - five cases 3 treated with halo, two with traction followed by halo C1-Jefferson – Hangman’s – one case treated with a collar

First Author Reference	Description of Study	Data Class	Conclusions
Levine AM and Edwards CC, 1986, <i>Orthop Clin North Am</i>	Review article on management of C1-C2 trauma.	Class III	<p>Comments on combined injuries:</p> <ol style="list-style-type: none"> 1. The presence of three injuries to the C1-C2 complex associated with a high likelihood of neurological injury 2. If find one injury or fracture, look carefully for another 3. Mechanism of injury usually consistent with the injury observed 4. Each injury needs to be evaluated individually, for example the presence of two fractures does not always indicate instability (posterior arch of C1 plus a non-displaced Hangman's fracture) 5. Staging of treatment may be required (as described by Lipson et al below) with allowing one fracture to heal before treating definitively
Levine AM and Edwards CC, 1985, <i>J Bone Joint Surg</i>	Case series of 53 patients with Hangman's fracture. Describes stable (Type I Hangman's) and unstable (Type II Hangman's) groups.	Class III	<p>Included nine cases of Type I Hangman's (stable) plus C2 fracture: Type II odontoid – 2 Type III odontoid – 3 Posterior arch – 1 Burst (Jefferson) – 2 Lateral mass – one</p> <p>Only one case Type II Hangman's (unstable) with C2 fracture Posterior arch – 1</p> <p>Only one case treated surgically Type I Hangman's plus Type II odontoid treated with posterior C1-C2 fusion.</p>
Pepin JW and Hawkins RJ, 1985, <i>Clin Orthop</i>	Case series of 41 odontoid fractures	Class III	<p>Includes nine cases of odontoid fracture in combination with another spinal fracture of which the C1-Jefferson – Type II odontoid was the most common</p> <p>All treated with either C1-C2 fusion or halo.</p> <p>Author recommends fusion in the elderly.</p>
Effendi B et al, 1981, <i>J Bone Joint Surg</i>	Case series of 131 Hangman's fracture with classification	Class III	<p>Includes combination fractures: C1 posterior arch – Hangman's – eight patients (8/131, six %) Odontoid fracture – Hangman's – two patients (2/131, two %) Specific outcomes not presented but all fused with either anterior or posterior C1-C2 fusion or halo –</p> <p>Overall mortality was nine %</p>
Ekong CE et al, 1981, <i>Neurosurgery</i>	Case series of 22 patients with odontoid fractures	Class III	<p>Included: C1- Jefferson -Type II odontoid — 1 C1-Jefferson -Type III odontoid — 2</p> <p>All treated with halo with one of the C1 Jefferson -Type III odontoid patients failing and requiring C1-C2 posterior fusion</p>

First Author Reference	Description of Study	Data Class	Conclusions
Lipson SJ, 1977, <i>J Bone Joint Surg</i>	Case series of three cases of atlas fracture plus Type II odontoid	Class III	The authors recommend combination therapy of halo immobilization from ten to 12 weeks until the posterior arch of the atlas fracture has healed, followed by atlanto-axial fusion (Gallie-type) to definitively manage the odontoid fracture.
Brashear R et al, 1975, <i>J Bone Joint Surg</i>	Case series of Hangman's fracture	Class III	Included two patients with C1 posterior arch fracture plus Hangman's treated with reduction and Minerva for 3-6 months.
Anderson LD and D' Alonzo RT, 1974, <i>J Bone Joint Surg</i>	Case series of odontoid fractures	Class III	Included one patient with combined C1-Type II odontoid fracture treated with O-C2 fusion
Elliot JM et al, 1972, <i>Radiology</i>	Case series	Class III	C1 posterior arch – Hangman's – two cases treated with immobilization
Sherk HH and Nicholson JT, 1970, <i>J Bone Joint Surg</i>	Case report	Class III	One case each of a combination C1- TII odontoid and a C1- Hangman's - both were treated with immobilization (reduction in traction followed by a Minerva brace) successfully.

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