Treatment of Axis Body Fractures
A Systematic Review

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Study Design: Evidence-based systematic review.

Objectives: To define the optimal treatment of fractures involving the C2 body, including those with concomitant injuries, based upon a systematic review of the literature.

Summary of Background Data: Axis body fractures have customarily been treated nonoperatively, but there are some injuries that may require operative intervention. High-quality literature is sparse and there are few class I or class II studies to guide treatment decisions.

Materials and Methods: A literature search was conducted using PubMed (MEDLINE), Cochrane Central Register of Controlled Trials, and Scopus (EMBASE, MEDLINE, COMPENDEX). The quality of literature was rated according to a grading tool developed by the Center for Evidence-based Medicine. Operative and nonoperative treatment of axis body fractures were compared using fracture bony union as the primary outcome measure. As risk factors for nonunion were not consistently reported, cases were analyzed individually.

Results: The literature search identified 62 studies, of which 10 were case reports which were excluded from the analysis. A total of 920 patients from 52 studies were included. The overall bony union rate for all axis body fractures was 91%. Although the majority of fractures were treated nonoperatively, there has been an increasing trend toward operative intervention for Benzel type III (transverse) axis body fractures. Nearly 76% of axis

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body fractures were classified as type III fractures, of which 88% united successfully. Nearly all Benzel type I and type II axis body fractures were successfully treated nonoperatively. The risk factors for nonunion included: a higher degree of subluxation, fracture displacement, comminution, concurrent injuries, delay in treatment, and older age.

Conclusions: High rates for fracture union are reported in the literature for axis body fractures with nonoperative treatment. High-quality prospective studies are required to develop consensus as to which C2 body fractures require operative fixation.

Key Words: axis fracture, C2 body fracture, type III odontoid fracture, union rate, nonunion

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The biomechanical and anatomic characteristics of the atlantoaxial (C1–C2) complex are unique, allowing the atlas (C1) to pivot on its articulation with the axis (C2) to provide rotational motion.[1–3] The dynamics of kinetic energy transfer to this complex as well as the location and anatomy of the axis contribute to the distinctive features and variety of axis fractures.[1,2,4,5] Fractures of the axis are not uncommon, accounting for between 17% and 27% of injuries to the cervical spine.[2,4,6–8] Such fractures can be divided into 3 clinically relevant categories: fractures of the odontoid process, hangman fractures (traumatic spondylolisthesis), and miscellaneous nonodontoid, nonhangman fractures.[1,3,9] Although fractures of the odontoid process and hangman fractures are by far the most common, this review will focus on fractures of the axis body in the region between the base of the odontoid process and the pars interarticularis.[5,10]

The most commonly used classification of axis body fractures was developed by Benzel et al[10] in 1994, based upon the orientation of the fracture line (Fig. 1). The first 2 subtypes are vertically oriented fractures. The fracture line of type I axis body fractures is oriented coronally, whereas the fracture line is sagittal in type II fractures. Type III fractures are characterized by transverse fracture lines. Rostral type III axis body fractures are equivalent to type III odontoid fractures, as defined by Anderson and D'Alonzo.[11] Although these may be classified as part of the series of odontoid fractures, the fracture line actually passes through the body of the axis.[6,10] A less commonly used alternate classification by Fujimura et al[12] characterized axis body fractures based upon 4 subtypes: avulsion, burst, transverse, and sagittal.

High-quality literature on the management of axis body fractures is sparse, and there are few class I or II studies.[1,3,13] The conventional treatment of axis body fractures is immobilization.[2,3,14] Axis body fractures are unlikely to compromise the spinal cord as they are often only minimally displaced, the bony ring remains intact, and the spacious upper cervical spinal canal provides a degree of safety compared with subaxial segments. Also, such fractures are often not comminuted and occur in well-vascularized cancellous bone, which increases the likelihood of achieving solid healing.[14]

However, several types of injuries present exceptions which may warrant stabilization. These include unstable Benzel type III fractures, axis body fractures with significant C2–C3 subluxation or comminution, fractures with other associated injuries, and fractures in the elderly, who may not tolerate extended periods of immobilization.[2,9,11,12,15–20] More recent literature also suggests that halo-devices may be poorly tolerated and are associated with high complication rates in elderly patients, and that nonoperative treatment may not be successful for highly displaced fractures.[21–23]

The purpose of this review was to provide an evidence-based analysis of the literature on operative and nonoperative treatment of axis body fractures including those with concomitant injuries to evaluate 2 hypotheses. While we hypothesize that a nonoperative approach is adequate for treatment of the vast majority of axis body fractures, we suspect that early operative fixation may be associated with higher union rates, especially in a subset of potentially unstable fractures or in patients with a

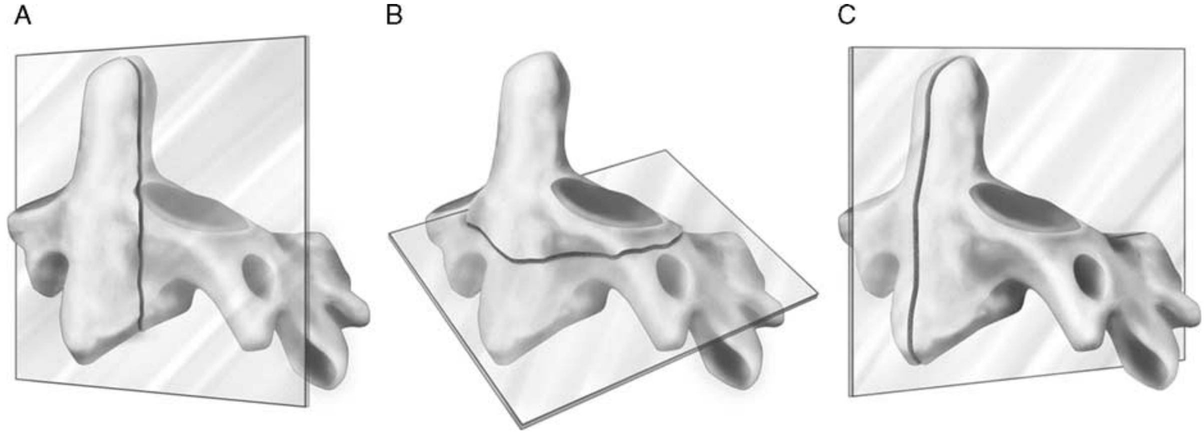


FIGURE 1. Benzel C2 body fracture classification which distinguishes fractures based on orientation of fracture plane: type I fractures are in the coronal plane (A), type II fractures are in the sagittal plane (B), and type III fractures are transversely oriented (C).

reduced capacity for healing. In addition, as suggested by the literature, we hypothesize that type III axis body fractures may be at higher risk for nonunion if inadequately stabilized (Table 1).[28]

MATERIALS AND METHODS

The optimal treatment for fractures involving the body of the axis vertebrae was evaluated through an evidence-based systematic review of the literature. The literature search was conducted using PubMed (MEDLINE), Cochrane Central Register of Controlled Trials, and Scopus (EMBASE, MEDLINE, COMPENDEX). The search strategy employed 3 components to provide a comprehensive, yet focused search using both plain language strings and standard MeSH/Index terms (Tables 2 and 3). The search returned 2643 results after removing duplicates. The title and abstract of each study was screened initially for relevance, and then full-text manuscripts were reviewed against specific inclusion criteria by 2 independent reviewers (C.K.K. and A.N.F.). This resulted in 30 articles that met these criteria (Fig. 2). The references and citing articles of all 30 selected studies were cross-referenced to ensure a comprehensive search list. This method introduced 34 additional studies to add to those obtained in the initial search. In 2 instances in which studies used repeat cases from the same institution, the study providing a more comprehensive case series was included and the other excluded. The 62 studies selected based upon the above methods were used as evidence for this review. Of these 62 studies, 10 were considered case reports and not used for statistical analyses. The relevant clinical data, including fracture classification, demographics, intervention, and bony union rate, were carefully extracted into evidence tables (Tables 4–6) and conflicting information within a study was reconciled. All studies were assigned a level of evidence using the evidence grading tool developed by the Centre for Evidence-based Medicine in Oxford, United Kingdom.[73]

TABLE 1. Axis Fracture Classifications

Classification	Axis Body
Benzel[10]	Type I (coronal) Type II (sagittal) Type III (transverse)
Fujimura[12]	Avulsion, burst, sagittal, transverse
	Odontoid
Anderson and D'Alonzo[11]	Type I (upper odontoid) Type II (odontoid junction) Type III (axis body)
Hadley variant[2]	Type IIa (comminution at base)
Grauer modification[24]	Type II A (nondisplaced) Type II B (displaced, transverse, or anterior superior to post-inferior) Type II C (comminuted or anterior inferior to post-superior)
	Hangman
Effendi[25]	Type I (isolated hairline with minimal displacement) Type II (displacement of anterior fragment) Extension, flexion, spondylolisthesis Type III (facet joints dislocated and locked)
Francis[26]	Type I (displaced < 3.5 mm, angulated < 11 degrees) Type II (displaced < 3.5 mm, angulated > 11 degrees) Type III (displaced between 3.5 mm and 1/2 vertebral width, angulated < 11 degrees) Type IV (displaced between 3.5 mm and 1/2 vertebral width, angulated > 11 degrees) Type V (disk disruption)
Levine and Edwards[27]	Type I (nondisplaced and no angulation) Type II (significant translation and some angulation) Type IIa (severe angulation, slight or no translation) Type III (severe angulation and displacement, facet dislocation)

TABLE 2. PubMed Search Strategy

Component 1	Component 2	Component 3
fracture*	"axis"[mh]	"body"
injur*	"axis"	"bodies"
"spinal injury"[mh]	"C2"	"C2 fracture*"
"spinal fracture"[mh]	Second cervical vertebra*	"type 3 odontoid"
"spinal cord injuries"[mh]		"type III odontoid"
"cervical vertebrae/ injuries"[mh]		
917,386	129,920	975,434
	1006 (1 duplicate)	

Inclusion and Exclusion Criteria

The principal requirement for inclusion was the reporting of data describing the treatment of fracture(s) of the axis body in one or more patients. This review included studies reporting on all 3 classes of axis body fractures, Benzel types I, II, and III, as well as those involving concomitant fractures and associated injuries of the spine. All literature published in English, as well as non-English studies that were readily available and translated into English was included. Studies were excluded if they did not provide at least minimal details regarding fracture classification, treatment (nonsurgical or surgical), and outcome (bony union rate). The review was limited to live human subjects of any age and studies using cadavers, non-human subjects, or laboratory simulations were excluded. Excluded from analysis were: letters to the editor, commentary, opinion articles, and studies without a clear methodology.

TABLE 3. Scopus Search Strategy

Component 1	Component 2	Component 3
All(injury or fracture)	ALL("axis")	ALL ("body")
INDEXTERMS("spinal injury")	ALL("C2")	ALL ("C2 fracture")
INDEXTERMS("spinal fracture")	ALL(second cervical vertebrae)	ALL ("type 3 odontoid")
INDEXTERMS("spinal cord injuries")	INDEXTERMS("axis")	ALL ("type III odontoid")
INDEXTERMS("cervical vertebrae/injury")		
2,233,924	41,868	2,597,285
	1793 (10 duplicates)	

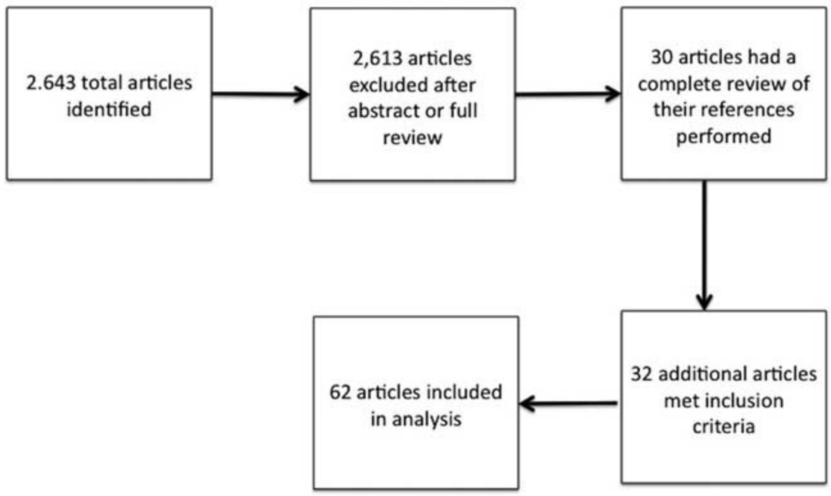


FIGURE 2. Flow chart demonstrating the literature search.

Statistical Analysis

The only consistently reported indicator of outcome was fracture union or the lack thereof, referred to by various terms including pseudarthrosis, nonunion, or fibrous union. Risk of nonunion was compared for operative and nonoperative treatment, all nonoperative treatment methods, axis body fracture classification (type I/II and type III), and year of publication using a logistic regression and relative risk/odds ratio analyses. Not all studies represented a homogenous random sampling of axis body fractures in the population, as 10 studies focused exclusively on operative management, 8 on halo treatment alone, and 5 studies only included elderly patients.[15,19,22,23,29,32,35,36,38–42,44,47–50,57,59,61,62] Finally, the lack of detailed treatment and patient-based outcome data may have tended to bias the results toward higher union rates. Nonunions were excluded when it was not clear which treatment method had led to the failure, whereas studies with 100% union did not require such clarification.

The quality and comprehensiveness of reported case data was not appropriate for applying meta-analytical statistics for the purposes of determining operative indications for axis body fractures. Qualitative risk factors which have been suggested to mitigate proper fracture union and thus indicate the use of operative intervention, such as subluxation, comminution, delay in treatment, associated injuries, and age were not consistently reported. Many larger studies only reported a collective mean age, treatment length, follow-up, and sex for all patients in their series, and often it was not possible to associate such characteristics with the specific subset of axis body fractures included in this review. Thus, we review the indications for surgical intervention and factors associated with fracture nonunion on a case-by-case basis.

RESULTS

Results for All Fractures

Sixty-two studies met the inclusion criteria, in which axis body fractures were treated either nonoperatively or operatively between 1974 and 2012. Ten illustrative case reports were not included in our analyses, but were summarized in Table 6. Of the 52 studies, 13 focused on axis body fractures, whereas 39 studies reported on odontoid fractures, and we only extracted evidence from those classified as type III. Almost all studies reported on <50 cases (48 of 52 studies) (Fig. 3).

A total of 3030 fractures were included in the 52 studies, of which 920 (30.1%) were identified as axis body fractures. Unfortunately, many different populations were surveyed to identify these fractures; thus, these data could not be used to determine the incidence of axis body fractures in any 1 population of injuries. Of these 920 cases, 70 (7.6%) were identified as type I fractures, 22 (2.4%) were type II fractures, and 696 (75.7%) were type III axis body fractures utilizing the Benzel classification. Type I and II classification in 132 (14.3%) cases could not be distinguished (Fig. 4). In addition, 124 of those 132 cases were considered miscellaneous nonodontoid, nonhangman fractures, which consisted mostly of axis body fractures, but were not further specified. In 10 case reports, there were 8 type I fractures, 1 type II fracture, and 6 type III fractures. In 234 cases in which sex was specifically identified, there were 157 men and 77 women. The frequency weighted mean age was 44.7 years, based on 233 of 920 cases, and mean follow-up was 34.9 months, based on 144 of 920 cases.

Treatment method was only reported for 868 of 920 cases, as 52 patients were either lost or died before treatment could commence. The majority of patients, 713 of 868 (82.1%), were managed nonoperatively. However, operative intervention has increased in prevalence in the literature-based upon year of publication (Fig. 5). Those studies published before 1995 reported nonoperative treatment in 301 of 332 (90.7%) cases, whereas those studies published after 1995 reported nonoperative treatment in 412 of 495 (83.2%) cases ($P = 0.002$). Since 2006, only 56.4% (44/78) of reported cases have been treated nonoperatively. The most commonly used method

TABLE 4. Treatment and Outcome of Type I and II Axis Body Fractures: Cases Reported in the Literature

References	CEBM	Type I/ Type II	Male/ Female	Mean Age (Range)	Mean Follow-up (Range) (mo)	Special Considerations	Nonoperative/Operative	Mean Treatment Period (Range)	Union/Nonunion	Treatment of Failure
Boran et al[24]	4	7/0	6/1	35 (21–68)	72	All ETFs	7 [2 halo, 2 collar, 3 minerva]/None	NA	7 of 7/None	—
Cooper et al[29]	4	2†	28/5 (AIS)	27 (9–66) (AIS)	6–18 (AIS)	1 C3 lamina and pedicle, 1 C1–C2 subluxation	2 [2 halo]/none	102 days (all complex fxs)	2 of 2/none	—
Benzel et al[10]	4	12/17	I: 10/2 II: 15/2	I: 41 (19–75) II: 42 (19–67)	25 (14–53) (AIS)	I: 9 avulsion 3 comminuted with hgm fx (2 of 3 operative) II: 2 conc. type III odontoid fxs (2 of 2 operative)	I: 10 [3 halo, 6 collar, 1 minerva]/2 [2 ant] II: 15 [6 halo, 9 collar]/2 [2 ant]	8–16 wk	I: 12 of 12/none II: 17 of 17/ none	—
German et al[14]	4	16/5	I: 9/7 II: 4/1	I: 47.1 ± 17.9 II: 40.0 ± 17.2	I: 7.1 ± 6.6 II: 5.0 ± 1.4	I: 6 avulsion, 1 conc. atlas fx II: none	I: 15 [1 halo, 4 collar, 10 minerva]/none II: 3 [3 minerva]/none	I: 3.4 mo ± 1.2 II: 3.75 mo ± 1.5	I: 15 of 15/none II: 3 of 3/ Nnone	—
Greene et al[13]	4	67*	209/131 (AIS)	40.8 (0.2–94) (AIS)	45 (1–96) (AIS)	1 conc. lateral mass fx 1 C2–C3 subluxation (5 mm) (1 of 1 operative)	62 [48 halo, 5 collar, 8 SOMI, 1 none]/1 [1 unspec.]	11 wk (7–17)	62 of 63/1 of 63 [halo]	1 [unspec.]
Hadley et al[30] Dickman et al[31]	4	7*	34/23 (AIS)	40.8 (14–86) (AIS)	40 (2–101) (AIS)	All conc. atlas fxs	7 [6 halo, 1 SOMI]/None	12 wk (10–22) (all C1–C2 fxs in series)	6 of 6/none	—
Hadley et al[2] Hadley et al[4]	4	47*	152/77 (AIS)	38 (0.16–94) (AIS)	57 (1–96) (AIS)	1 conc. lateral mass fx 1 C2–C3 subluxation (5 mm) (1 of 1 operative)	43 [36 halo, 3 collar, 4 SOMI]/1 [1 post]	10 wk (8–17)	43 of 44/1 of 44 [halo–4 mm C2–C3 subluxation]	1 [post]
Hughes et al[32]	4	2†	6/2 (AIS)	36 (19–66) (AIS)	15 (> 1.5) (AIS)	None	2 [2 halo]/none	24–30 wk (AIS)	2 of 2/none	—
Koller et al[16]	4	7/0	5/2	40.3 (26–74)	81.9 (23–142)	1 JBF 3 transverse process fxs (1 of 3 operative)	6 [3 halo, 3 collar]/1 [1 ant]	8.7 wk (6–12) [halo] 7.7 wk (6–9) [collar]	31 of 35/4 of 35 (AIS)	NA
Kontautas et al[33]	2b	3*	18/11 (AIS)	52 (17–80) (AIS)	NA	All conc. atlas fxs	3 [1 halo, 2 SOMI]/none	10 wk (AIS)	3 of 3/none	—
Korres et al[25]	4	4†	6/3 (AIS)	48 (AIS)	144 (24–216) (AIS)	3 avulsion, 4 conc. hgm fxs, 1 conc. odontoid fx	4 [4 halo or minerva]/none	3 mo (AIS)	4 of 4/none	—
Korres et al[26]	4	14/0	8/6	47 (16–73)	97.2 (24–168)	All ETFs	12 [12 traction only]/none	3–6 wk	12 of 12/none	—
Watanabe et al[34]	4	13/0	9/4	49.5 (25–79)	20.75 (3–60)	All ETF 2 C2/3 subluxation (3, 4 mm) 1 esophageal compression (1 of 1 operative)	11 [5 halo, 6 collar]/1 [1 ant]	4–10 wk [halo]	9 of 9/none	—

*Unspecified miscellaneous non-odontoid, nonhangman's fxs.
†Type I and II not distinguished.
AIS indicates all in series; ETF, extension teardrop fx; Hgm fx, hangman's fx; JBF, Jefferson burst fx; Ant, anterior operative approach; Post, posterior operative approach; Conc., concomitant; SOMI, sternal occipital mandibular immobilizer.

of external immobilization was the halo-device (Fig. 6), which was used in 404 of 713 (56.7%) nonoperative cases. The hard collar, Minerva cast, and sternal occipital mandibular immobilizer were used in 166 of the remaining 202 nonoperative cases in which treatment method was designated. Those nonoperative cases categorized as "other" included treatment with traction alone, 2 cases using a Guilford brace, and 1 case using a soft collar. When documented in the literature, operative procedures were categorized as anterior or posterior approach. Anterior approach was used in 124 of 155 (80.0%) operative cases, considerably more than the 20 cases treated posteriorly. However, 19 of 28 operative interventions after failed nonoperative treatment utilized a posterior approach, whereas only 4 cases were documented to have undergone anterior operative treatment.

As suggested above, bony union was the principal outcome measure used to assess successful treatment. Unfortunately, 10 of 52 studies (134 cases) did not sufficiently document fracture union and could not be included in statistical analyses. Also, 7 fractures treated operatively in a study by Li et al[49] were revisions of old fractures that had initially failed to unite, and were thus not included in the analyses. The overall union rate for all 734 fractures studied was 91.0% [95% confidence interval (CI), 88.9–93.1]. Nonoperative treatment of 666 fractures resulted in 604 successful unions, indicating a union rate of 90.7% (95% CI, 88.5–92.9). This included 6 cases that were left untreated, of which 4 did not successfully fuse. Despite having so few cases that did not undergo any formal treatment, there was a significant increase in relative risk of nonunion for patients who received no treatment of 7.6 (95% CI, 4.1–14.1) compared with patients treated nonoperatively. Of the various nonoperative treatment methods, the hard collar had the highest risk of nonunion, which occurred in 10 of 86 (11.6%) cases. The relative risk for nonunion in cases treated with a hard collar was 30% (95% CI −32 to +145) higher than that of other nonoperative cases, although this was not statistically significant. On the contrary, halo-devices performed better than other nonoperative methods with a union rate of 96.7%, reducing relative risk by 80% (95% CI, 64–89). Cases treated with a Minerva cast, sternal occipital mandibular immobilizer brace, or "other" methods had union rates of 96.0% (95% CI, 88.3–103.7), 100%, and 89.9% (95% CI, 77.0–100.8), respectively.

Operative treatment of 68 fractures resulted in 64 successful unions, with a union rate of 94.1% (95% CI, 88.5–99.7). The only reported cases of nonunion following operative treatment were from a single study by Chiba et al.[17] The operative treatment in these cases included anterior screw fixation in 2 cases and 1 case each of transoral anterior fusion and bone peg fixation. All 4 of these nonunions occurred after anterior approach interventions, which decreased the overall union rate for anterior operative cases to 90.5% (95% CI, 81.6%–99.4%). Although a higher union rate was achieved operatively and relative risk was reduced by 37% (95% CI, −68 to 76), reduced risk of nonunion in operative compared with nonoperative cases was not statistically significant according to a logistic regression ($P = 0.27$). It is important to note that operative cases are likely qualitatively different from those treated nonoperatively due to selection bias.

There was no change in likelihood of nonunion on a year-by-year basis ($P = 0.095$). The strongest statistical relationship demonstrated that axis body fractures classified as type III were at a greater risk for nonunion than type I or II fractures ($P = 0.0036$). The odds of nonunion were16.3 times higher for type III fractures compared with type I or II. Thus, the remaining analysis considers type I/II and type III axis body fractures separately.

Type I and II Results

Of the 62 studies identified for this review, 18 reported on treatment strategy of a total of 224 type I or II axis body fractures. Five of these studies were case reports and therefore not included in analyses. There were 66 men and 25 women in the 91 cases that identified sex. The frequency weighted mean age was 44.1 years, based on 84 of 224 cases, and mean follow-up was 45.9 months, based on 62 of 224 cases. The vast majority of cases, 202 of 210 (96.2%), were treated nonoperatively, whereas only 8 of 210 (3.8%) were managed operatively.

There were various indications for operative management in these 8 cases. Two type I fractures treated operatively in a study by Fujimura and colleagues were comminuted fractures with concomitant hangman fractures. In that same study, 2 type II fractures with concomitant type III odontoid fractures were managed operatively.[12] In studies by Greene et al[2] and Hadley et al,[13] 2 fractures with 5 mm C2–C3 subluxation and concomitant lateral mass fractures were treated operatively. In a case report by Marotta et al,[72] a type I fracture with a substantial C2–C3 subluxation and a hangman fracture was treated operatively. One of 3 axis body fractures with a concomitant transverse process fracture reported by Koller et al[16] underwent operative management. Finally, a type I axis body fracture, considered to be an extension teardrop fracture, underwent surgical repair due to dysphagia caused by esophageal compression.[34] There were 34 additional cases considered to be extension teardrop fractures, as well as 18 avulsion fractures that were not specified as "tear drop." All of these injuries were managed nonoperatively. Similarly, type I or II axis body fractures with concomitant injuries (2 Jefferson burst fractures, 8 atlas fractures, and 4 hangman fractures) were all treated successfully with nonoperative methods. Only 2 of 200 type I or II axis body fractures did not successfully unite, representing a union rate of 99.0% (95% CI, 97.6%–100.4%). Both cases of nonunion were treated initially with a halo-device, and subsequently underwent operative intervention after failure. One of these cases was reported to have a 4 mm subluxation of C2–C3.[2,4]

Type III Results

Of the 62 studies identified for this review, 50 discussed treatment strategy of a total of 696 cases of type

TABLE 5. Treatment and Outcome of Type III Axis Body Fractures: Cases Reported in the Literature

References	CEBM	Type III	Male/ Female	Mean Age (Range)	Avg. Follow-up (Range) (mo)	Special Considerations	Nonoperative/ Operative	Mean Treatment Period (Range)	Union/Nonunion	Treatment of Failure
Anderson and D'Alonzo[11]	4	15	NA	40.7(3–76)	22 (6–228) (AIS)	NA	13 [13 collar]/2 [2 unspec.]	4.8 mo (4–8) [collar]	14 of 15/1 of 15 [collar-5 wk delay for treatment]	NA
Andersson et al[35]	4	5	11/18 (AIS)	78 (66–99) (AIS)	51 (24–89) (AIS)	None	4 [1 halo, 3 collar]/1 [1 ant]	NA	15 of 27/12 of 27 [8 of 10 nonop, 3 of 10 ant op, 1 of 7 post op] (AIS)	2 [1 ant, 1 post] (AIS)
Apfelbaum et al[15]	4	9	98/49 (AIS)	50.1 (15–92) (AIS)	18.2 (3–60)	Op indications: > 4–6 mm dislocation, > 40–65 y of age, subluxation, and comminution	None/9 [9 ant]	—	107 of 117/10 of 117 (AIS)	6 [collar], 4 [unspec. operative]
Böhler[36]	4	7	6/1	46.4 (17–81)	NA	Acute and chronic	None/7 [7 ant]	—	7 of 7/none	—
Chen et al[22]	3c	7	25/31 (AIS)	81.2 (≥ 65) (AIS)	NA	Surgical group—larger degree of displacement	5 [collar or halo]/2 [2 unspec.]	NA	NA	NA
Chiba et al[17]	4	31	79/25 (AIS)	35 (3–83) (AIS)	30 (> 12 nonop, > 24 op) (AIS)	8 old fxs (> 3 wk posttrauma) (7 of 8 operative, 1 nonoperative malunion)	17 [5 halo, 8 collar or SOMI, 4 minerva]/14 [13 ant, 1 post]	15.7 wk [halo] 12.3 wk [collar] 16.3 wk [minerva]	21 of 32/11 of 32 [5 collar or SOMI, 1 minerva, 1 other, 4 ant op]	NA
Clark and White[37]	4	50	30/17	43.9 (11–86)	NA	40% nonunion when displacement > 5 mm, 22% nonunion when angular deformity > 10 degrees	42 [16 halo, 10 collar, 8 traction, 5 sand bad stabilization, 3 none] /6 [2 ant, 4 post]	NA	34 of 46/13 of 46 [3 none, 1 halo, 5 collar, 3 traction]	1 [halo], 3 [ant], 6 [post]
Coyne et al[38]	4	2	23/9 (AIS)	46.5 (14–88) (AIS)	56.4 (24–96) (AIS)	None	None/2 [2 post]	—	2 of 2/none	—
Dunn and Seljeskog[27]	4	22	85/43 (AIS)	NA	> 6–120 (AIS)	None	17 [17 halo or SOMI]/ NA [All post]	13–23 wk	15 of 15/0 of 15 [halo]	—
Eap et al[39]	4	10	15/21 (AIS)	70.3 (16.8–94.9) (AIS)	36 (4–96) (AIS)	None	None/10 [ant]	—	35 of 36/1 of 36 (AIS)	—
Ekong et al[40]	4	6	16/6 (AIS)	53 (20–86) (AIS)	30 (6–50) (AIS)	2 JBF (1 with AS)	5 [5 halo]/none	3 mo	4 of 5/1 of 5 [1 halo-JBF and AS]	1 [post]
Fountas et al[41]	4	2	25/13 (AIS)	48.4 (17–81) (AIS)	58.4 (39–87) (AIS)	None	None/2 [2 ant]	—	27 of 31/ 4 of 31 (AIS)	1 [post]
Fujii et al[18]	4	19	44/14 (AIS)	34 (3–81) (AIS)	NA	Most old cases (> 3 wk) treated operatively	14 [14 halo]/6 [5 ant, 1 post]	NA	15 of 19/ 4 of 19 [4 halo]	—
Benzel et al[10]	4	2	1/1	38 (21–54)	25 (14–53) (AIS)	None	2 [2 collar]/none	8–16 wk	2 of 2/none	—
Glaser et al[42]	4	12	184/61 (AIS)	35 (5–85) (AIS)	NA	30 degrees kyphotic deformity (1 of 1 loss of reduction)	12 [12 halo]/none	3 mo	12 of 12/none	—
Govender et al[43]	2b	74	163/33 (AIS)	36.7 (18–64) (AIS)	26.3 (12–60) (AIS)	None	183 [63 minerva, 120 SOMI]/None (AIS)	14 wk (12–20) (AIS)	53 of 74/21 of 74	—
Greene et al[13]	4	77	209/131 (AIS)	40.8 (0.2–94) (AIS)	45 (1–96) (AIS)	5 malalignment, 1 marked C2–C3 subluxation (6 of 6 operative)	69 [67 halo, 2 SOMI]/6 [2 ant, 4 post]	12 wk (10–20)	74 of 75/1 of 75 [halo-conc. atlas fx]	1 [post]
Hadley et al[30] Dickman et al[31]	4	5	34/23 (AIS)	40.8 (14–86) (AIS)	40 (2–101) (AIS)	All conc. atlas fxs	5 [4 halo, 1 SOMI]/none	12 wk (10–22) (all C1–C2 fxs in series)	5 of 5/none	—

Hadley et al[2] Hadley et al[4]	4	49	152/77 (AIS)	38 (0.16–94) (AIS)	57 (1–96) (AIS	1 marked C2–C3 subluxation (1 of 1 operative)	48 [46 halo, 2 SOMI]/1 [1 unspec.]	11 wk (10–20)	49 of 49/none	—
Hanigan et al[44]	4	3	9/10 (AIS)	86.2 (> 80–99) (AIS)	18.3 (7–37)	1 posterior displacement (2 mm) (1 of 1 malunion)	3 [3 collar]/None	NA	2 of 3/1 of 3 [collar-2 mm displacement]	NA
Hanssen and Cabanela[45]	4	16	12/4	43 (14–76)	26 (5–102)	2 subaxial cervical fxs	16 [7 halo cast, 7 halo vest, 2 CT brace]/ none	12.3 wk (8–24)	16 of 16/none (1 delayed union-halo)	—
Henry et al[19]	4	52	48/33 (AIS)	57 (15–92) (AIS)	16.6 (3–120) (AIS)	Op indications: shallow base, > 30% displacement, multiple injuries (ISS > 15)	None/52 [52 ant]	–	56 of 61/5 of 61 (AIS)	None
Kim et al[46]	4	10	22/9 (AIS)	39.3 (AIS)	25.1 (12–84.3) (AIS)	Mostly nonop before 2006, then mostly operative after 2006	5 [5 halo]/5 [5 unspec.]	NA	24 of 31/7 of 31 [6 halo, 1 unspec. op] (AIS)	NA
Koller et al[16]	4	11	4/7	62.2 (25–80)	66 (7–125)	1 JBF, 1 conc. atlas fx, 1 conc. facet fx 1 post. comminution (1 of 1 operative)	10 [4 halo, 3 collar, 3 minerva]/1 [1 ant]	13 wk (12–16) [halo] 8 wk (6–12) [collar] 14 wk (2–18) [minerva]	31 of 35/4 of 35 (AIS)	NA
Komadina et al[47]	4	5	3/2	33.6 (24–39)	NA	5 ant. displaced (3–5 mm)	5 [halo]/none	12 wk	5 of 5/none	—
Kontautas et al[33]	2b	1	18/11 (AIS)	52 (17–80) (AIS)	NA	All conc. atlas fxs	7 [5 halo, 2 collar]/none (type II and III odontoid)	10 wk	1 of 1/none	—
Lee and Sung[48]	4	2	2/0	31.5 (24–39)	18.6 (3–36) (AIS)	1 displaced (2 mm)	None/2 [2 ant]	—	2 of 2/none	—
Li et al[49]	4	7	17/9 (AIS)	32.8 (17–58) (AIS)	29 (24–36) (AIS)	Revision operations for old malunions	NA	—	NA	7 [post]
Lind et al[50]	4	5	3/2	50.6 (28–71)	~24	1 displaced (> 4 mm)	5 [5 halo]/none	11.7 wk (8–12) (AIS)	5 of 5/none	—
Maiman and Larson[51]	4	2	40/11 (AIS)	NA	72 (16–180) (AIS)	None	2 [2 minerva]/none	6 wk (4–10) [minerva] (AIS)	2 of 2/none	—
Marar and Tay[52]	4	2	22/4 (AIS)	9–75 (AIS)	NA	None	2 [2 traction only]/none	< 10 wk	2 of 2/none	—
Moon et al[53]	4	2	NA	23—58 (AIS)	12–120 (AIS)	None	None/2 [2 ant]	—	2 of 2/none	—
Müller et al[54]	4	7	13/13 (AIS)	59.1 (15–86) (AIS)	25.4 (12–75) (AIS)	Stable fxs with < 5 mm displacement only	7 [7 collar]/none	3.2 mo (3–4) (AIS)	6 of 7/1 of 7	NA
Pepin et al[21]	4	21	23/19 (AIS)	4–92 (AIS)	> 3	Older than 78 (1 of 1 halo malunion)	13 [3 halo, 10 collar]/7 [7 post]	12 wk	18 of 20/2 of 20 [1 halo, 1 collar]	NA
Polin et al[55]	4	18	12/6	44	7.4	Greater displacment in fxs treated with halo (halo-2.2 mm, collar-1.4 mm)	18 [13 halo, 5 collar]/ none	NA	18 of 18/none	—
Ekong et al[40]	4	8	16/4 (AIS)	NA	NA	None	7 [3 halo, 4 collar]/1 [1 ant]	12 wk	6 of 8/2 of 8 [2 nonop unspec.]	NA
Ryan and Taylor[56]	4	6	17/6 (AIS)	47.4 (AIS)	NA	1 required intubation and had no orthosis	6 [2 halo, 2 minerva, 1 SOMI, 1 none]/none	NA	6 of 6/none	—
Schweigel[57]	4	20	41/24 (AIS)	49 (16–87) (AIS)	NA	Displacement of 10 mm (halo) and 7 mm (none) (2 of 2 malunion)	20 [19 halo, 1 none]/ none	8 wk (3–12) [halo] (AIS)	17 of 19/2 of 19 [1 halo, 1 none]	NA
Seybold and Bayley[58]	4	20	12/8	48.7 (19–84)	28.2 (0–100)	84 y old (1 of 1 operative) 5.5 mm ant displacement, heavy smoker (1 of 1 malunion)	19 [18 halo, 1 collar]/1 [1 unspec.]	10.7 wk (0–12) [halo]	19 of 20/1 of 20 [1 halo-5 mm displacement]	1 [ant]

(*Continued*)

TABLE 5. Treatment and Outcome of Type III Axis Body Fractures: Cases Reported in the Literature (*continued*)

References	CEBM	Type III	Male/Female	Mean Age (Range)	Avg. Follow-up (Range) (mo)	Special Considerations	Nonoperative/Operative	Mean Treatment Period (Range)	Union/Nonunion	Treatment of Failure
Song et al[59]	4	4	4/0	44.5 (24–60)	41.4 (12–88) (AIS)	None	None/4 [4 ant]	—	4 of 4/none	—
Tashjian et al[23]	4	18	NA	80.7 (> 65) (AIS)	NA	1 conc. atlas fx all > 65 y	61 [34 halo, 27 collar]/17 [17 unspec.] (AIS)	NA	NA	NA
Wang et al[60]	4	12	18/7 (AIS)	40 (17–80) (AIS)	NA	None	12 [10 halo, 2 collar]/none	3 mo	12 of 12/none	—
Wang et al[61]	2b	5	26/16 (AIS)	47.1 (32–65) (AIS)	25.1 (13–45) (AIS)	None	None/5 [5 ant]	—	40 of 42/2 of 42 (AIS)	NA
Weller et al[62]	4	5	2/3	77 (72–82)	NA	All elderly 2 atlas fxs (2 of 3 halo) 1 halo intolerance	5 [3 halo, 2 collar]/none	10–12 wk [halo]	3 of 4/1 of 4 [1 collar]	1 [post]
Ziai and Hurlbert[63]	4	30	58/35 (AIS)	57 (16–94) (AIS)	6 (3–92) (AIS)	3 chronic fxs (1 of 3 malunion) 1 elderly (1 of 1 soft collar)	29 [12 halo, 8 collar, 6 SOMI, 1 soft collar, 2 other]/1 [1 post]	2–4 mo	17 of 21/4 of 21 [2 halo, 1 collar, 1 unknown]	1 [post]

AIS indicates all in series; AS, ankylosing spondylitis; JBF, Jefferson burst fx; Ant, anterior operative approach; Post, posterior operative approach; Conc., concomitant; SOMI, sternal occipital mandibular immobilizer.

III axis body fractures. Five of these studies were case reports and therefore not included in the analyses. There were 91 men and 52 women in the 143 cases that identified sex. The frequency weighted mean age was 45.0 years, based on 149 of 696 cases, and mean follow-up was 26.6 months, based on 82 of 696 cases. Five studies specifically reported only on fractures in elderly patients and 1 study specifically discussed revision surgery following nonunion.

Considerably more type III axis body fractures were treated operatively, 147 (22.3%), compared with 8 (3.8%) type I or II fractures ($P < 0.001$). Operative indications were reported in 10 studies. The most commonly suggested indications for operative intervention were a large degree of displacement or subluxation.[2,4,13,15,19] Studies by Apfelbaum et al[15] and Henry et al[19] proposed surgical stabilization for fractures with displacement of > 4–6 mm or 30%. Also, 2 cases with marked C2–C3 subluxation were managed operatively in studies by Greene and colleagues.[2,4,13] In the same study performed by Greene and colleagues, 5 additional cases were treated operatively due to malalignment. In addition to dislocation and subluxation, Apfelbaum et al[15] recommended operative treatment for comminuted fractures and fractures in patients older than 40–65 years of age. One fracture with posterior comminution in a study by Koller et al[16] and another in an 84 year old in a study by Seybold and Bayley[58] underwent operative management. Henry et al[19] advocated operative repair of fractures with a shallow base or in patients with multiple injuries and an injury severity score > 15. Several authors have suggested that shallow type III fractures may behave more like unstable type II odontoid fractures.[9,15,20] Finally, 3 studies suggested that old fractures, most often defined as > 3 weeks after trauma, should be treated operatively to encourage successful union.[17,18,49] In a study by Chiba et al,[17] 7 of 8 old fractures were successfully treated operatively. However, the single chronic fracture treated nonoperatively failed to unite.

Although many type III axis body fractures were treated operatively, the majority (77.7%) were still managed conservatively. As with type I and II fractures, the halo-device was used more than any other nonoperative method for external immobilization. Several studies provided indications for the use of a halo-device or hard collar. According to a study by Polin et al,[55] halo-devices were used in fractures with greater displacement (mean, 2.23 mm; range, 0–8 mm) compared with those treated with a hard collar (mean, 1.4 mm; range, 0–3 mm). The hard collar is likely best suited for stable fractures with less severe displacement.[74] Also, some elderly patients may not be able to tolerate a halo-device. Thus, these patients would be treated with a hard collar or even soft collar if their medical or mental status does not allow for rigid external stabilization.[62,63] Similar to type I and II fractures, type III axis body fractures with concomitant injuries (1 Jefferson burst fractures, 8 atlas fractures, and 1 facet fracture) were all treated successfully with nonoperative methods.[16,30,31,62]

TABLE 6. Treatment and Outcome of Axis Body Fractures: Case Reports Only

References	CEBM	Type (I/II/III)	Male/ Female	Mean Age (Range)	Avg. Follow-up (Range) (mo)	Special Considerations	Nonoperative/ Operative	Mean Treatment Period (Range)	Union/ Malunion	Treatment of Failure
Bohay et al[64]	CR	3/0/0	3/0	39.7 (23–39)	14 (3–30)	1 ETF, 1 JBF	3 [1 halo, 1 collar, 1 traction only]/none	NA	3 of 3/ none	—
Goldschlager et al[65]	CR	0/0/1	0/1	48	18	Hgm fx (1 of 1 malunion)	1 [halo]/none	12 wk	0 of 1/1 of 1	1 [post]
Hahnle et al[66]	CR	3/0/0	2/1	28.3 (17–34)	10 (3–20)	17 mm anterior displacement	3 [3 halo]/none	11 (8–13)	3 of 3/ none	—
Iizuka et al[67]	CR	1/0/0	1/0	73	8	1 spinous process fx	1 [1 halo]/none	16 wk	1 of 1/ none	—
Jakim and Sweet[68]	CR	0/0/1	1/0	24	24	None	1 [1 SOMI]/ none	6 wk	1 of 1/ none	—
Johnson and Jayasekera[3]	CR	0/0/1	1/0	64	NA	None	1 [1 SOMI]/ none	NA	1 of 1/ none	—
Korres et al[69]	CR	0/0/2	1/1	60.5 (55–66)	90 (3–12)	1 avulsion	2 [1 halo, 1 collar]/none	12 wk	2 of 2/ none	—
Lozano-Requena et al[70]	CR	0/1/0	0/1	15	3	None	1 [1 minerva]/ none	3 mo	1 of 1/ none	—
Maki[71]	CR	0/0/1	1/0	29	6	None	1 [1 halo]/none	4 mo	1 of 1/ none	—
Marotta et al[72]	CR	1/0/0	1/0	35	NA	Hgm fx and C2–C3 subluxation (1 of 1 operative)	None/1 [1 post]	NA	1 of 1/ none	—

CR indicates case report; ETF, extension teardrop fracture; Hgm fx, hangman's fx; JBF, Jefferson burst fx; Ant, anterior operative approach; Post, posterior operative approach; SOMI, sternal occipital mandibular immobilizer.

The union rate for type III axis body fractures was 88.0% (95% CI, 85.2–90.8), considerably lower than that of type I and II fractures. An increased risk for nonunion was observed for both nonoperative and operative cases. Of the 473 cases managed conservatively, 60 failed to establish union, which represents a union rate of 87.3% (95% CI, 84.3–90.3). Three reported cases of nonunion were old or chronic fractures that were treated non-operatively.[17,63] A study by Clark and White[37] reported a 40% nonunion rate for type III fractures with a displacement >5 mm and a 22% nonunion rate for type III fractures with an angular deformity of >10 degrees. Four additional studies described displaced fractures that failed to unite. Two of such fractures were treated with a halo: 1 case involved a heavy smoker with a 5.5 mm displacement and a second fracture was displaced by 10 mm.[57,58] Another fracture was displaced by only 2 mm and treated with a collar, and the final case involved an elderly patient who declined to undergo treatment for a fracture displaced by 7 mm.[44] Several patients with concomitant injuries did not have successful fracture union. These included a patient with a Jefferson burst fracture and ankylosing spondylitis, another patient with an atlas fracture, and a third patient with a hangman fracture. All

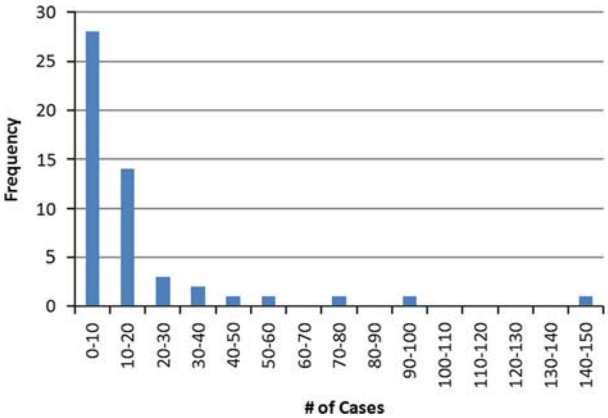


FIGURE 3. Histogram showing breakdown of study size. full color online

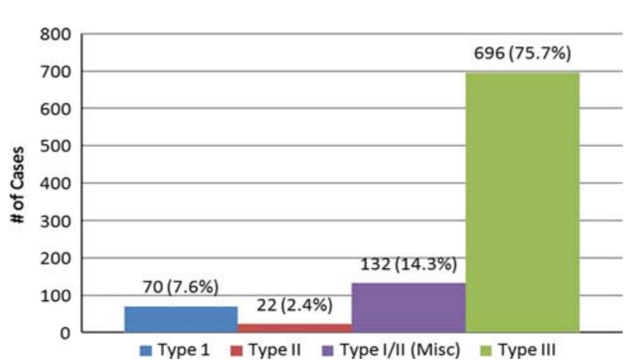
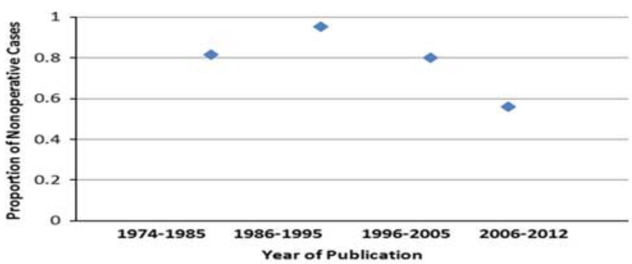


FIGURE 4. Classification of axis body fractures: incidence reported in the literature. full color online

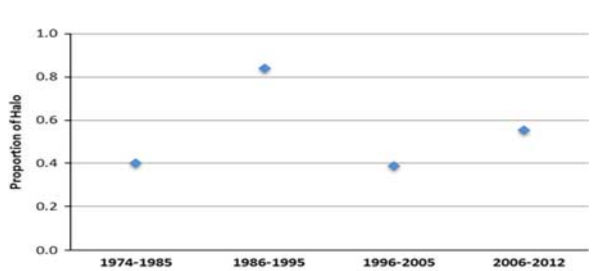


Year Range	Non-operative	Operative
1985 or before	82.0% (99/121)	18.2% (22/121)
1986-1995	95.7% (202/211)	4.3% (9/211)
1996-2005	80.3% (368/458)	19.7% (90/458)
2006 or later	56.4% (44/78)	43.6% (34/78)

FIGURE 5. Operative and nonoperative treatment of axis body fractures: by year of publication. full color online

3 of these cases were treated with halo-devices.[13,40,65] Finally, a study by Pepin and colleagues attributed 1 case of nonunion to old age following treatment with a halo-device. The patient was one of 3 over the age of 78 years with an odontoid fracture that failed to unite after treatment with a halo-device (both other patients had type II odontoid fractures).[21] As opposed to operative management of type I and II fractures, all of which resulted in solid bony union, 4 of 61 type III fractures treated operatively did not unite. This corresponds to a union rate of 93.4% (95% CI, 87.2%–99.6%). As discussed earlier, all 4 of these cases were treated by anterior approach and were reported in a study by Chiba et al.[17] Many other cases did not successfully unite but, as suggested earlier, factors that may have explained nonunion were often not reported.

Although we could not determine the incidence of axis body fractures in any 1 population of injuries, there were sufficient data to determine the proportion of type III odontoid fractures out of all reported odontoid fractures. From 22 studies reporting on odontoid fractures, type III fractures accounted for 33.0% (564 of 1708) of reported cases. As type I odontoid fractures are quite rare, ranging from 1% to 3%, the majority of fractures are classified as type II odontoid.[11,13] In 6 studies discussing treatment of odontoid fractures with anterior odontoid screw fixation, often at a single institution, only 10.7% (32 of 299) of fractures were classified as type III. This is in direct contrast to 4 studies reporting on treatment of odontoid fractures with halo-devices, in which 35.0% (28 of 80) of cases were type III odontoid fractures. Finally, the incidence of type III fractures in studies including only elderly patients was 20.5% (38 of 185).



Year Range	Halo	Other Non Op
1985 or before	40.4% (40/99)	59.6% (59/99)
1986-1995	84.3% (156/185)	15.7% (29/185)
1996-2005	39.1% (185/473)	60.9% (288/473)
2006 or later	55.6% (50/90)	44.4% (40/90)

FIGURE 6. Halo and other nonoperative treatment of axis body fractures: by year of publication. full color online

DISCUSSION

A detailed review of the evidence on C2 axis body fractures was performed in an attempt to reconcile the indications for operative and nonoperative treatment. Although it is apparent that nonoperative intervention has been quite successful in treating axis body fractures, resulting in a 91% union rate, there are cases that may require operative fixation. According to the literature, such cases may include fractures with concomitant injuries, marked subluxation or displacement, comminution, delayed treatment, fractures in the elderly, or Benzel type III fractures with a shallow base mimicking a type II odontoid fracture.[2,9,11,12,15–20] Nearly 18% of cases in this review were treated operatively, and an increasing proportion of cases were treated operatively based upon publication year. However, it is important to note that not all cases were treated in the same year in which a study was published, and the purpose of this assessment was to establish a general trend. A study by Kim et al[46] noted that most patients in the authors' institution were treated nonoperatively before 2006, and operatively thereafter. While a similar trend in this current review may not be as dramatic, 43.6% of cases were treated operatively since 2006. This is likely the result of improved surgical techniques and ensuing outcomes. In addition, surgical stabilization may be increasingly selected by treating surgeons because of an increased understanding of the complications associated with halo-vest fixation. The large majority (80%) of primary operative cases were treated from an anterior approach, including a growing trend toward anterior odontoid screw fixation in recent literature. However, revision operations following nonunion were most frequently performed from a posterior approach.

The body of literature on axis body fractures was systematically reviewed dating back to Anderson and D'Alonzo's classification of odontoid fractures in 1974. Considerably more evidence was available with regard to the treatment of type III axis body fractures, also considered type III odontoid fractures, as nearly 76% of fractures in this review were classified as type III. However, a higher incidence of type III fractures compared with type I and II may not, in itself, account for this disparity. The Benzel classification system for axis body fractures was developed 20 years after that of odontoid fractures.[10] Also, there seems to be a perception by many clinicians that axis body fractures, especially those classified as type I or II, are relatively benign injuries.

TABLE 7. Treatment of Axis Body Fractures: Breakdown by Treatment Method Reported in the Literature

	n (%)		
Treatments	**Type I/II**	**Type III**	**All**
Halo	116 (55.2)	288 (43.8)	404 (46.5)
Collar	40 (19.1)	73 (11.1)	113 (13.0)
Minerva	17 (8.1)	11 (1.7)	28 (3.2)
SOMI	13 (6.2)	12 (1.8)	25 (2.9)
Other	12 (5.7)	18 (2.7)	30 3.45)
No orthosis	1 (0.5)	5 (0.8)	6 (0.7)
Not designated	3 (1.4)	104 (15.8)	107 (12.3)
Nonoperative	202 (96.2)	511 (77.7)	713 (82.1)
Ant operation	6 (2.9)	118 (17.9)	124 (14.3)
Post operation	1 (0.5)	20 (3.0)	21 (2.4)
Not designated	1 (0.5)	9 (1.4)	10 (1.2)
Operative	8 (3.8)	147 (22.3)	155 (17.9)
Total	210 (100.0)	658 (100.0)	868 (100.0)

Ant indicates anterior operative approach; Post, posterior operative approach; SOMI, sternal occipital mandibular immobilizer.

There was a clear distinction between the treatment and outcome of type I or II axis body fractures and those classified as type III. Approximately 96% of type I or II fractures were treated nonoperatively with a successful union rate of 99%, compared with 78% of type III fractures which were treated nonoperatively with a union rate just above 87%. The small number of type I or II fractures treated operatively all united, whereas 4 (10.5%) type III fractures treated with an anterior approach did not. This review suggests that type III axis body fractures are less benign, and have a substantially higher risk for nonunion than type I or II fractures.

Although we analyzed the relative risk of nonunion for nonoperative and operative methods, there is a near certainty that the baseline risk for a negative outcome is quite different between treatment groups. For instance, only fractures with considerable instability or reduced healing capacity are likely to undergo operative treatment. Still, the union rate following operative intervention was 94.1%, a 37% reduction in relative risk compared with nonoperative treatment, although this was shown not to be statistically significant. Fracture union was only reported for 68 cases treated operatively, and thus more studies are required to increase the power of this analysis. It is unclear whether the trend toward increased rate of nonunion by year is related to treatment preferences, changes in imaging protocols or modalities, or some other factor. Similar to the comparison of operative and nonoperative intervention, halo-devices are often used for fractures with greater displacement than those treated with a hard collar. Thus, a direct comparison based upon union rates alone is not helpful in determining treatment indications. Finally, the clinical relevance of fracture nonunion cannot be identified from this study given the lack of patient-based outcome measures in the literature.

The evidence currently available for evaluating indications for operative management is based upon qualitative factors associated with fractures that failed to achieve union. These factors may directly contribute to ineffective healing and thus predict cases at increased risk for nonunion. However, this is speculative and we cannot definitively establish causality through a review of retrospective studies. We assume operative stabilization would help mitigate the negative effects of instability or poor healing potential to reduce the incidence of nonunion in those cases most at risk. This same approach can be used to compare fractures treated by nonoperative methods such as a halo-device or hard collar. Unfortunately, the majority of studies have not adequately reported relevant risk factors and often only provided the number of patients successfully treated by a particular method. Thus, we were only able to investigate risk factors for nonunion on a case-by-case basis. We also reviewed the literature to present criteria used as rationale for selection of operative treatment. Not only do these cases provide insight into which fractures are perceived to be at an increased risk for nonunion, but they demonstrate the effectiveness of operative stabilization in treating high-risk fractures.

The literature suggests that 2 fundamental fracture characteristics are thought by spine surgeons to be associated with an increased risk for nonunion: an increase in instability and a decrease in healing capacity. Type III odontoid fractures normally heal well due to a large surface area of cancellous bone along the fracture line.[9,20,28] Fracture displacement reduces the area of

TABLE 8. Fracture Union Rate Following Nonoperative and Operative Treatment of Axis Body Fractures (±95% CI)

Treatment	**Type I/II**		**Type III**		**All**	
Halo	98.1% ± 2.6	105/107	96.1% ± 2.4	249/259	96.7% ± 1.8	354/366
Collar	100.0% ± 0	31/31	81.8% ± 10.2	45/55	88.4% ± 6.8	76/86
Minerva	100.0% ± 0	17/17	87.5% ± 22.9	7/8	96.0% ± 7.7	24/25
SOMI	100.0% ± 0	13/13	100.0% ± 0	6/6	100.0% ± 0	19/19
Other	100.0% ± 0	12/12	80.0% ± 20.2	12/15	88.9% ± 11.9	24/27
No orthosis	100.0% ± 0	1/1	20.0% ± 35.0	1/5	33.3% ± 37.7	2/6
Nonoperative	99.0% ± 1.4	191/193	87.3% ± 3.0	413/473	90.7% ± 2.2	604/666
Ant operation	100.0% ± 0	4/4	89.5% ± 9.8	34/38	90.5% ± 8.9	38/42
Post operation	100.0% ± 0	1/1	100.0% ± 0	20/20	100.0% ± 0	21/21
Operative	100.0% ± 0	7/7	93.4% ± 6.2	57/61	94.1% ± 5.6	64/68
Total	99.0% ± 1.4	198/200	88.0% ± 2.8	470/534	91.0% ± 2.1	668/734

Ant indicates anterior operative approach; CI, confidence interval; Post, posterior operative approach; SOMI, sternal occipital mandibular immobilizer.

TABLE 9. Relative Risk and Odds Ratio Statistical Comparisons for all Axis Body Fractures

Comparisons	Relative Risk (95% CI)	Change in Relative Risk (95% CI)	Odds Ratio (95% CI)
Type I/II-Type III	0.083 (0.021–0.34)	92% reduction (66%–98%)	0.074 (0.018–0.31)
Op-Nonop	0.63 (0.24–1.7)	37% reduction (−68% to 76%)	0.61 (0.21–1.7)
Halo-Other nonop	0.20 (0.11–0.36)	80% reduction (64%–89%)	0.17 (0.088–0.33)
Collar-Other nonop	1.3 (0.69–2.5)	30% increase (−32% to 145%)	1.34 (0.65–2.7)
Minerva-Other nonop	0.42 (0.06–2.9)	58% reduction (−191% to 94%)	0.40 (0.053–3.0)
SOMI-Other nonop	0	100% reduction	∼0
No treat-Other nonop	7.6 (4.1–14.1)	659% increase (309%–1306%)	20.8 (3.7–116)
Post op-Ant op	0	100% reduction	∼0

CI indicates confidence interval; Nonop, nonoperative; Op, operative; Post op, posterior operative approach; SOMI, sternal occipital mandibular immobilizer.

contact between fragments, potentially contributing to nonunion.[56] In type III fractures, 5 mm of displacement has been described as unstable.[18] Instability can also be introduced by marked vertebral subluxation, fracture comminution, or concomitant injuries. Also, type III fractures with minimal involvement of the axis body are considered to be "shallow" and therefore unstable.[15,20] External orthoses must be quite rigid to eliminate movement and allow for successful healing.[56] Reduced healing capacity might be observed for fractures in elderly patients or after a delay in treatment. Although the blood supply to the odontoid process seems to be disrupted in type II odontoid fractures, this does not seem to be an issue for fractures involving the axis body alone.[28,37,56] Clearly, the risk for nonunion is multifactorial, and all factors need to be considered when selecting an optimal treatment plan.

Several studies have reported higher instances of nonunion in elderly patients. A study by Ekong et al[40] reported a mean age of 58 in patients with nonunion, whereas patients with successful union averaged 45 years of age. Elderly patients also suffer from a significant increase in morbidity and mortality associated with axis body fractures and treatment.[20–22] Specifically, the halo-device seems to be poorly tolerated and associated with a high rate of complications, including respiratory compromise, in elderly patients.[20–23] Primary operative treatment may reduce associated morbidity and mortality in elderly patients unless medical debility contraindicates against operative intervention.[20]

About 16% of axis fractures have been reported to also involve the atlas, including about 20% of type III axis body fractures and 28% of miscellaneous axis fractures.[9,31] While some studies suggest that there is a higher incidence of neurological deficit in these combination injuries, most cases seemed to respond to external immobilization similar to isolated fractures of the axis body.[12,13,31,33,75] In this review, 16 of 17 atlantoaxial fractures were successfully treated nonoperatively and only a single type III fracture treated with a halo failed to unite.[13]

Limitations to this manuscript exist, and they are the inherent limitations to any systematic review. A systematic review can only analyze and report the result of the existing literature, and in the case of fracture to the axis, the majority of the studies are retrospective case series, and there is heterogeneity in the methods used to evaluate the primary outcome of fusion. Furthermore, there is a clear limitation in the assumption of a positive clinical outcome based upon fracture union, which consistently was the key method for assessing outcomes in the literature. Failure to obtain union does not always result in a negative clinical outcome for the patient, as stable "fibrous union" may result in a symptom-free patient with normal function. This is the basis in some studies for reserving surgical intervention for failure of nonoperative treatment.[6] It is important to determine when "fibrous union" will lead to the development of myelopathy or persistent instability, and when such cases will be stable and free of continuing risk to the patient.[28,35,50] In this study we felt having a firm bony union was the most appropriate endpoint, but it certainly does not mean that every nonunion requires surgical intervention. Finally, we cannot develop treatment recommendations based on case-by-case analyses. A collection of cases describes the treatment and outcome of only a small number of fractures and cannot be used to optimize outcomes at the population level. Future prospective studies using validated patient-based outcome measures are clearly needed to develop consensus between surgeons regarding those

TABLE 10. Union Rate by Year of Publication and Fracture Classification

	n/N (%)		
Year Range	Type I/II Union Rate	Type III Union Rate	All Union Rate
1985 or before	4/4(100.0)	99/115 (86.1)	109/126 (86.5)
1986–1995	61/62 (98.4)	139/146 (95.2)	200/208 (96.2)
1996–2005	123/124 (99.2)	218/257 (84.8)	341/381 (89.5)
2006 or later	9/9 (100.0)	14/16 (87.5)	23/25 (92.0)

TABLE 11. Nonunion Following Halo or Other Nonoperative Treatment by Year of Publication

Year Range	Halo	Other Nonoperative
1985 or before	3	13
1986–1995	6	2
1996–2005	5	25
2006 or later	6	0

fractures best suited for operative intervention. Such a consensus would provide a basis for developing a classification system that more closely resembles a treatment algorithm (Tables 7–11).

REFERENCES

1. Hadley MN. Isolated fractures of the axis in adults. *Neurosurgery*. 2002;50(suppl):S125–S139.
2. Hadley MN, Dickman CA, Browner CM, et al. Acute axis fractures: a review of 229 cases. *J Neurosurg*. 1989;71(5I):642–647.
3. Johnson B, Jayasekera N. Fracture through the body of the axis. *Internet J Orthop Surg*. 2008;8:1.
4. Hadley MN, Browner C, Sonntag VKH. Axis fractures: a comprehensive review of management and treatment in 107 cases. *Neurosurgery*. 1985;17:281–290.
5. Burke JT, Harris JH Jr. Acute injuries of the axis vertebra. *Skeletal Radiol*. 1989;18:335–346.
6. Pryputniewicz DM, Hadley MN. Axis fractures. *Neurosurgery*. 2010; 66(suppl):68–82.
7. Julien TD, Frankel B, Traynelis VC, et al. Evidence-based analysis of odontoid fracture management. *Neurosurg Focus*. 2000;8:6.
8. Ersmark H, Kalen R. Injuries of the atlas and axis. A follow-up study of 85 axis and 10 atlas fractures. *Clin Orthop Relat Res*. 1987;217:257–260.
9. Martin GJ, Haid RW, Rodts GE. Injuries to the atlantoaxial complex: diagnosis & classification. *Contemp Neurosurg*. 1997;19:12.
10. Benzel EC, Hart BL, Ball PA, et al. Fractures of the C-2 vertebral body. *J Neurosurg*. 1994;81:206–212.
11. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Jt Surg Ser A*. 1974;56:1663–1674.
12. Fujimura Y, Nishi Y, Kobayashi K. Classification and treatment of axis body fractures. *J Orthop Trauma*. 1996;10:536–540.
13. Greene KA, Dickman CA, Marciano FF, et al. Acute axis fractures: analysis of management and outcome in 340 consecutive cases. *Spine*. 1997;22:1843–1852.
14. German JW, Hart BL, Benzel EC. Nonoperative management of vertical C2 body fractures. *Neurosurgery*. 2005;56:516–-21. Discussion 516-21.
15. Apfelbaum RI, Lonser RR, Veres R, et al. Direct anterior screw fixation for recent and remote odontoid fractures. *J Neurosurg*. 2000; 93(suppl):227–236.
16. Koller H, Acosta F, Forstner R, et al. C2-fractures: part II. A morphometrical analysis of computerized atlantoaxial motion, anatomical alignment and related clinical outcomes. *Eur Spine J*. 2009;18:1135–1153.
17. Chiba K, Fujimura Y, Toyama Y, et al. Treatment protocol for fractures of the odontoid process. *J Spinal Disord*. 1996;9:267–276.
18. Fujii E, Kobayashi K, Hirabayashi K. Treatment in fractures of the odontoid process. *Spine*. 1988;13:604–609.
19. Henry AD, Bohly J, Grosse A. Fixation of odontoid fractures by an anterior screw. *J Bone Joint Surg Br*. 1999;81:472–477.
20. Marchesi DG. Management of odontoid fractures. *Orthopedics*. 1997;20:911–916.
21. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. *Clin Orthop Relat Res*. 1985; 193:178–183.
22. Chen YR, Boakye M, Arrigo RT, et al. Morbidity and mortality of C2 fractures in the elderly: surgery and conservative treatment. *Neurosurgery*. 2012;70:1055–1059.
23. Tashjian RZ, Majercik S, Biffl WL, et al. Halo-vest immobilization increases early morbidity and mortality in elderly odontoid fractures. *J Trauma Inj Infect Crit Care*. 2006;60:199–203.
24. Boran S, Hurson C, Gul R, et al. Functional outcome following teardrop fracture of the axis. *Eur J Orthop Surg Traumatol*. 2005; 15:229–232.
25. Korres DS, Papagelopoulos PJ, Mavrogenis AF, et al. Multiple fractures of the axis. *Orthopedics*. 2004;27:1096–1099.
26. Korres DS, Zoubos AB, Kavadias K, et al. The "tear drop" (or avulsed) fracture of the anterior inferior angle of the axis. *Eur Spine J*. 1994;3:151–154.
27. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. *Neurosurgery*. 1986;18:306–310.
28. Chutkan NB, King AG, Harris MB. Odontoid fractures: evaluation and management. *J Am Acad Orthop Surg*. 1997;5:199–204.
29. Cooper PR, Maravilla KR, Sklar FH, et al. Halo immobilization of cervical spine fractures. Indications and results. *J Neurosurg*. 1979; 50:603–610.
30. Hadley MN, Dickman CA, Browner CM, et al. Acute traumatic atlas fractures: management and long term outcome. *Neurosurgery*. 1988;23:31–35.
31. Dickman CA, Hadley MN, Browner C, et al. Neurosurgical management of acute atlas-axis combination fractures. A review of 25 cases. *J Neurosurg*. 1989;70:45–49.
32. Hughes SP, Cairns T, Iyer V, et al. Halo-body device. *Paraplegia*. 1984;22:260–266.
33. Kontautas E, Ambrozaitis KV, Kalesinskas RJ, et al. Management of acute traumatic atlas fractures. *J Spinal Disord Tech*. 2005;18: 402–405.
34. Watanabe M, Sakai D, Yamamoto Y, et al. Clinical features of the extension teardrop fracture of the axis: review of 13 cases—clinical article. *J Neurosurg Spine*. 2011;14:710–714.
35. Andersson S, Rodrigues M, Olerud C. Odontoid fractures: high complication rate associated with anterior screw fixation in the elderly. *Eur Spine J*. 2000;9:56–60.
36. Böhler J. Anterior stabilization for acute fractures and non-unions of the dens. *J Bone Joint Surg [Am]*. 1982;64:18–27.
37. Clark CR, White AA III. Fractures of the dens. A multicenter study. *J Bone Joint Surg Am*. 1985;67:1340–1348.
38. Coyne TJ, Fehlings MG, Wallace MC, et al. C1-C2 posterior cervical fusion: long-term evaluation of results and efficacy. *Neurosurgery*. 1995;37:688–693.
39. Eap C, Barresi L, Ohl X, et al. Odontoid fractures anterior screw fixation: a continuous series of 36 cases. *Orthop Traumatol Surg Res*. 2010;96:748–752.
40. Ekong CEU, Schwartz ML, Tator CH. Odontoid fracture: management with early mobilization using the halo device. *Neurosurgery*. 1981;9:631–637.
41. Fountas KN, Kapsalaki EZ, Karampelas I, et al. Results of long-term follow-up in patients undergoing anterior screw fixation for type II and rostral type III odontoid fractures. *Spine (Phila Pa 1976)*. 2005; 30:661–669.
42. Glaser JA, Whitehill R, Stamp WG, et al. Complications associated with the halo-vest. A review of 245 cases. *J Neurosurg*. 1986;65: 762–769.
43. Govender S, Maharaj JF, Haffajee MR. Fractures of the odontoid process. *J Bone Jt Surg Ser B*. 2000;82:1143–1147.
44. Hanigan WC, Powell FC, Elwood PW, et al. Odontoid fractures in elderly patients. *J Neurosurg*. 1993;78:32–35.
45. Hanssen AD, Cabanela ME. Fractures of the dens in adult patients. *J Trauma*. 1987;27:928–934.
46. Kim SK, Shin JJ, Kim TH, et al. Clinical outcomes of halo-vest immobilization and surgical fusion of odontoid fractures. *J Korean Neurosurg Soc*. 2011;50:17–22.
47. Komadina R, Brilej D, Kosanovic M, et al. Halo jacket in odontoid fractures type II and III. *Arch Orthop Trauma Surg*. 2003;123:64–67.
48. Lee SH, Sung JK. Anterior odontoid fixation using a 4.5-mm Herbert screw: the first report of 20 consecutive cases with odontoid fracture. *Surg Neurol*. 2006;66:361–366. Discussion.

49. Li TS, Xiao ZM, He ML. Posterior screw-plate system for treating old fracture of the odontoid process. *Orthop Surg*. 2010;2:156–160.
50. Lind B, Hordwall A, Sihlbom H. Odontoid fractures treated with halo-vest. *Spine*. 1987;12:173–177.
51. Maiman DJ, Larson SJ. Management of odontoid fractures. *Neurosurgery*. 1982;11:471–476.
52. Marar BC, Tay CK. Fracture of the odontoid process. *Aust New Zealand J Surg*. 1976;46:231–236.
53. Moon MS, Moon JL, Sun DH, et al. Treatment of dens fracture in adults: a report of thirty-two cases. *Bull Hosp Jt Dis*. 2006;63:108–112.
54. Müller EJ, Schwinnen I, Fischer K, et al. Non-rigid immobilisation of odontoid fractures. *Eur Spine J*. 2003;12:522–525.
55. Polin RS, Szabo T, Bogaev CA, et al. Nonoperative management of types II and III odontoid fractures: the Philadelphia collar versus the halo vest. *Neurosurgery*. 1996;38:450–457.
56. Ryan MD, Taylor TKF. Odontoid fractures. A rational approach to treatment. *J Bone Jt Surg Ser B*. 1982;64:416–421.
57. Schweigel JF. Management of the fractured odontoid with halo-thoracic bracing. *Spine (Phila Pa 1976)*. 1987;12:838–839.
58. Seybold EA, Bayley JC. Functional outcome of surgically and conservatively managed dens fractures. *Spine*. 1998;23:1837–1846.
59. Song KJ, Lee KB, Kim KN. Treatment of odontoid fractures with single anterior screw fixation. *J Clin Neurosci*. 2007;14:824–830.
60. Wang GJ, Mabie KN, Whitehill R, et al. The nonsurgical management of odontoid fractures in adults. *Spine*. 1984;9:229–230.
61. Wang J, Zhou Y, Zhang ZF, et al. Comparison of percutaneous and open anterior screw fixation in the treatment of type II and rostral type III odontoid fractures. *Spine (Phila Pa 1976)*. 2011;36:1459–1463.
62. Weller SJ, Malek AM, Rossitch E Jr.. Cervical spine fractures in the elderly. *Surg Neurol*. 1997;47:274–281.
63. Ziai WC, Hurlbert RJ. A six year review of odontoid fractures: the emerging role of surgical intervention. *Can J Neurol Sci*. 2000;27:297–301.
64. Bohay D, Gosselin RA, Contreras DM. The vertical axis fracture: a report on three cases. *J Orthop Trauma*. 1992;6:416–419.
65. Goldschlager T, Leach JC, Williamson OD, et al. Oblique axis body fracture—pitfalls in management. *Injury*. 2012;43:505–508.
66. Hahnle UR, Wisniewski TF, Craig JB. Shear fracture through the body of the axis vertebra. *Spine (Phila Pa 1976)*. 1999;24:2278–2281.
67. Iizuka H, Shimizu T, Hasegawa W, et al. Fractures of the posterior part of the body and unilateral spinous process of the axis: a case report. *Spine (Phila Pa 1976)*. 2001;26:E528–E530.
68. Jakim I, Sweet MB. Transverse fracture through the body of the axis. *J Bone Joint Surg Br*. 1988;70:728–729.
69. Korres DS, Papagelopoulos PJ, Mavrogenis AF, et al. Chance-type fractures of the axis. *Spine (Phila Pa 1976)*. 2005;30:E517–E520.
70. Lozano-Requena JA, Pina-Medina A, Aracil-Silvestre J, et al. Sagittal fracture of the second cervical vertebral body. *Int Orthop*. 1994;18:114–115.
71. Maki NJ. A transverse fracture through the body of the axis. A case report. *Spine (Phila Pa 1976)*. 1985;10:857–859.
72. Marotta TR, White L, TerBrugge KG, et al. An unusual type of hangman's fracture. *Neurosurgery*. 1990;26:848–850. Discussion 850–851.
73. Ball C, Sackett D, Phillips B. Levels of evidence and grades of recommendation. *Centre for Evidence-Based Medicine*. 2006.
74. Müller EJ, Wick M, Russe OJ, et al. Anterior screw fixation for odontoid fractures. *Unfallchirurg*. 2000;103:38–43.
75. Hadley MN. Management of combination fractures of the atlas and axis in adults. *Neurosurgery*. 2002;50:S140–S147.

