Predictors of treatment outcomes in geriatric patients with odontoid fractures: AOSpine North America multi-centre prospective GOF study.

Michael G Fehlings  
*Toronto Western Hospital, University Health Network, University of Toronto*

Ranganathan Arun  
*Toronto Western Hospital, University Health Network, University of Toronto*

Alex R. Vaccaro  
*Thomas Jefferson University Hospital and The Rothman Institute*

Paul M Arnold  
*University of Kansas Medical Center, Kansas City*

Jens R Chapman  
*University of Washington Medical Center, Seattle, WA*

Follow this and additional works at: [https://jdc.jefferson.edu/orthofp](https://jdc.jefferson.edu/orthofp)

Let us know how access to this document benefits you

Recommended Citation

Fehlings, Michael G; Arun, Ranganathan; Vaccaro, Alex R.; Arnold, Paul M; Chapman, Jens R; and Kopjar, Branko, "Predictors of treatment outcomes in geriatric patients with odontoid fractures: AOSpine North America multi-centre prospective GOF study." (2013). *Department of Orthopaedic Surgery Faculty Papers*. Paper 48.  
https://jdc.jefferson.edu/orthofp/48

This Article is brought to you for free and open access by the Jefferson Digital Commons. The Jefferson Digital Commons is a service of Thomas Jefferson University's Center for Teaching and Learning (CTL). The Commons is a showcase for Jefferson books and journals, peer-reviewed scholarly publications, unique historical collections from the University archives, and teaching tools. The Jefferson Digital Commons allows researchers and interested readers anywhere in the world to learn about and keep up to date with Jefferson scholarship. This article has been accepted for inclusion in Department of Orthopaedic Surgery Faculty Papers by an authorized administrator of the Jefferson Digital Commons. For more information, please contact: JeffersonDigitalCommons@jefferson.edu.
Predictors of Treatment Outcomes in Geriatric Patients With Odontoid Fractures

AOSpine North America Multi-Centre Prospective GOF Study

Michael G. Fehlings, MD, PhD,* Ranganathan Arun, DM FRCS (Tr&Orth), PGDip (Orth Engin), MRCS(Ed),* Alexander R. Vaccaro, MD, PhD,† Paul M. Arnold, MD,‡ Jens R. Chapman, MD,§ and Branko Kopjar, MD, PhD¶

Study Design. Multicenter prospective cohort study.
Objective. To identify patient and treatment characteristics associated with treatment success or failure in the management of odontoid fractures.
Summary of Background Data. Odontoid fractures are the most common cervical spine fractures in the elderly and represent a significant management challenge with widely divergent views regarding operative versus nonoperative management.
Methods. A total of 159 patients 65 years and older with radiographically confirmed type II odontoid fractures were enrolled at 10 sites in the United States and 1 site in Canada between January 2006 and May 2009. Subjects were followed at 6 and 12 months post–initial treatment with Neck Disability Index and SF-36v2 scores. Final treatment outcome was classified as failure or success. Treatment failure was defined as death by any cause, decline in Neck Disability Index by more than 9.5 absolute points, or occurrence of a major treatment-related complication. Baseline characteristics between the groups were compared using t test for the continuous variables and χ² test for the categorical variables.

Baseline characteristics associated with treatment outcomes were identified by multiple logistic stepwise regression analysis.

Results. A total of 101 (63.5%) patients were treated surgically and 58 (36.5%) conservatively. Forty-four (27.7%) patients had a successful outcome and 86 (54.1%) had a treatment failure; for 29 patients (18.2%), treatment status could not be determined (3 withdrew; 26 were lost to follow-up). Twenty-nine (18.2%) patients expired before the 12-month follow-up. Follow-up information was available for 103 of 127 surviving (81.1%) patients. Twelve-month SF-36v2 scores were worse in the failure group. The characteristics associated with treatment failure were older age (odds ratio [OR] = 4.13), female sex (OR = 4.33), and baseline neurological system comorbidity (OR = 4.13).

Conclusion. Older age, initial nonsurgical treatment, and male sex are associated with failure of treatment in patients with geriatric odontoid fractures.

Key words: odontoid fracture, type II, geriatric, treatment outcomes, predictors, surgical treatment, conservative treatment.

Spine 2013;38:881–886

Odontoid fractures comprise 11% of all traumatic cervical spine injuries, with type II odontoid fractures accounting for 40% to 60% of these fractures.1-3

Within the geriatric population, type II odontoid fractures are the most common cervical spine injury and commonly occur because of low-energy falls to the same level.4,5 With the geriatric population representing the fastest growing demographic segment in North America, the number of geriatric odontoid fractures is increasing.6,7 Although geriatric patients generally sustain this injury without neurological damage, these patients often have significant medical comorbidities that increase mortality.1,7,8 Elderly patients are more likely to experience significant complications as a result of treatment, including nonunion, morbidity, and mortality.8,9

Despite type II odontoid fractures being the most common spinal fracture in older adults, there is no consensus on treatment. Previous literature consists primarily of small and uncontrolled cohort studies with varying inclusion criteria that do not allow for direct comparison of surgical and conservative treatment.7,10 Furthermore, there is a paucity of
information regarding clinical outcomes. Although rates of nonunion have been found to be higher in patients treated conservatively, it is unknown whether a lack of fusion correlates to decreased function and quality of life.11 There are presently no studies in the literature investigating the factors that cause failure of treatment and result in a poor outcome in elderly patients with type II odontoid fractures.

MATERIALS AND METHODS
A multicenter cohort study was conducted to compare the outcomes after conservative and surgical treatment in patients 65 years and older. Between January 2006 and May 2009, a total of 10 sites in the United States and 1 in Canada prospectively enrolled 159 patients with radiographically confirmed type II odontoid fractures. The key inclusion criteria were type II odontoid fracture; age 65 years and older; stable and unstable fracture patterns; and a cooperative, mentally competent patient without previous odontoid fractures. Patients with pathological fractures and any form of mental incapacity or substance abuse were excluded.

The decision for operative or nonoperative treatment was made by the treating surgeons in each of the centers on the basis of surgeons’ and patients’ personal preferences. Nonoperative options ranged from skeletal traction, followed by hard or soft collar immobilization, to primary immobilization in a soft or hard collar, to halo immobilization. Operative techniques used were anterior odontoid screw fixation, anterior C1–C2 facet screw fixation, posterior C1 lateral mass and C2 isthmus or pedicle screw fixation, posterior C2–C1 transarticular screw fixation, C1 sublaminar and C2 spinous process wiring (Gallie technique), and Brooks fusion (C1–C2 sublaminar wire placement). Each participant consented for the trial at the time of treatment.

The patient demographics recorded were age, sex, marital status, race, ethnicity, preinjury occupation, preinjury living situation, socioeconomic status, litigation, and workers’ compensation. The injury factors recorded were date and type of fracture, stability, presence of subluxation or dislocation, Frankel grade, ASIA (American Spinal Injury Association) score, Injury Severity Score, and presence of associated injuries. General health demographics assessed were medical history, and ASA (American Society of Anesthesiologists) physical status classification.

Subjects were followed prospectively in clinic at 6 and 12 months post–initial treatment with the Neck Disability Index (NDI)12 and SF-36v2,13 as well as for adverse events. Pretreatment NDI and SF-36v2 scores were based on subjects’ recollection of their status prior to injury. The SF-36v2 Physical Component Summary and Mental Component Summary scores were calculated using the 1998 US norms and the orthogonal approach to transformation. Adverse events were adjudicated for the relationship to the treatment. The study was externally monitored to ensure that the data were accurate, reliable, and complete.

Data Analysis
Subjects were classified in success and failure groups, based on treatment outcomes. Treatment failure was defined as death by any cause; decline in NDI by more than 9.5 absolute points (a literature-based clinically significant difference), or occurrence of a major treatment-related complication. The NDI threshold of 9.5 was based on a literature-reported significant clinical difference for NDI.12

The study endpoints were the absolute changes between the preinjury and 6 and 12 month post-treatment scores in the NDI, 8 SF-36v2 health dimensions, and 2 SF-36v2 composite scores (Physical Component Summary and Mental Component Summary). Missing scores for subjects who failed to attend their follow-up visit at 12 months were imputed using the last-value carryforward approach if a 6-month score was available.

The main analysis of differences between the failure and success groups was performed using repeated-measures analysis of variance. To adjust for potential differences between the groups, the following approach was adopted. The selection of baseline characteristics to be used in the adjustment was performed in 2 steps, separately for each of the 11 outcomes. First, screening for potential adjustment variables was performed by calculating the Pearson correlation coefficient between the candidate variable and the target change in the outcome score. The variables that were included as candidate predictors were demographics, comorbidities, presence of associated injuries, and Injury Severity Score. Second, candidate predictors with a P value of 0.2 or less were carried into a stepwise forward elimination multiple regression model with a threshold probability to stay in the model of 0.1 or less. The variables that stayed in the multiple regression models were used as adjustment variables in the repeated-measures analysis of variance.

The analysis of predictors of treatment failure was performed by multivariate logistic regression. The predictor variables were age, sex, race, treatment type, smoking status, comorbidities, baseline SF-36v2 scores, and Injury Severity Score, and Abbreviated Injury Scale scores. The forward stepwise model was used with the probability for a variable to enter the model of 0.15 and probability for a variable to stay in the model of 0.10.

RESULTS
Of the 159 subjects in the study, 101 (63.5%) were treated surgically and 58 (36.5%) nonsurgically. Nonunions occurred in 12 (20.7%) patients who were treated nonsurgically compared with 5 (5%) patients who received surgical treatment (Fisher exact P = 0.0030). Thirteen (22.8%) patients in the nonoperative arm failed nonoperative treatment and received subsequent surgical treatment. Altogether, 29 (18.2%) patients died, and 3 (1.9%) patients withdrew before the 12-month follow-up. Patient outcomes information was available for 103 of 127 surviving (81.1%) patients.

Of the 159 patients enrolled in the study, 44 (27.7%) had a successful outcome, 86 (54.1%) had a treatment failure, and the status for 29 (18.2%) could not be determined (3 patients...
withdrew and 26 were lost to follow-up). Patients in the failure group were older (average age 81.7 and 77.9 years in the failure and success groups, respectively, \( P < 0.05 \)). Also, patients in the failure group were more likely to be treated nonoperatively (47.7% and 18.2% in the failure and success groups, respectively, \( P < 0.05 \)). There were no differences in race, marital status, baseline comorbidities, and baseline injury scores between the 2 groups (Table 1). The average scores for SF-36v2 and NDI at the baseline in the failure and success groups are shown in Table 2. Patients in the failure group had higher SF-36v2 Bodily Pain scores than those in the success group (49.7 and 45.6, respectively, \( P < 0.05 \)). There were no differences between the groups in other SF-36v2 dimensions and NDI.

In the surviving patients, 12-month SF-36v2 scores were worse in the failure group compared with those in the success group (Table 3). The NDI improved an average of 6.5 points in the success group but declined an average of 20.6 points in the failure group \( (P < 0.05) \). SF-36v2 Bodily Pain scores improved in the success group and declined in the failure group \( (3.4 \text{ and } -5.4, \text{ respectively, } P < 0.05) \). The SF-36v2 Global Health improved slightly in the success group and declined in the failure group \( (0.5 \text{ and } -4.8, \text{ respectively, } P < 0.05) \). SF-36v2 Mental Health improved in the success group but declined in the failure group \( (2.6 \text{ and } -5.3, \text{ respectively, } P < 0.05) \). The average change in Role Limitation Physical was \(-0.6 \) and \(-7.6 \) in the success and failure groups, respectively \( (P < 0.01) \). Social Functioning improved in the success group but declined in the failure group \( (4.2 \text{ and } -7.1, \text{ respectively, } P < 0.01) \). Energy/Fatigue declined for \(-0.4 \) and \(-8.3 \) in the success and failure groups, respectively \( (P < 0.05) \). Physical Component Summary score was almost unchanged in the success group \( (0.1) \), but declined in the failure group \( (-4.8, P < 0.05) \). Finally, Mental Component Summary score increased in the success group but declined in the failure group \( (1.2 \text{ and } -8.4, \text{ respectively, } P < 0.05) \).

Odds ratios (ORs) of baseline characteristics associated with treatment are shown in Table 4. Factors that were associated with an increased risk of treatment failure were nonoperative treatment \( (OR = 3.09; 95\% \text{ confidence interval [CI], 1.19–8.00; } P = 0.0203) \), male sex \( (OR = 4.33; 95\% \text{ CI, 1.62–11.57; } P = 0.0034) \), age in years \( (OR = 1.08; 95\% \text{ CI, 1.02–1.15; } P = 0.0121) \), and SF-36v2 Bodily Pain \( (OR = 1.06; 95\% \text{ CI, 1.01–1.11; } P = 0.0262) \). The better baseline physical function was associated with a reduced risk of treatment failure \( (OR = 0.97; 95\% \text{ CI, 0.930–1.006; } P = 0.0971) \).

**DISCUSSION**

This large, multicenter, prospective study reports novel data demonstrating that nonoperative treatment, older age, and male sex are associated with failure of treatment in patients with geriatric odontoid fractures. Better baseline SF-36v2 Physical Function is associated with treatment success.

Both operative and nonoperative treatment options for type II odontoid fractures in the geriatric population carry a high risk of treatment failure and poor outcomes.4,14,15 Surgical

### Table 1. Patient Demographics by Type of Treatment

|                      | Success (N = 44) | Failure (N = 86) | P     |
|----------------------|------------------|-----------------|-------|
| Age, mean ± SD, yr   | 77.9 ± 7.1       | 81.7 ± 7.7      | 0.0071|
| Female sex           | 64.5%            | 51.7%           | 0.1327|
| Race                 |                  |                 | 0.5091|
| White                | 97.7%            | 94.2%           |       |
| African-American     | 2.3%             | 1.2%            |       |
| Asian                | 0.0%             | 2.3%            |       |
| American Indian      | 0.0%             | 0.0%            |       |
| Other                | 0.0%             | 2.3%            |       |
| Marital status       |                  |                 | 0.7356|
| Married              | 56.4%            | 47.5%           |       |
| Single (never married)| 2.6%            | 13%             |       |
| Divorced             | 2.6%             | 3.8%            |       |
| Widowed              | 42.6%            | 39.7%           |       |
| Associated injuries  | 65.9%            | 70.9%           | 0.5572|
| Residential status   |                  |                 | 0.7397|
| At home without support| 71.4%           | 75.3%           |       |
| At home with caregiver support | 21.4% | 15.3% |       |
| Nursing home/retirement home (independent) | 4.8% | 5.9% |       |
| Nursing home/retirement home (dependent) | 0% | 2.4% |       |
| Other                | 2.4%             | 12.2%           |       |
| Comorbidities        |                  |                 |       |
| Cardiac              | 79.5%            | 87.2%           | 0.2518|
| Respiratory          | 11.9%            | 12.1%           | 0.9720|
| Gastrointestinal     | 6.8%             | 16.3%           | 0.1300|
| Renal                | 2.3%             | 9.3%            | 0.1352|
| Endocrine system     | 13.6%            | 19.8%           | 0.3860|
| Psychiatric          | 18.2%            | 11.6%           | 0.3059|
| Rheumatological      | 7.9%             | 5.2%            | 0.5109|
| Neurological         | 4.5%             | 19.8%           | 0.0201|
| Smoking              | 3.5%             | 2.3%            | 0.6963|
| AIS score, mean ± SD | 0.568 ± 1.228    | 0.918 ± 1.588   | 0.2028|
| ISS, mean ± SD       | 9.64 ± 7.01      | 8.22 ± 5.46     | 0.2073|
| Treatment type       |                  |                 | 0.0010|
| Nonoperative         | 18.2%            | 47.7%           |       |
| Operative            | 81.8%            | 52.3%           |       |

AIS indicates Abbreviated Injury Scale; ISS, Injury Severity Score.
management is complicated in this population because of high levels of medical comorbidities, poor bone quality, and impaired physiological reserves. A literature review revealed that the in-hospital mortality rate after surgery for type II odontoid fractures in the geriatric population was 6.2%. The mortality rate at 1 year in other studies averaged 21%, 29%, and 45% for patients with type II odontoid fractures aged 65 to 74 years, 75 to 84 years, and 85 years and older, respectively. Comparatively, the results from this trial indicate a mortality rate at 1 year of 13.9 per 100 in patients older than 65 years who were treated surgically. Studies have shown that anterior approaches have a greater effect on patient morbidity as a result of complications related to implant fixation. Other factors that can affect surgical outcomes, such as age or medical comorbidities, have not been analyzed to the same extent. A retrospective study designed to compare the outcomes between subaxial and atlantoaxial injuries in older adults showed identical mortality rates in both groups. Studies have also shown that the mortality rate in operatively treated patients with subaxial injury was significantly higher than in the nonoperatively treated patients. The 1-year mortality rate in elderly patients after hip fractures, for example, ranges between 27% and 33%. Early surgical treatment has shown significant improvements in this mortality rate.

Nonsurgical management techniques (varying from traction, followed by halo, halo alone, or collar alone) also have accompanying risks. Compliance in wearing a halo or rigid cervical orthosis in this age group is poor and may contribute to high rates of nonunion. Outcomes vary in conservatively treated patients, with reported mortality rates of patients treated with halo vests ranging from 6% to 40%. This lower rate could be attributed to meticulous treatment of minor complications associated with halo vests, treatment in a spinal cord injuries center (as opposed to a general trauma center), and the patient group including both traumatic and nontraumatic cases. Studies have shown that older age is the greatest risk factor for failure of halo vest immobilization.

Previous studies have reported that irrespective of the type of orthosis used, patients achieved fracture stability, although only 35% to 50% achieved radiographical osseous union. Paradoxically, clinical results do not seem to correlate with radiological findings. Hence, for the purposes of our trial, it was determined that defining results in terms of functional outcome was more relevant.

Smith et al concluded that the rate of in-hospital complications was high in octogenarians with type II odontoid fractures irrespective of the type of treatment. The acute in-hospital mortality rate was 12.5% in the surgical group and 15% in the nonsurgical group (P > 0.05). However, these data were collected retrospectively. Some of the previous studies comment on matching the patients’ physical demographics in the surgical and nonsurgical groups, but none of the studies discuss the functional status of the patients before injury. This may lead to selection bias in patients who are more fit being treated surgically and patients who are less fit being treated nonsurgically. In our trial, the surgical and nonsurgical groups were matched for all domains of SF-36v2 and NDI (Table 1). This was further reinforced by making statistical adjustments to remove the confounding effects of variables, including baseline comorbidities. Data collected from

| Variable                  | Success (N = 43) | Failure (N = 58) | P      |
|---------------------------|------------------|------------------|--------|
| Neck Disability Index     | -6.5 (11.2)      | 20.6 (14.5)      | <0.0001|
| SF-36v2                   |                  |                  |        |
| Bodily Pain               | 3.4 (10.7)       | -5.4 (15)        | 0.0014 |
| Global Health             | 0.5 (9.8)        | -4.8 (9.5)       | 0.0067 |
| Mental Health             | 2.6 (10)         | -5.3 (11.8)      | 0.0008 |
| Physical Function         | -2.8 (12.3)      | -4.8 (14.2)      | 0.4363 |
| Role Limitation Emotional | -3.3 (14.9)      | -8.8 (18.1)      | 0.1023 |
| Role Limitation Physical  | -0.6 (15)        | -7.6 (14.7)      | 0.0201 |
| Social Functioning        | 4.2 (12.5)       | -7.1 (13.9)      | <0.0001|
| Energy/Fatigue            | -0.4 (10)        | -8.3 (11.7)      | 0.0006 |
| Physical Component Summary| 0.1 (10.1)       | -4.8 (11.8)      | 0.0294 |
| Mental Component Summary  | 1.2 (11.4)       | -8.4 (13.6)      | 0.0003 |

The values given are mean (SD).

884 www.spinejournal.com

May 2013

Copyright © 2013 Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.
TABLE 4. Odds Ratios for Factors Associated With Treatment Failure

| Treatment Type          | Odds Ratio | 95% Confidence Interval | P       |
|-------------------------|------------|-------------------------|---------|
| Treatment type (conservative) | 3.087      | 1.192–7.997             | 0.0203  |
| Age, yr                 | 1.079      | 1.017–1.145             | 0.0121  |
| Sex (male)              | 4.332      | 1.623–11.565            | 0.0034  |
| SF-36v2 Physical Function | 0.967      | 0.930–1.006             | 0.0971  |
| SF-36v2 Bodily Pain      | 1.056      | 1.006–1.108             | 0.0262  |

our trial indicated that initial conservative treatment had a 2.92 times higher risk of failure than that with early surgical treatment. On the basis of these results, early operative treatment of type II odontoid fractures in the geriatric population is associated with a better outcome than that with nonsurgical treatment.

The incidence of neurological compromise after type II odontoid fractures is approximately 13%, and this rate does not seem to show any predisposition to age. The main cause for acute neurological deficit after these fractures is due to posterior displacement of the odontoid. A recent study found that the mortality risk associated with a type II odontoid fracture and accompanying neurological deficit was 6 times higher than that without neurological deficit. These patients also had an 11-fold higher increased threat of respiratory distress.

Few studies have looked at the functional outcome after surgical or nonsurgical treatment of these fractures. The outcome tool used to determine success or failure of treatment in most studies is the presence either of osseous union of the fracture or of a stable fibrous union. Platz et al showed that 83% of patients with type II odontoid fracture returned to preinjury level within 1 year. However, most of the patients were young and the outcomes in the geriatric age group were not presented. In our study, failure of initial treatment was defined as death, major complications, or failure to improve clinically in 1 year with respect to NDI scores. Because radiological findings do not clinically correlate with functional outcome in odontoid fractures, the presence of osseous union was not considered a measure of successful treatment.

In our study, the group with poor outcome had significantly lower scores for all components of NDI and SF-36v2. There seemed to be a greater risk for poor functional outcome with advancing age in our cohort of patients. This risk was found to increase by 1.05 times for every year beyond the age of 65.

This study has several important limitations, primarily the absence of randomization and determination of treatment in concordance with the personal preference of the surgeon. The study is thus prone to selection bias, because it is possible that surgeons tended to operate on healthier patients and opted for nonsurgical measures in the more frail patients. To overcome this possible bias, our results were adjusted by a series of confounding variables including baseline comorbidity.

Furthermore, our site-specific data show that the choice of treatment is primarily surgeon preference and not the patient status. However, unadjusted confounding represents a possible source of limitation. A second limitation of our study is the relatively short follow-up period of 1 year. This time frame was chosen to account for the patients’ advanced age and hence their high mortality rate as seen in previous studies.

Our study suggests that older age, male sex, and initial nonsurgical treatment were associated with failure of treatment in patients with geriatric odontoid fractures.

Key Points

- Type II odontoid fractures are the most common spinal fractures in the geriatric population and represent a significant management challenge; however, there is no consensus on treatment.
- Both surgical and nonsurgical treatment options of type II odontoid fractures in the geriatric population carry a high risk of treatment failure and poor outcomes. Surgical management in this population is complicated because of high levels of medical comorbidities, poor bone quality, and impaired physiological reserves.
- There are currently no published studies investigating the factors associated with treatment failure and poor outcomes in elderly patients with type II odontoid fractures.
- Data collected from our trial indicated that initial conservative treatment had a 2.92 times higher risk of failure than that with early surgical treatment. On the basis of these results, early operative treatment of type II odontoid fractures in the geriatric population is associated with a better outcome than that with nonsurgical treatment.
- This large, multicenter, prospective study identified the factors associated with failure of treatment in geriatric patients with type II odontoid fractures as nonsurgical treatment, older age, male sex, and neurological impairment.

Acknowledgments

The authors would like to acknowledge funding from AOSpine. The authors thank Drs. Christopher Bono, Roger Hartl, Ziya Gokaslan, Mark Dekutoski, Rick Sasso, Darrel Brodkle, Christopher Shaffrey, Joseph Cheng, Sangwook Tim Yoon, and John France and Emma Seager, BASc, and Karen K. Anderson, BS, for their contributions.

References

1. Pointillart V, Orta AL, Freitas J, et al. Odontoid fractures. Review of 150 cases and practical application for treatment. Eur Spine J 1994;3:282–5.
2. Chiba K, Fujimura Y, Toyama Y, et al. Treatment protocol for fractures of the odontoid process. J Spinal Disord 1996;9:267–76.
3. Marton E, Billeci D, Carteri A. Therapeutic indications in upper cervical spine instability. Considerations on 58 cases. J Neurosurg Sci 2000;44:192–202.
4. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. Injury 1992;23:38–40.
5. Malik SA, Murphy M, Connolly P, et al. Evaluation of morbidity, mortality and outcome following cervical spine injuries in elderly patients. Eur Spine J 2008;17:585–91.
6. Smith HE, Kerr SM, Maltenfort M, et al. Early complications of surgical versus conservative treatment of isolated type II odontoid fractures in octogenarians: a retrospective cohort study. J Spinal Disord Tech 2010;23:501–5.
7. Smith HE, Kerr SM, Fehlings MG, et al. Trends in epidemiology and management of type II odontoid fractures: 20-year experience at a model system spine injury tertiary referral center. J Spinal Disord Tech 2010;23:501–5.
8. Sasso RC. C2 dens fractures: treatment options. J Spinal Disord 2001;14:453–63.
9. Apuzzo ML, Heiden JS, Weiss MH, et al. Acute fractures of the odontoid process. An analysis of 45 cases. J Neurosurg 1978;48:85–91.
10. Harrop JS, Hart R, Anderson PA. Optimal treatment for odontoid fractures in the elderly. Spine 2010;35(suppl):S219–27.
11. Schatzker J, Rorabeck CH, Waddell JP. Non-union of the odontoid process. An experimental investigation. Clin Orthop Relat Res 1975:127–37.
12. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. J Manipulative Physiol Ther 1991;14:409–15.
13. Kopjar B. The SF-36 health survey: a valid measure of changes in health status after injury. Inj Prev 1996;2:135–9.
14. Hanigan WC, Powell FC, Elwood PW, et al. Odontoid fractures in elderly patients. J Neurosurg 1993;78:32–5.
15. Muller EJ, Wick M, Ruise O, et al. Management of odontoid fractures in the elderly. Eur Spine J 1999;8:360–5.
16. White AF, Hashimoto R, Norvell DC, et al. Morbidity and mortality related to odontoid fracture surgery in the elderly population. Spine 2010;35(suppl):S146–77.
17. Schoenfeld AJ, Bono CM, Reichmann WM, et al. Type II odontoid fractures of the cervical spine: do treatment type and medical comorbidities affect mortality in elderly patients? Spine 2011;36:879–85.
18. Platter P, Thalhammer G, Sarahrudi K, et al. Nonoperative management of odontoid fractures using a halothoracic vest. Neurosurgery 2007;61:522–9.
19. Sokolowski MJ, Jackson AP, Haak MH, et al. Acute outcomes of cervical spine injuries in the elderly: atlantaxial vs subaxial injuries. J Spinal Cord Med 2007;30:238–42.
20. Jensen JS, Tondevold E. Mortality after hip fractures. Acta Orthop Scand 1979;50:161–7.
21. Roche JJ, Wenn RT, Sahota O, et al. Effect of comorbidities and postoperative complications on mortality after hip fracture in elderly people: prospective observational cohort study. BMJ 2005;331:1374.
22. Zuckerman JD, Skovron ML, Koval KJ, et al. Postoperative complications and mortality associated with operative delay in older patients who have a fracture of the hip. J Bone Joint Surg Am 1996;77:1551–6.
23. Moran CG, Wenn RT, Sikand M, et al. Early mortality after hip fracture: is delay before surgery important? J Bone Joint Surg Am 2005;87:483–9.
24. Garfin SR, Botte MJ, Waters RL, et al. Complications in the use of the halo fixation device. J Bone Joint Surg Am 1986;68:320–5.
25. Horn EM, Theodore N, Feiz-Erfan I, et al. Complications of halo fixation in the elderly. J Neurosurg Spine 2006;5:46–9.
26. van Middendorp JJ, Slooff WB, Nellestein WR, et al. Incidence of and risk factors for complications associated with halo-vest immobilization: a prospective, descriptive cohort study of 239 patients. J Bone Joint Surg Am 2009;91:71–9.
27. Lennarson PJ, Mostafavi H, Traynells VC, et al. Management of type II dens fractures: a case-control study. Spine 2000;25:1234–7.
28. Koech F, Ackland HM, Varma DK, et al. Nonoperative management of type II odontoid fractures in the elderly. Spine 2008;33:2881–6.
29. Molinari RW, Khera OA, Gruhn WL, et al. Rigid cervical collar treatment for geriatric type II odontoid fractures. Eur Spine J 2012;21:855–62.
30. Patel AA, Smith H, Radcliff KE, et al. Spinal cord injury associated with type II odontoid fractures: a retrospective cohort analysis. Paper presented at: the 2011 Annual Meeting of the American Academy of Orthopaedic Surgeons; San Diego, CA, 15–19 February 2011. Paper 24.