Clin Orthop Relat Res (2011) 469:742–750
DOI 10.1007/s11999-010-1677-x

SYMPOSIUM: CURRENT CONCEPTS IN CERVICAL SPINE SURGERY

The Best Surgical Treatment for Type II Fractures of the Dens Is Still Controversial

Vincenzo Denaro MD, Rocco Papalia MD, PhD, Alberto Di Martino MD, PhD, Luca Denaro MD, PhD, Nicola Maffulli MD, MS, PhD, FRCS(Orth)

Published online: 16 December 2010

Abstract

Background Odontoid fractures are the most common odontoid injury and often cause atlantoaxial instability. Reports on postoperative status of patients who underwent surgery for such injuries are limited to small case series, and it is unclear whether any one technique produces better outcomes than another.

Questions/purposes We assessed the quality of the available literature for management of Type II odontoid fractures and surgery-related parameters, including surgical indications, clinical failure rate, and survivorship, postoperative ROM and function, neurologic deficits, complication and death rates, and radiographic healing rates related to either anterior dens screw or posterior C1–C2 fusion.

Methods We performed a systematic search in PubMed, Ovid, Cochrane Reviews, and Google Scholar databases. We used the methodology score proposed by Coleman et al. to rate study quality. Postoperative imaging bone union rates were extracted. Postoperative complications and neurologic impairment data were also collected.

Results Sixteen retrospective studies of overall low quality (average methodology score, 37.1) reporting a total of 518 patients were included. The methodology score and publication year were positively associated. The bone union rate approximated 83% (range, 33%–100%), with higher nonunion rates among patients older than 65 years. The death rate ranged widely (0%–28.6%) among different centers. Residual cervical pain was documented postoperatively from 10.5% to 26.7%, while survivorship ranged from 72% to 96.6%. No ROM data were reported.

Conclusions Current data on patients who had surgery for fracture of the dens did not allow us to establish superiority of one surgical approach over another.

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
This work was performed at University Campus Bio-Medico of Rome, University of Padua, and Queen Mary University of London Barts and The London School of Medicine and Dentistry Institute of Health Sciences Education.

V. Denaro, R. Papalia, A. Di Martino (✉)
Department of Orthopaedics and Trauma Surgery, University Campus Bio-Medico of Rome, Via Alvaro del Portillo, 200, 00155 Rome, Italy
e-mail: a.dimartino@unicampus.it

L. Denaro
Department of Neuroscience, University of Padua, Padua, Italy

N. Maffulli
Centre for Sports and Exercise Medicine, Queen Mary University of London Barts and The London School of Medicine and Dentistry Institute of Health Sciences Education, Mile End Hospital, London, UK

Introduction

Odontoid fractures account for 5% to 15% of all cervical spine injuries, with an increased rate in elderly patients [27, 37]. Type II odontoid fractures [4] are the most common odontoid injury and produce atlantoaxial instability [11]. There is no single universally accepted method of management of these fractures [11, 25]. Nonoperative treatment with a rigid brace can result in fracture healing without need for surgery [5], but a mortality rate of 26% to 47% in elderly patients has been reported, perhaps as a result of respiratory-related complications due to prolonged external immobilization [7, 23, 31, 35]. Reported healing after external immobilization has varied widely from 7% to

100% [26–28]. In most series, however, reported rates of successful healing ranged from 37% to 75% [3, 6, 13, 38]. To overcome the problems associated with nonoperative management, surgical stabilization procedures were introduced. In patients undergoing traditional posterior C1–C2 arthrodesis, union rates from 92.8% [30] to 100% [11] have been reported. Decreased cervical motion is a consequence of this procedure: movement at C1–C2 accounts for more than 50% of all cervical spine rotatory motion. Also, there is reduced cervical spine flexion-extension by 10% [39]. Direct anterior screw fixation provides immediate stability, relative high rates of fracture healing (varying from 73% [9] to 100% [10–12, 20]), and conserved C1–C2 motion [5, 40].

Almost all studies reporting surgical treatment are case series with small sample sizes reporting on patients operated on with posterior fusion or anterior fixation and assessed using no standard measures [1, 2, 8, 10–12, 15, 20, 24]. Given that available postoperative data are heterogeneous, there is a need to systematically review the literature to investigate whether these procedures are equivalent to one another in the hands of an experienced surgeon. Owing to various reported healing rates and subsequent function, our purpose was to establish the clinical and imaging status of these patients.

We therefore determined (1) the quality of the literature reporting function in patients undergoing surgery for management of Type II odontoid fractures; (2) the indications for surgery; (3) the clinical failure rate and survivorship for different approaches; (4) the ROM after surgery; (5) the function and the ability to return to preoperative status; (6) whether neurologic status is impaired; (7) the complication and death rates; and (8) the radiographic healing rates related to either the anterior (dens screw) or posterior approach (C1–C2 fusion).

Search Strategy and Criteria

We performed a search using the keywords “Type II odontoid fracture” and “surgical management” and “surgery,” “fixation,” “internal fixation,” “arthrodesis,” “fusion” in combination with “anterior approach” and “posterior approach,” with no limit regarding the year of publication. The following databases were accessed on November 26, 2009: PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez/); Ovid (http://www.ovid.com); Cochrane Reviews (http://www.cochrane.org/reviews/); and Google Scholar. Given the linguistic capabilities of the research team, we considered publications in English, Spanish, French, Portuguese, and Italian (Fig. 1). All journals were considered. These searches yielded 207 articles. We excluded 22 articles because an abstract was not available. Two authors (RP, AD) read the abstract of each of the

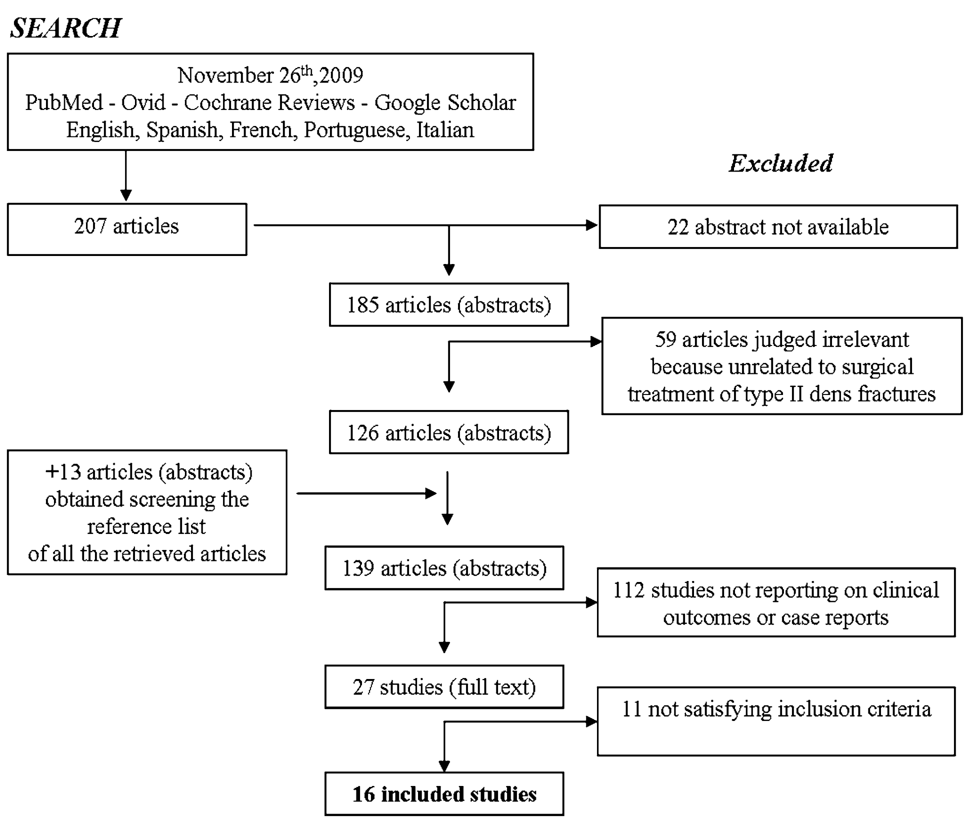

Fig. 1 A flowchart shows the inclusion and exclusion process used in the literature search for this review.

185 remaining papers. Based on the abstract we excluded 59 articles we judged irrelevant because they were unrelated to surgical treatment of Type II dens fractures. In addition, the search was extended by screening the reference list of all the articles. This added 13 articles to the 126 identified by the searches.

From the total of 139 articles, we excluded 112 not reporting outcomes of surgery in the abstract such as case reports, letters to the editor, technical descriptions, or because the article was not published in peer-reviewed journals. In case of doubt about inclusion of an article, the senior author (VD) made the decision. For the remaining 27 articles we obtained full-text versions. To avoid bias in including the articles, the publications selected were examined and discussed by all the authors. After this further selection, 16 publications relevant to the topic at hand were included (Fig. 1). All studies were retrospective.

Two investigators (RP, NM) used the criteria developed by Coleman et al. [14, 36] to assess blindly the methods of each article twice. Briefly, this methodology score [14] consists of two sections (A and B) of seven and three questions, respectively. In Part A, the score is determined by giving points to the study size, mean followup, number of surgical procedures, type of study (randomized, prospective, retrospective), diagnostic certainty (in terms of radiographic and histopathologic examinations), description of surgical procedures, and postoperative rehabilitation. In Part B, scores are given based on which outcome criteria are used, method of assessing outcomes, and subject selection process. The final score is the sum of the separate scores from the two sections. Each selected study was scored for each of the 10 criteria to give a total methodology score of between 0 and 100. A perfect score of 100 would represent a study design that largely avoids the influence of chance, various biases, and confounding factors. To assess interobserver variability, the intraclass correlation coefficient was calculated. It was 0.91, showing a high correlation between the methodology scores awarded to each scientific article by each independent marker (substantial agreement).

Three of us (LD, AD, VD) extracted from the 16 retained articles the following information: (1) indications for surgery; (2) clinical failure rate in terms of residual cervical pain and/or survivorship for the different approaches; (3) ROM after surgery; (4) function and the ability to return to preoperative status; (5) whether neurologic status was impaired; (6) complication and death rates; and (7) radiographic healing rates related to either the anterior (dens screw) or posterior approach (C1–C2 fusion). For imaging assessment, postoperative imaging data were extracted to determine bone healing and union rates. To avoid bias, only reported data on solid union rates were included, excluding data on nonanatomic bone union and fibrous union rates. In addition, postoperative complications and neurologic impairment data were collected when available. If studies included Types I, II, and III odontoid fracture patients, only Type II fractures undergoing surgery were taken into account for the purpose of the study.

To assess the impact of methods on reported outcomes, the methodology scores were correlated with reported success rates (in percent) and with the level of evidence rating using Spearman rank correlation (r). We used the Pearson correlation coefficient to assess the relationship between the year of publication and the methodology score. Analysis was performed using SPSS® software (Version 16.0; SPSS Inc, Chicago, IL).

Results

The 16 retrospective studies (Table 1) reported 518 patients: 477 (92.1%) underwent surgery for Type II odontoid fracture and 41 (7.9%) were managed for Type III fractures. The mean methodology score of 37.1 (range, 21.0 [19] to 55.0 [32, 33]) suggested an overall low methodologic quality. The association between the methodology score and year of publication ($r = 0.44$, $p = 0.037$) demonstrated the quality of methods has improved over the decades, particularly in the last 5 years.

The indications for surgery varied among different studies (Table 1). Falls and motor vehicle accidents were the leading causes (34%) of fracture in patients undergoing surgery.

Residual cervical pain was documented postoperatively from 10.5% [8] to 26.7% [15]. Almost all studies provided survivorship data ranging from 72% at 11 months [11] to 96.6% [30] at 18 months.

Three of the 16 studies [1, 12, 32] noted assessment of cervical ROM but none reported numerical data.

One study [32] reported return to preinjury activity level after surgery: postoperatively, 45 of 48 patients (93%) returned to preinjury activity. No study investigated the ability to participate in sports after surgery.

While preoperative neurologic impairment was reported in 104 of the 518 patients (20%), postoperative status-related outcomes were reported in few studies (Table 2). Platzer et al. [33] observed neurologic deficits in 16 of 110 patients (14.5%) preoperatively. Four patients showed motor deficits, three sensory deficits, and nine motor and sensory deficits. Postoperatively, neurologic deficits were diagnosed in six patients (5%) (five American Spinal Injury Association [17] Grade D, one Grade C). Two patients showed motor deficits, three sensory deficits, and one motor and sensory deficits. A complete recovery of neurologic function was seen after rehabilitation in four patients, whereas incomplete deficit resolution was noted in

Table 1. Features of the cited studies

Study	Type of study	Sample size	Followup (months)*	Time from injury to surgery (days)*	Age (year)*	Etiology (number of patients)	Coleman Methodology Score
Aebi et al. [1] (1989)	Retrospective	17	16 (12–51)	7 (0–24)	53 (18–79)	Fall (10), MVA (6), unknown (1)	41
Alfieri [2] (2001)	Retrospective	9		From 2nd to 25th day			32
Apfelbaum et al. [5] (2000)	Retrospective	147	18.2 (3–60)		50.1 (15–92)	MVA (68), fall (64), blow to the head (3), diving injury (2), bicycle accident (2), unknown (8)	53
Berlemann and Schwarzenbach [8] (1997)	Retrospective	19	54 (12–132)	Within 1 day (12), 4 days (3), and 2 weeks (4)	75 (65–87)	Fall (18), MVA (1)	36
Borm et al. [9] (2003)	Retrospective	27	16.6	10			39
Borne et al. [10] (1988)	Retrospective	9			54.3 (19– 85)	MVA (7), fall from a horse (1), fall after a heart attack and loss of consciousness (1)	30
Campanelli et al. [11] (1999)	Retrospective	7	10.6				30
Chang et al. [12] (1994)	Retrospective	12	(12–30)	5 (Group 1); 14 (Group) 2 (1–35)	42 (19–61)		45
Crockard et al. [15] (1993)	Retrospective	16			44.4 (17–84)	MVA (8), pedestrian accident (4), fall (4)	23
Etter et al. [18] (1991)	Retrospective	23	Minimum 12				42
Fujii et al. [19] (1988)	Retrospective	26			34 (3 –81)	Traffic accidents were the major cause	21
Geisler et al. [20] (1989)	Retrospective	9	Minimum 6	Within 5 days	58 (24–85)	MVA (3), fall (5), rafting mishap (1)	42
Harrop et al. [24] (2000)	Retrospective	10	10		80 (67–92)	Fall (8), MVA (1), diving accident (1)	30
Omeis et al. [30] (2009)	Retrospective	29	18 ± 2.2 (3–72)		79.9 (70–94)	Fall (24), pedestrian struck by a moving vehicle (3), MVA (2)	30
Platzer et al. [33] (2007)	Retrospective	110		5 (1–21)	54 (7–83)	MVA (34), sports-related injuries (31), low-energy falls (27), falls from a considerable height or down stairs (16), other (2)	55
Platzer et al. [32] (2007)	Retrospective	48	24	6	71.4 (66–83)	High-energy trauma (37), low-energy trauma (19)	44

* Values expressed as mean or mean ± SD, with range in parentheses; MVA = motor vehicle accident.

Table 2. Neurologic impairment and death rates

Study	Type of surgery	Neurologic impairment	Death rate and death causes
Aebi et al. [1] (1989)	Anterior screw fixation	1 patient experienced Lhermitte's sign and 1 hyperesthesia in both upper extremities	5.9% (1/17): undetermined
Alfieri [2] (2001)	Anterior screw fixation		
Apfelbaum et al. [5] (2000)	Anterior screw fixation	Partial deficit in 12 (9%), complete deficit (quadriplegia) in 2 (1%)	6% (7/147): 6 for nonsurgery-related causes, 1 (1%) for respiratory-related causes after screw backout
Berlemann and Schwarzenbach [8] (1997)	Anterior screw fixation	3 patients with loss of consciousness; 1 patient with diffuse dysesthesia in all extremities directly after the trauma; 1 patient with hyperesthesia in the C6 dermatome bilaterally	1 death for unrelated causes
Borm et al. [9] (2003)	Anterior screw fixation	Neurological status at admission and after treatment was similar in both groups	3.7% (1/27), 6.7% (1/15): unspecified
Borne et al. [10] (1988)	Direct screw fixation via anterolateral retropharyngeal approach	Six patients had no neurologic signs, two with immediate severe quadriparesis, and one with right brachial paresis	22.2% (2/9): tetraparetic on admission
Campanelli et al. [11] (1999)	Posterior C1–C2 transarticular fixation		28.6% (2/7): 1 unrelated malignancy, 1 intracranial hematoma
Chang et al. [12] (1994)	Anterior screw fixation	One with quadriparesis partially resolved but hemiparesis remained on the left side; 3 with hoarseness, 2 with dysphagia	
Crockard et al. [15] (1993)	Anterior transoral decompression, posterior internal stabilization		
Etter et al. [18] (1991)	Anterior screw fixation		4.3% (1/23): unspecified
Fujii et al. [19] (1988)	Conservative management; transoral atlantoaxial fusion; posterior atlantoaxial fusion; posterior decompression; bone peg fixation	Temporary unconsciousness as brain stem symptoms in 8; spinal cord symptoms (quadriparesis or numbness of the extremities in 16): spinal cord symptoms usually subside when good reduction and bony union are obtained; no case had neurologic deterioration after surgery); C2 neuralgia as nerve root symptoms in 23	
Geisler et al. [20] (1989)	Anterior screw fixation	At presentation, 5 patients no neurologic deficit, 2 with complete quadriplegia, 2 with incomplete neurologic lesions; postoperatively, 3 patients with severe quadriparesis at presentation showed neurologic improvement	22.2% (2/9): 1 adult respiratory distress syndrome, 1 secondary to pulmonary hemorrhage during a bronchoscopic examination
Harrop et al. [24] (2000)	Anterior screw fixation	In only one patient neurologic injury; this patient had sustained a C2 fracture that caused complete tetraplegia in a diving accident	10% (1/10): pneumonia

Table 2. continued

Study	Type of surgery	Neurologic impairment	Death rate and death causes
Omeis et al. [30] (2009)	Anterior screw fixation; posterior C1–C2 fusion; posterior C1–C3 fusion; Posterior occipitocervical fusion	27 neurologically intact at presentation and 2 with central cord syndrome started on a methhylprednisolone protocol for 24 hours	1 death for unrelated causes
Platzer et al. [33] (2007)	Anterior screw fixation	Preoperatively, 4 patients showed motor deficits, 3 patients incurred sensory deficits, 9 patients had motor and sensory deficits; postoperatively, 2 patients showed motor deficits, 3 patients had sensory deficits, 1 patient incurred motor and sensory deficits	4%
Platzer et al. [32] (2007)	Anterior screw fixation; posterior cervical fusion.	Neurologic deficits in 9	6% (4/56): 1 cardiac arrest, 2 severe pneumonia, pulmonary embolism

two patients. All other patients with preoperative neurologic deficits recovered fully after surgery. Of 24 patients who temporarily lost consciousness and had neurologic involvement, such as quadriparesis or numbness of the extremities, two had persistent symptoms after treatment, with no neurologic deterioration after surgery. Finally, comparing pre- and postoperative neurologic status, improvement was observed in several cases [12, 20].

Perioperative and postoperative complication rates ranged from 6.2% [15] to 33.9% [32] and classified as local and general [33] (Table 3).

According to available imaging data, the mean preoperative displacement ranged from 3.8 mm (range, 0–8 mm) [32] to 8.66 mm (range, 6–10 mm) [11]. Three hundred ninety-three of 475 (82.7%) radiographically assessed patients showed postoperative bone healing, with bone union rates ranging from 33% [30] to 100% [10–12, 20] (Table 3) and increased union rates in patients operated on within 6 months of injury [5]. Omeis et al. [30] found higher bone healing rates in patients undergoing anterior odontoid screw fixation compared to patients receiving posterior procedures, with no intergroup difference in flexion–extension stability. With regard to age-related bone union imaging assessment, higher nonunion rates were detected in geriatric ($\geq$ 65 years) (12%) than in nongeriatric patients (< 65 years) (5%).

Discussion

Odontoid fractures are the most common odontoid injury, often resulting in atlantoaxial instability. Reports on postoperative status of patients who underwent surgery for such injuries are limited to small case series, and it is unclear whether any one technique produces better outcomes than another. We performed a systematic review of the literature on the outcome of patients undergoing surgery for Type II odontoid fractures. We assessed the outcomes of management of Type II odontoid fractures, the most commonly detected spinal fractures in patients 70 years of age or older, with evidence of increasing incidence in this population [34]. We also assessed the methodologic quality of the relevant clinical studies. Finally, we extracted information on clinical and neurologic status and complication, survivorship, and death rates in operated patients. We differentiated between bone fusion data and bone healing data. The former were applicable to patients operated on using a posterior arthrodesis and the latter to anterior screw fixation for which radiographic outcomes were considered.

There are numerous limitations in the literature reviewed. First, the level of surgeons' experience and variability in patient selection may have influenced results in the individual studies. Second, we found great variability in the instruments assessing results and used to identify specific parameters. The studies selected for this review were heterogeneous for methods of assessment, methods of reporting results, and outcomes. Given the apparent biases introduced by different assessment criteria used for clinical evaluation, it is difficult to know how the 83% overall bone union rate should be interpreted. Third, limited data were reported in the selected studies. Fourth, the methodology score assesses the quality of reporting, not the quality of the study. Unless the individual authors are contacted directly, this is an inherent weakness of all methodology scores, as they do not necessarily reflect the true validity of the study but are biased by the quality of reporting. We found a generally low methodologic quality in the articles included based on the results of the methodology score.

Table 3. Fusion rate and complications

Study	Healing rate/fusion rate	Complications
Aebi et al. [1] (1989)	13/17 (76.5%: healing rate)	1 postoperative hematoma, 1 screw fracture, 2 fracture redisplacement, screw breakage in the dens in 1 patient
Alfieri [2] (2001)		Transient dysphagia in one patient
Apfelbaum et al. [5] (2000)	99/117 (85%: healing rate) in recently fractured patients, 4/16 (25%: healing rate) in late managed group	Postoperative hardware-related complications occurred in 10 patients (9%); two (2%) suffered superficial wound infections; in the late management group, hardware-related problems in 4 patients (25%); 1 patient (6%) had a small esophageal leak at C5–C6
Berlemann and Schwarzenbach [8] (1997)	16/18 (88.9%: healing rate)	1 hematoma, 1 patient suffered from postoperative episodes of apnea
Borm et al. [9] (2003)	11/15 (73%: healing rate) > 70 years and 9/12 (75%: healing rate) < 70 years	20% of patients > 70 years and 8% of patients < 70 years
Borne et al. [10] (1988)	9/9 (100%: healing rate)	
Campanelli et al. [11] (1999)	7/7 (100%: fusion rate)	1 patient with transient respiratory failure from pulmonary edema. 1 patient experienced vertebral artery injury during placement of the left transarticular screw
Chang et al. [12] (1994)	12/12 (100%: healing rate)	
Crockard et al. [15] (1993)		1 patient developed local pharyngeal infection, a cerebrospinal fluid leak, and meningitis
Etter et al. [18] (1991)	20/22 (90.9%: healing rate)	Major complication rate of 17.8% (4/23): 1 death, 2 posterior fracture redisplacements, a single screw fracture that evolved into a nonunion
		Minor complications: 1 inconsequential intrafragment screw fracture, 2 wound hematomas (3/23, 13%)
Fujii et al. [19] (1988)	22/26 (84.6%: fusion rate)	
Geisler et al. [20] (1989)	7/7 (100%: healing rate)	1 patient died for adult respiratory distress syndrome (1 secondary to pulmonary hemorrhage during a bronchoscopic examination, a broken drill bit was retrieved from the body of C2); 1 patient developed an occipital decubitus from cervicothoracic postoperative bracing (halo vest)
Harrop et al. [24] (2000)	8/9 (88.9%: healing rate)	1 patient developed postoperative pneumonia and myocardial infarction, 1 patient died of pneumonia that developed 3 weeks after surgery
Omeis et al. [30] (2009)	6/16 (37.5%: healing rate) for anterior screw fixation, 4/14 (28.5%: fusion rate) for posterior fixation	Perioperative complications occurred in 3 patients (10.3%): intraoperative cardiac arrest with successful resuscitation (during extubation after C1–C2 fusion), reoperation for screw backout (after odontoid screw fixation), tracheostomy and percutaneous endoscopic gastrostomy for prolonged intubation (in an old man with fixation for Type II dens fracture)
Platzer et al. [33] (2007)	102/110 (93%: healing rate)	Failures of reduction and fixation in 12 patients (11%); general intraoperative or postoperative complications occurred in 16/117 patients, leading to an overall morbidity rate of 14%; in the nongeriatric patients, morbidity rate of 8%; in the geriatric patients, the incidence of intraoperative or postoperative complications 22%
Platzer et al. [32] (2007)	44/48 (92%) (combined fusion-healing rate)	Specific (9, or 16%): nonunion in 4, incorrect reduction in 3, secondary loss of reduction in 2, malpositioning of implants in 2, implant loosening in 1, reoperation in 3 (5%)
		General: cardiac failure in 1, respiratory failure in 2, pneumonia in 4, severe infection in 1, thromboembolism in 2, death in 4 (6%, 1 cardiac arrest, 2 severe pneumonia, pulmonary embolism)

Fifth, any search will invariably miss some published studies, and it is unlikely any review is definitive. Our initial search involved a high number of abstracts. Indeed, because we limited our interest to articles published in English, Spanish, French, Portuguese, and Italian, we may have missed articles published in other languages. Sixth, we excluded many studies (Fig. 1) because the postoperative status was reported for combined populations of Types I, II, and III odontoid injuries. Seventh, none of the studies mentioned compliance with the rehabilitation protocol. We do not know whether this might influence the outcome. Eighth, all selected studies were retrospective. Retrospective studies are simpler to perform, take less time to conduct, and are cheaper [21] but are prone to various sorts of biases, including selection and recall, not to mention missing data. Ninth, the studies we did identify lacked uniformity in pre- and postsurgical management and assessment of pre- and postoperative neurologic status and undertook clinical and imaging followup at variable times and for variable periods. Finally, most studies in our investigation included relatively few patients assessed at short-term followup, but long-term prospective studies of a large size are difficult to perform and are expensive in terms of money and time [29].

Although many Type I and III fractures can be treated using simple collar immobilization, Type II fractures continue to cause controversy. Several surgical options are available, but there is no consensus on the best treatment for these fractures. Several authors have suggested more than 4 to 6 mm of dens displacement [6, 22], increasing age (> 40–65 years) [6, 16], posterior odontoid subluxation [16], and comminution of the base of the dens [22] would predict lower rates of fracture union. Therefore, patients with one or more of these criteria or who refuse external immobilization are considered surgical candidates by some surgeons [5]. We found an association between bone union rates at imaging and the methodology score. The retrospective design of all selected studies did not allow us to correlate the methodology score with the level of evidence rating. The methodology score correlated positively with the year of publication, showing the methodologic quality of published studies has improved over the years. Although posterior fusion was associated with a lower fusion rate and decreased cervical rotatory and segmental flexion–extension motion, the poor data did not allow us to compare anterior and posterior surgical management. Based on the data extracted from the studies identified, we could not establish any correlation between bone healing/fusion rates or mortality and preoperative displacement status. However, comparing pre- and postoperative neurologic and imaging status, there is evidence of postoperative improvement in neurologically impaired patients. According to the available data, the reported postoperative complications and death rates after surgery seem to decrease over time. This finding appears difficult to interpret, given the increased frequency with which the operation has been performed over the past 20 years and likely changes in the characteristics of patients undergoing surgery, but it is possible concentration of patients in specialist centers and subspecialization may play a role.

In conclusion, reported mortality, bone healing rate, and risk of complications due to surgical management for Type II odontoid fractures are heterogeneous. Much of the variability arises from differences in study methodology, in particular related to performed outcome assessment measures. The utility of surgical management cannot be properly assessed without randomized clinical trials, but reported results suggest benefits are likely to be considerable. Randomized controlled trials are required in this field, especially when comparing operative and nonoperative treatment. When a randomized controlled design is not feasible, the study should be at least prospective, taking into account as many of the features of a randomized controlled trial as possible. Although the available literature does not allow determination of the best surgical approach to Type II odontoid fractures, the overall bone union, mortality, and complication rates were in line with current recommendations for surgery.

Acknowledgment We thank Dr. Angelo Del Buono for editing the manuscript.

References

1. Aebi M, Etter C, Coscia M. Fractures of the odontoid process: treatment with anterior screw fixation. *Spine (Phila Pa 1976).* 1989;14:1065–1070.
2. Alfieri A. Single-screw fixation for acute Type II odontoid fracture. *J Neurosurg Sci.* 2001;45:15–18.
3. Althoff B. Fracture of the odontoid process: an experimental and clinical study. *Acta Orthop Scand Suppl.* 1979;177:1–95.
4. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am.* 1974;56:1663–1674.
5. Apfelbaum RI, Lonser RR, Veres R, Casey A. Direct anterior screw fixation for recent and remote odontoid fractures. *J Neurosurg.* 2000;93:227–236.
6. Apuzzo ML, Heiden JS, Weiss MH, Ackerson TT, Harvey JP, Kurze T. Acute fractures of the odontoid process: an analysis of 45 cases. *J Neurosurg.* 1978;48:85–91.
7. Bednar DA, Parikh J, Hummel J. Management of Type II odontoid process fractures in geriatric patients: a prospective study of sequential cohorts with attention to survivorship. *J Spinal Disord.* 1995;8:166–169.
8. Berlemann U, Schwarzenbach O. Dens fractures in the elderly: results of anterior screw fixation in 19 elderly patients. *Acta Orthop Scand.* 1997;68:319–324.
9. Borm W, Kast E, Richter HP, Mohr K. Anterior screw fixation in Type II odontoid fractures: is there a difference in outcome between age groups? *Neurosurgery.* 2003;52:1089–1092; discussion 1092–1084.

10. Borne GM, Bedou GL, Pinaudeau M, Cristino G, Hussein A. Odontoid process fracture osteosynthesis with a direct screw fixation technique in nine consecutive cases. *J Neurosurg.* 1988;68:223–226.
11. Campanelli M, Kattner KA, Stroink A, Gupta K, West S. Posterior C1-C2 transarticular screw fixation in the treatment of displaced Type II odontoid fractures in the geriatric population—review of seven cases. *Surg Neurol.* 1999;51:596–600; discussion 600–691.
12. Chang KW, Liu YW, Cheng PG, Chang L, Suen KL, Chung WL, Chen UL, Liang PL. One Herbert double-threaded compression screw fixation of displaced Type II odontoid fractures. *J Spinal Disord.* 1994;7:62–69.
13. Clark CR, White AA 3rd. Fractures of the dens: a multicenter study. *J Bone Joint Surg Am.* 1985;67:1340–1348.
14. Coleman BD, Khan KM, Maffulli N, Cook JL, Wark JD. Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies. Victorian Institute of Sport Tendon Study Group. *Scand J Med Sci Sports.* 2000;10:2–11.
15. Crockard HA, Heilman AE, Stevens JM. Progressive myelopathy secondary to odontoid fractures: clinical, radiological, and surgical features. *J Neurosurg.* 1993;78:579–586.
16. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. *Neurosurgery.* 1986;18:306–310.
17. El Masry WS, Tsubo M, Katoh S, El Miligui YH, Khan A. Validation of the American Spinal Injury Association (ASIA) motor score and the National Acute Spinal Cord Injury Study (NASCIS) motor score. *Spine (Phila Pa 1976).* 1996;21:614–619.
18. Etter C, Coscia M, Jaberg H, Aebi M. Direct anterior fixation of dens fractures with a cannulated screw system. *Spine (Phila Pa 1976).* 1991;16:S25–32.
19. Fujii E, Kobayashi K, Hirabayashi K. Treatment in fractures of the odontoid process. *Spine (Phila Pa 1976).* 1988;13:604–609.
20. Geisler FH, Cheng C, Poka A, Brumback RJ. Anterior screw fixation of posteriorly displaced Type II odontoid fractures. *Neurosurgery.* 1989;25:30–37; discussion 37–38.
21. Green JS, Morgan B, Lauder I, Finlay DB, Allen M, Belton I. The correlation of bone scintigraphy and histological findings in patellar tendinitis. *Nucl Med Commun.* 1996;17:231–234.
22. Hadley MN, Browner C, Sonntag VK. Axis fractures: a comprehensive review of management and treatment in 107 cases. *Neurosurgery.* 1985;17:281–290.
23. Hanigan WC, Powell FC, Elwood PW, Henderson JP. Odontoid fractures in elderly patients. *J Neurosurg.* 1993;78:32–35.
24. Harrop JS, Przybylski GJ, Vaccaro AR, Yalamanchili K. Efficacy of anterior odontoid screw fixation in elderly patients with Type II odontoid fractures. *Neurosurg Focus.* 2000;8:e6.
25. Lennarson PJ, Mostafavi H, Traynelis VC, Walters BC. Management of Type II dens fractures: a case-control study. *Spine (Phila Pa 1976).* 2000;25:1234–1237.
26. Lind B, Nordwall A, Sihlbom H. Odontoid fractures treated with halo-vest. *Spine (Phila Pa 1976).* 1987;12:173–177.
27. Maak TG, Grauer JN. The contemporary treatment of odontoid injuries. *Spine (Phila Pa 1976).* 2006;31:S53–S60; discussion S61.
28. Maiman DJ, Larson SJ. Management of odontoid fractures. *Neurosurgery.* 1982;11:820.
29. Movin T, Gad A, Reinholt FP, Rolf C. Tendon pathology in long-standing achillodynia: biopsy findings in 40 patients. *Acta Orthop Scand.* 1997;68:170–175.
30. Omeis I, Duggal N, Rubano J, Cerabona F, Abrahams J, Fink M, Das K. Surgical treatment of C2 fractures in the elderly: a multicenter retrospective analysis. *J Spinal Disord Tech.* 2009;22:91–95.
31. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. *Clin Orthop Relat Res.* 1985;193:178–183.
32. Platzer P, Thalhammer G, Oberleitner G, Schuster R, Vecsei V, Gaebler C. Surgical treatment of dens fractures in elderly patients. *J Bone Joint Surg Am.* 2007;89:1716–1722.
33. Platzer P, Thalhammer G, Ostermann R, Wieland T, Vecsei V, Gaebler C. Anterior screw fixation of odontoid fractures comparing younger and elderly patients. *Spine (Phila Pa 1976).* 2007;32:1714–1720.
34. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. *Injury.* 1992;23:38–40.
35. Ryan MD, Taylor TK. Odontoid fractures in the elderly. *J Spinal Disord.* 1993;6:397–401.
36. Tallon C, Coleman BD, Khan KM, Maffulli N. Outcome of surgery for chronic Achilles tendinopathy: a critical review. *Am J Sports Med.* 2001;29:315–320.
37. Vaccaro AR, Madigan L, Ehrler DM. Contemporary management of adult cervical odontoid fractures. *Orthopedics.* 2000;23:1109–1113; quiz 1114–1105.
38. Wang GJ, Mabie KN, Whitehill R, Stamp WG. The nonsurgical management of odontoid fractures in adults. *Spine (Phila Pa 1976).* 1984;9:229–230.
39. White AAI, Panjabi MM, eds. *Clinical Biomechanics of the Spine.* 2nd ed. Philadelphia, PA: JB Lippincott; 1990.
40. Woolf SH. Practice guidelines: a new reality in medicine. III. Impact on patient care. *Arch Intern Med.* 1993;153:2646–2655.