



Fusion rates for odontoid fractures after treatment by anterior odontoid screw versus posterior C1–C2 arthrodesis: a meta-analysis

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Abstract

Objective For odontoid fractures, surgical treatment approaches including anterior odontoid screw fixation approach and the posterior C1–C2 arthrodesis approach are generally adopted in practice. However, the choice of different surgical procedures remains controversial. In addition to surgical technique, the fusion rate is an important factor contributing to the clinical efficacy. Therefore, this study was aimed to investigate the discrepancy in fusion rate between these two surgical approaches through synthesizing the currently available evidence on the topic.

Methods A computerized search of Ovid, Medline, Embase, and the Cochrane library up to December 2017 for literature on the complication rate during odontoid fracture treatment was conducted. Risk ratio (RR) with its 95% confidence interval (CI) was pooled to assess fusion rates after surgical treatments, including anterior odontoid screw fixation approach or posterior C1–2 arthrodesis procedure, for patients with odontoid fractures.

Results Thirteen studies were enrolled in the meta-analysis. Results show that no significant difference was found in the overall fusion rate (RR = 0.96, 95% CI 0.90–1.01). There was no significant heterogeneity among the studies (p value = 0.60). As to age- and economic-level subgroups, there was no statistical evidence to suggest an association of the patient age and economy development level with the choice of surgical approach. However, it is shown that better fusion rates of patients (≥ 60 years) in developed countries received a better fusion rates after posterior fixation compared with anterior group using the fixed-effect model (RR = 0.88, 95% CI 0.79–0.98).

Conclusion Elderly patients (≥ 60 years) underwent posterior C1–2 arthrodesis fixation shows higher fusion rates in developed countries comparing with patients who underwent anterior odontoid screw fixation. Overall, there is no significant discrepancy between these two surgical approaches. However, the conclusion should be verified by further study enrolling larger sample size.

Keywords Odontoid fractures · Anterior odontoid screw · Posterior C1–2 arthrodesis · Complication rate · Meta-analysis

Introduction

Odontoid fractures have been considered as the most common type of acute axis fracture that remains to be the subject of many investigations. The incidence of odontoid fracture has increased considerably in recent years accounting for approximately 15% of cervical spine traumatic injuries [1, 2]. Odontoid fractures are classified into three types,

of which the majority are type II or type III fractures [3, 4]. However, the presentation of type II odontoid fractures obviously increased. The type II fracture occurs at the waist of the odontoid process and it is predisposed towards displacement and nonunion. The therapeutic approaches contain conservative approaches including halo-vest immobilization, rigid cervical orthosis and surgical approaches, which can be divided into anterior approaches and posterior approaches. However, the choice of surgical treatment for odontoid fractures remains controversial. Physicians who favor the anterior odontoid screw argue that the technique enables direct osteosynthesis at the fracture site and potentially reduces limitations associated with the loss of C1–C2 motion [5–8]. On the other side, those who strongly support the usage of the posterior C1–C2 arthrodesis believe that it

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is suitable for all types of odontoid fractures and a variety of procedures has been performed to improve posterior cervical stabilization [9–11]. As a result, reports vary considerably on the comparison of anterior odontoid screw and posterior C1–C2 arthrodesis toward the odontoid fracture treatment. Actually, it is still hard to define which approach is the optimal treatment modality for odontoid fractures because there are a lot of influencing factors including degree of injury, patient condition and even local economy level, which are necessary to be taken into account for the surgical approach choice. In addition to surgical technique, fusion rate is one of the important factors for clinical efficacy. Recently, anterior screw technique has gained an increased popularity in the treatment of type II odontoid fractures, and posterior C1–2 fixation achieves higher fusion rates although it is a challenging surgical technique [5, 12–14]. However, the optimal technique for odontoid fractures still remains controversial.

A meta-analysis designed by Shen et al. proved that patients who underwent posterior C1–C2 arthrodesis surgeries showed significantly higher fusion rates comparing with those treated with anterior odontoid screw fixation [15]. Recently, a study that enrolled large sample size supported that, for odontoid fractures, posterior C1–C2 arthrodesis surgeries and anterior odontoid screw fixation treatment had a similar fusion rate [16]. Thus, we further performed a meta-analysis on studies based on both approaches and compared the fusion rate resulting from two procedures toward the treatment of odontoid fractures.

Materials and methods

Search strategy

Literature searches were conducted in Ovid, Medline, Embase and the Cochrane library from inception between November 2015 and December 2017 with keywords “odontoid fracture” or “odontoid process fracture” and “anterior screw” and “posterior C1–2” or “surgical”. The search was not restricted to any specific language or by year of publication. Moreover, to increase completeness, a recursive hand search of cited bibliographies was also performed.

Inclusion criteria

The following inclusion criteria were applied: (1) searched studies focused on the association of post-operative fusion rates with surgical treatment in patients with odontoid fracture; (2) only adult samples (age 16 or older) were enrolled in the included studies; (3) anterior or posterior surgical treatment was performed on patients throughout the study period; and (4) published with English abstracts as of December 2017.

Exclusion criteria

Studies were excluded if they belonged to any of the following situations: (1) studies not focused on human subjects; (2) unrelated studies; (3) literature review or case reports or meta-analysis articles; (4) studies not regarding to surgical procedures; or (5) studies not related to both anterior and posterior surgical treatments.

Data extraction and quality assessment

All data were extracted independently by two investigators according to the predesigned extraction form. The following information was collected from each study: (1) authors and publication time; (2) country of study; (3) study design; (4) total sample size; (5) sample size for the two treatment groups; (6) follow-up time; (7) mean age of study participants; and (8) post-operative complications. The odontoid fracture-related complications of interest include: loosening or breakage of screws, redisplacement, cardiac failure, neurological deficits, urinary tract infection, nonunion, infection and hemiplegia, quadriplegia, hemiplegia, monoplegia, paraplegia and bilateral arm numbness.

In the present study, the quality of each study was assessed by the Newcastle–Ottawa Scale (NOS) with a maximum of nine points [17]. Three categories, including four points for selection of the study groups, two points for comparability and three points for ascertainment of the outcome of interest in the cohorts, were calculated in the scale. Scores of 7–9 were regarded as indicative of high-quality research, 4–6 were indicative of moderate quality, and scores lower than 3 were of low quality.

Statistical analyses

Fusion rate after surgery was the primary endpoint focused in the meta-analysis. The effect sizes for data between the anterior odontoid screw group and posterior C1–2 group were measured by risk ratio (RR) with its 95% confidence interval (CI). Heterogeneity across individual studies was calculated by the I^2 test that describes the percentage of variation owing to heterogeneity [18, 19]. Heterogeneity was considered to be significant if $I^2 > 50\%$. Then, the random-effects model was applied to the collect data set. A very often factor to be considered for choosing an approach is age. Subgroup analysis based on the age categorization (≥ 60 vs. < 60) was further conducted. The choice of surgical approaches between the age groups was compared using a X^2 test. Pooled risk ratios for each of the

Table 1 Characteristics of the 13 studies enrolled in meta-analysis

Reference	Country of study	Study design	Total sample size	Sample size for the two treatment groups	Follow-up time (months)	Mean age of study participants (years)	Post-operative complications
Andersson et al. [22]	Sweden	Retrospective	29	A:11(8)/P:7(7)	24–89	78	A: abandoned technique peroperative; loosening of screws; redisplacement; skin blister from collar; Local neck pain. P: cardiac failure
Ziai et al. [29]	Canada	Retrospective	93	A:13(13)/P:7(7)	3–96	57	Screw pull-out; loss of reduction
Kim et al. [25]	Korea	Retrospective	31	A:6(5)/P:10(10)	Average 25.19	39.3	Neurological deficits (one spinal cord contusion)
Mashhadinezhad et al. [27]	Iran	Retrospective	46	A:15(13)/P:31 (28)	9	33	Urinary tract infection
Platzer et al. [28]	Austria	Retrospective	56	A:37(33)/P:19(19)	12 and 24	71.4	Nonunion, incorrect reduction; secondary loss of reduction; malpositioning of implants; implant loosening and/or cut-out
Konieczny et al. [26]	Germany	Retrospective	69	A:13(10)/P:25(25)	Average 9.7	64.5	Death; neurological disorder; breakage of screws
Fujii et al. [24]	Japan	Retrospective	58	A:10(8)/P:7(7)	NA	64.5	Death; neurological disorder; breakage of screws
Chiba et al. [23]	Japan	Retrospective	104	A:45(40)/P:10(8)	NA	34	Nonunion; spinal cord symptoms
Sawarkar et al. [17]	Indian	Retrospective	142	A: 85(82) P: 57(55)	22	4–75	A: fixation failure, dysphagia; P: fixation failure, breakage of K wire
Andrei et al. [30]	United States	Retrospective	29	A:11(8)/P:7(8)	51	65	A: severe dysphagia and early pneumonia; P: blood loss, vertebral artery injury, infection, dural tears
Fagin et al. [31]	America	Retrospective	35	A:23(20)/P:12(10)	76	60	Post-operative edema; post-operative swelling
Guo et al. [32]	United States	Retrospective	40	A:19(20)/P:19(20)	Temporary Fixation Group (44.8 ± 26.0); Anterior Screw Fixation Group (42.5 ± 24.5)	Temporary Fixation Group (39.8 ± 12.1); Anterior Screw Fixation Group (38.8 ± 10.6)	Neck stiffness
Omreis et al. [33]	United States	Retrospective	29	A:15(16)/P:12(13)	3–24	70–94	Central cord syndrome; myocardial infarction

A: anterior screw fixation treatment, P: posterior C1–2 fixation treatment

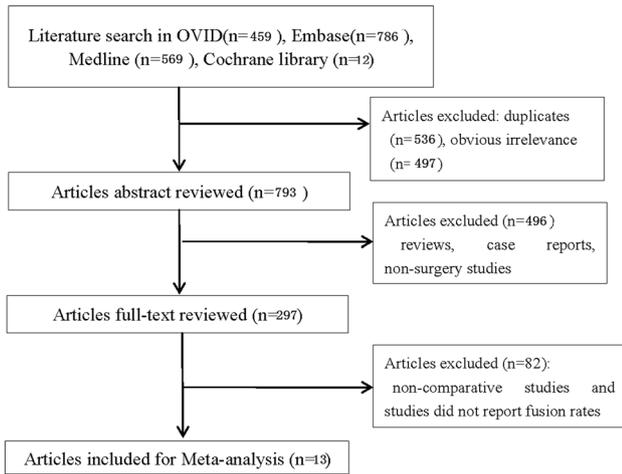


Fig. 1 Literature search and study selection

age groups were also calculated to assess the impact of age. In addition, subgroup analyses of economic growth were further performed. Publication bias was assessed by constructing funnel plots [20]. All statistical analyses were carried out by Revman 5.2.

Results

Study selection

The initial search identified 13 studies eligible for the meta-analysis, as Table 1 shown. The search results and process of selecting studies for the present study are shown in Fig. 1. Totally, 1826 publications were originally enrolled

after initial search by two reviewers independently (OVID: 459 studies, Embase: 786 studies, Medline: 569 studies, Cochrane library: 12 studies). A total of 1033 papers were excluded which were duplicates and reported unrelated topics. Then, 496 papers were further excluded from the remaining 793 publications because they were reviews, case reports, and non-surgery studies. After reviewing full-text of the remaining 297 articles, 284 studies were further excluded. Finally, 13 papers were included in this meta-analysis [16, 21–32].

Characteristics and quality of the enrolled studies

The basic information for the meta-analysis is shown in Table 1. The enrolled 13 studies included a total of 761 patients. The studies were conducted in various countries around the world, mostly in Europe and Asia. All studies used the fusion rate to measure the clinical outcome. A retrospective cohort study approach was the choice design for all of the studies. The follow-up time of the 13 studies ranged from 3 months to 8 years except for two papers which did not report the follow-up times [22, 23]. In a few of the studies, medical treatments were not limited to anterior screw fixation and posterior C1–C2 fixation. Other conservative treatments, such as cervical collars, halo-vest immobilization [21, 23–25, 28], and alternative surgical treatments [22] were also evaluated as a correctional treatment for odontoid fractures. We excluded other types of treatment in our analysis. The fusion rate of both treatment approaches, anterior screw fixation and posterior C1–C2 fixation, was a focus through the study. Additionally, the NOS scores of the included studies ranged from 7 to 9, indicating that the studies were high-quality researches.

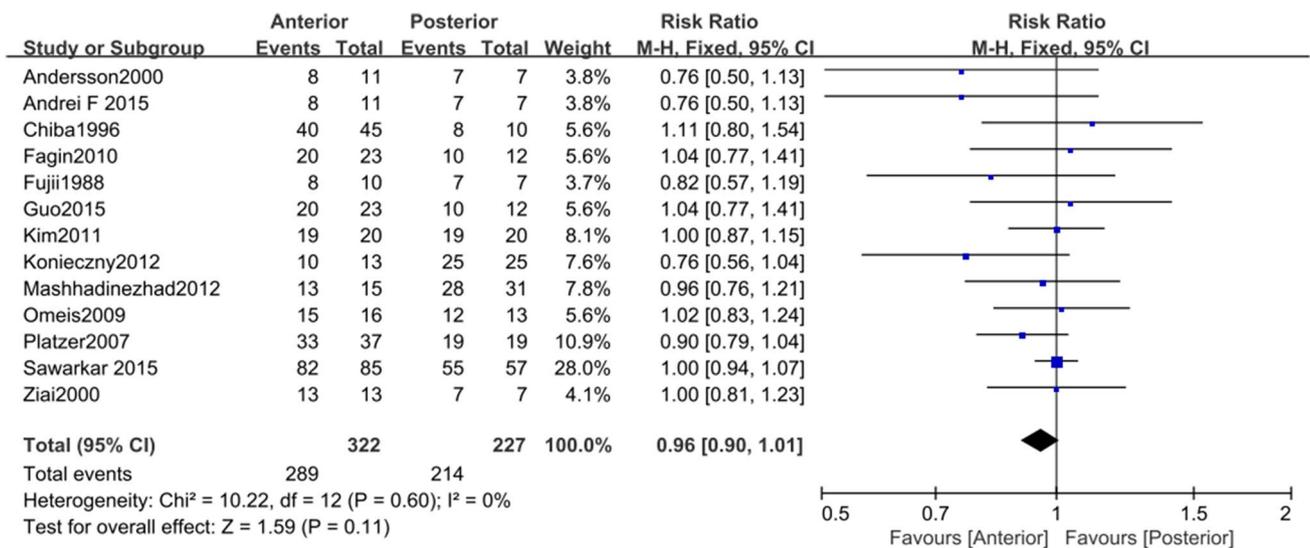


Fig. 2 Forrest plots for odds ratio of the fusion rate between anterior odontoid screw and posterior C1–2 arthrodesis

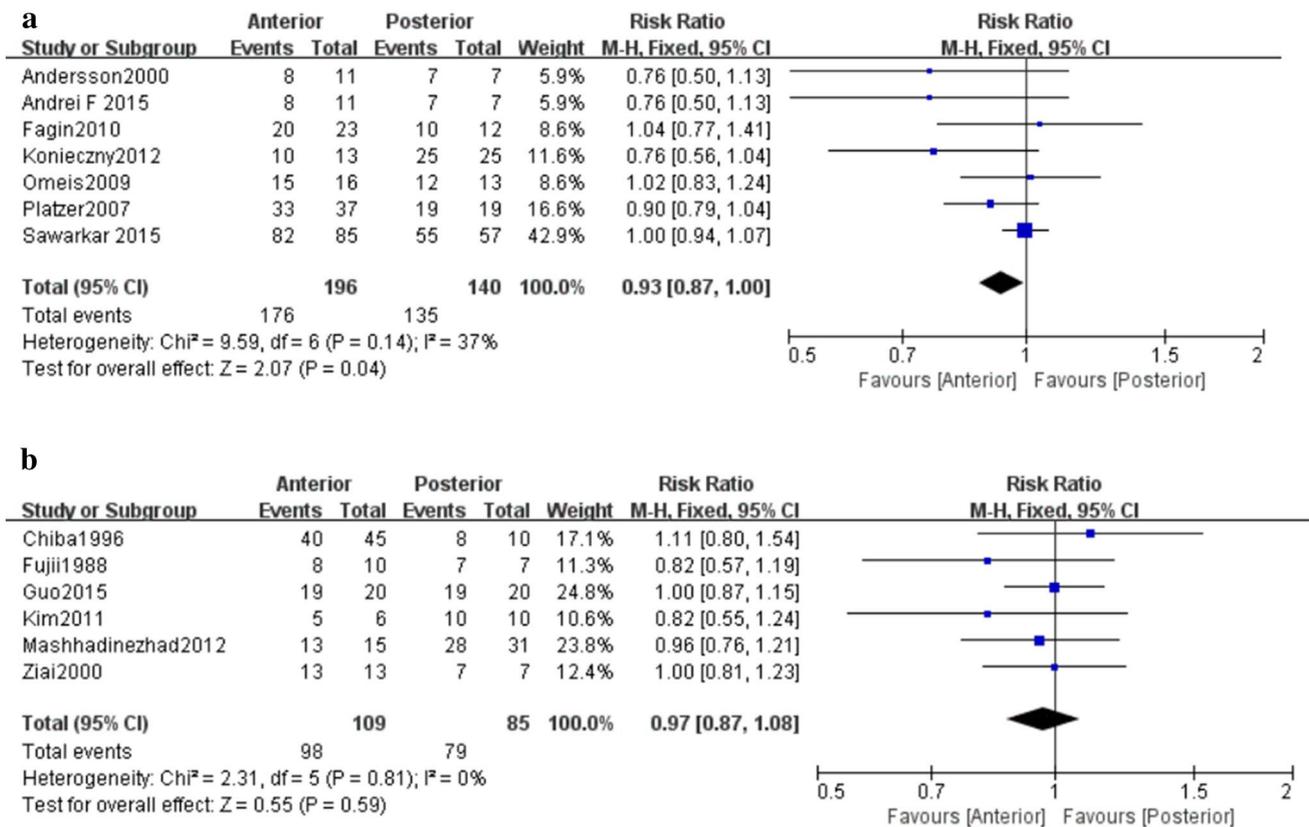


Fig. 3 Forrest plots for odds ratio of fusion based on patient age subgroup; **a** studies with mean age ≥ 60 ; **b** studies with mean age < 60

Meta-analysis on fusion rates after surgery

The forest plot on fusion rates evaluation between anterior and posterior C1–2 screw fixation procedures is shown in Fig. 2. Briefly, there were 322 patients who were subjected to anterior procedure and 227 patients underwent posterior treatment in all 13 selected studies. And the fusion rate was used for the measurement of clinical outcome. As shown in Fig. 2, by comparison, the fusion rate of both groups was similar without significant difference using the fixed-effect model (RR = 0.96, 95% CI 0.90–1.01). Moreover, there was no significant heterogeneity among individual studies ($I^2 = 0\%$, P value = 0.60).

To further assess the impact of age on the choice of surgical approach, we divided the included 13 studies into two groups based on the reported mean age of study participants. 336 patients from seven studies [21, 23, 25, 27, 29, 30, 32] were in the elderly group (mean age ≥ 60), while 194 patients from the other six studies [22–24, 26, 28, 31] were categorized as the younger age group (mean age < 60). Within the elderly group, 196 out of 336 patients underwent the anterior procedure, while 140 patients underwent the posterior procedure. For younger age group, 109 out of 194 patients were treated with anterior approach, and 85

patients with posterior approach. As Fig. 3a (RR = 0.93, 95% CI 0.87–1.00) and b (RR = 0.97, 95% CI 0.87–1.08) shown, there was no strong evidence to suggest an association between age and the choice of surgical approach.

Furthermore, we performed a subgroup analysis based on economic growth situation, as shown in Fig. 4. Ten articles were performed in developed countries [21–23, 25, 27–32] including 199 patients who underwent anterior C1–2 arthrodesis procedure and 127 patients who underwent posterior C1–2 arthrodesis procedure. A fixed-effect model was used for pooling RR; significant higher fusion rates were found in patients underwent posterior C1–2 procedure (RR = 0.93, 95% CI 0.85–1.00, Fig. 4c). However, as shown in Fig. 4d, in developing countries, 106 out of 204 patients underwent anterior C1–2 arthrodesis procedure and 98 patients underwent posterior C1–2 arthrodesis procedure. And no significant difference on fusion rates was found between the two surgical strategies (RR = 0.98, 95% CI 0.91–1.05).

Last, we conducted another subgroup analysis based on the age in a developed country. Result shown in Fig. 5 indicates that the protective effect of posterior C1–2 procedure on fusion remains significant in the elderly subgroup (for the fixed-effect model: RR = 0.88, 95% CI 0.79–0.98). However, the same effect is no longer significant in the younger

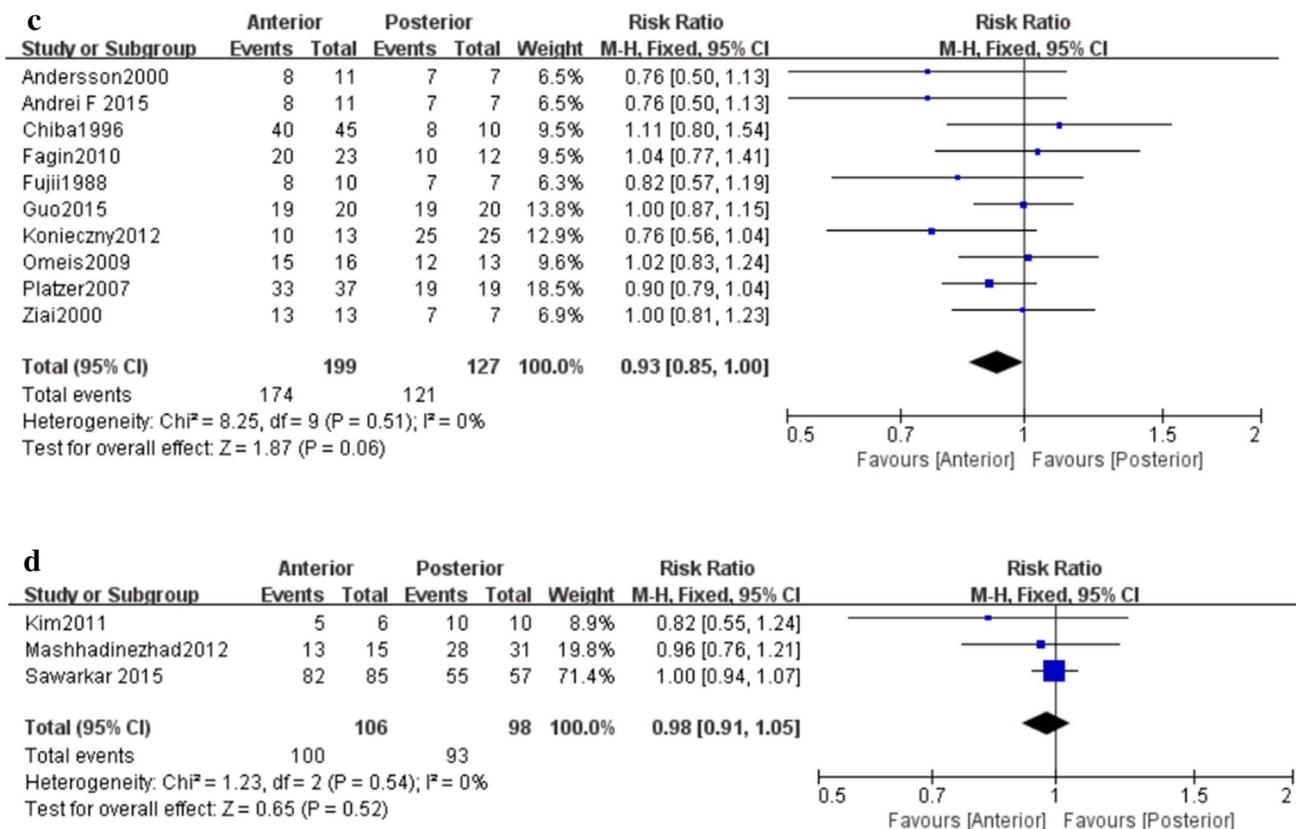


Fig. 4 Forrest plots for odds ratio of fusion based on national economic development. **c** Studies in developed countries. **d** Studies in developing countries

age subgroup (for the fixed-effect model: RR = 1.00, 95% CI 0.88–1.13).

Discussion

At the current stage, an optimal treatment modality for odontoid fracture is yet in place. Management options for odontoid fractures were divided into conservative treatment approach and surgical treatment. Conservative treatment approaches comprise cervical collar fixation and fixation of Halo frame. Various literature about the achievement rate of cervical collar-fixation is available [33, 34]. And Halo frame-related complications were observed with high non-union rate [35]. Especially for elderly patients, conservative external fixation treatment approaches should be carefully selected. And the surgical procedure for odontoid fractures remains comparatively effective and reliable.

However, in clinical works, the choice for optimal surgical procedure remains controversial because surgical intervention is associated with a variety of complications. And the surgical risk is increasing with age. It is reported that the incidence of post-operative complications for odontoid

fracture remains high at 62% [33] and post-operative mortality also reached almost 21% only 1 year after surgical operation for odontoid fracture [36]. Moreover, a study suggested that the fusion rate of posterior C1–C2 arthrodesis was only at 30.7%, and that of anterior odontoid screw remained at 37.5%. Most of the literature reports that the post-operative mortality of patients with odontoid fracture is high and nonunion is also high [37, 38]. However, a study suggested that the fusion rate of surgical procedure for odontoid fracture reaches 87% and conservative approach remains only 66% [39]. There are many important factors contributing to clinical outcome, such as the loosening of screws, redisplacement, local neck pain, cardiac failure, fracture stability, patient age, and degree of neurological deficit. Based on the current studies, no solid evidence on these factors exists to support either the anterior or the posterior approach. The purpose of this meta-analysis is to perform a systematic review on the most commonly available endpoint, fusion rate, to provide evidence-based recommendations on surgical choices for odontoid fracture in general practice. We do acknowledge that multiple factors including the fracture type, degree of injury, and the condition of the patient should still be considered when making surgical choices.

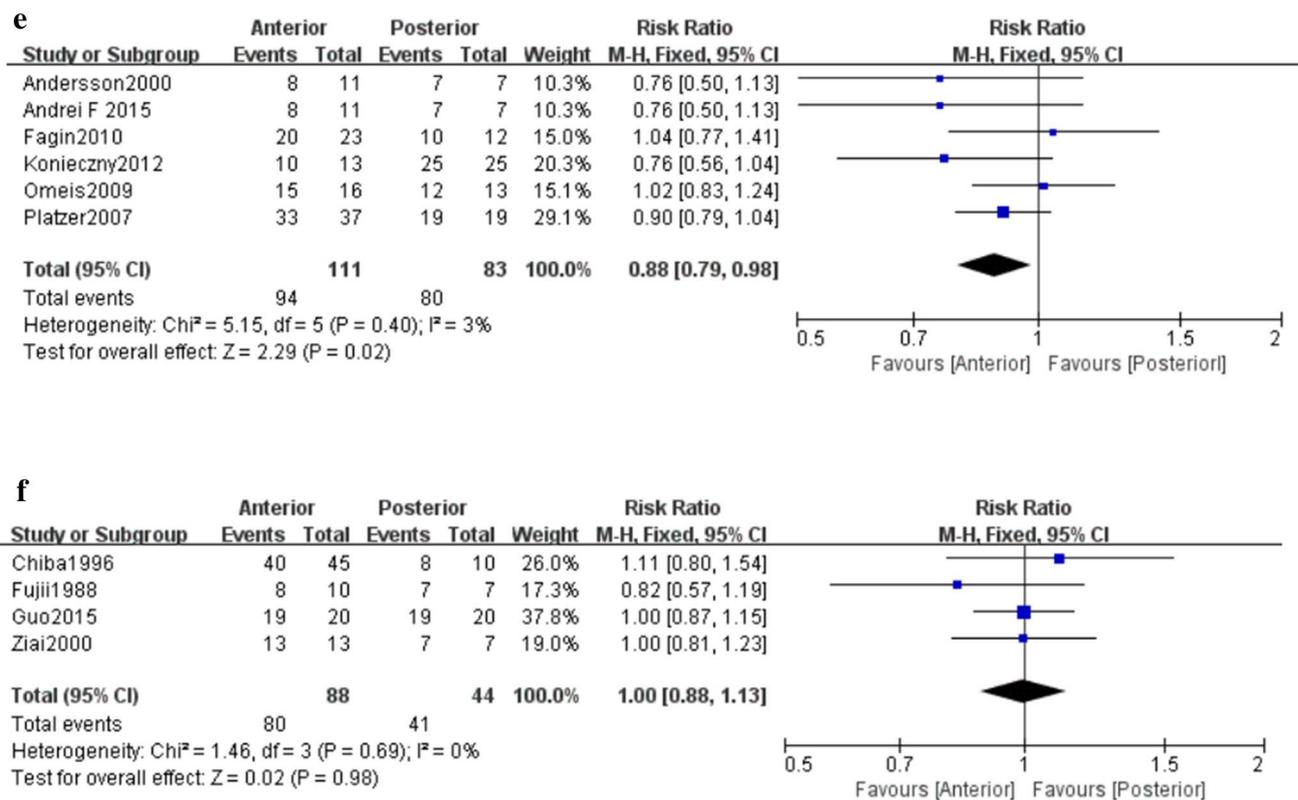


Fig. 5 Forrest plots for odds ratio of fusion based on patient age in developed countries; **e** studies with mean age ≥ 60 ; **f** studies with mean age < 60

Our meta-analysis focused on the fusion rate between the two surgical approaches. The studies included in this meta-analysis are all comparative analyses with fusion rate. Non-comparative studies were excluded from an overall assessment to control for selection bias. Fusion rates serving as an important clinical outcome were commonly reported in odontoid fracture studies. Based on the reported mean age of study participants, 13 studies were divided into the elderly group (mean age ≥ 60) and the younger age group (mean age < 60). However, there is no statistical evidence to suggest an association between the patient age and the choice of surgical approach in the enrolled sample. As to the subgroup of economic situation, there is also no statistically significant difference in fusion rate between the economic growth and the choices of surgical approaches. However, significant higher fusion rates were found in patients (≥ 60), who had ever underwent posterior C1–C2 arthrodesis approach screw fixation in developed countries.

Many clinical and radiological factors should be taken into account when choosing the best surgical approach. Previously, anterior odontoid screws are expected to obtain advantages compared with posterior procedures. However, the treatment comes with a high complication rate in previous reports. Moreover, arguments for the posterior approach always exist, such

as its few complications, high success rate and the relative tolerance of the resulting limitation among elderly patients [40, 41]. Additionally, the protection of posterior C1–2 procedure on fusion for old patients was supported by previous studies [21, 42]. With regard to patients in developed countries, especially for older patients, posterior cervical instrumented fusion seems to be a better choice relative to anterior odontoid screw fixation when we took fusion rates into consideration. It is probably because the technology of posterior C1–2 procedure has become maturer and more standardized in developed country, thus higher fusion rate was more likely to be achieved for old patients. What's more, the developed countries enjoy relatively high living standards, and good physical fitness of old people may also be a contributing factor for higher fusion rate.

The meta-analysis results should be cautiously interpreted due to some limitations. First, many confounding factors such as bone quality and location of the fracture line might contribute to the choice of surgical strategy. However, due to limited number of comparative studies, fusion rates were the only major outcome considered in this study. Thus, further study is necessary by enrolling a large number of high-quality studies. Second, the success rate of treatment for odontoid fractures is based on a variety factors, including age, surgeons' experience and patient's self-assessment. Most confounding factors

cannot be fully controlled in this meta-analysis. Third, only retrospective studies are included and there is indeed a lack of prospective studies. Finally, the different lasting of follow-up time in enrolled studies may influence the observed results.

Conclusion

In summary, results from this meta-analysis demonstrate the protection role of posterior C1–2 arthrodesis fixation on fusion rates in developed countries comparing patients who underwent anterior odontoid screw fixation. However, the conclusion should be verified by further study enrolling larger sample size.

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Author contributions LB and CJ contribute equally to the paper. They together designed the research. LB analysed the data and prepared the typescript. CJ revised the manuscript. The other authors provided the subject data. Both two authors read and approved the final manuscript.

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Data availability All data are fully available without restriction.

Compliance with ethical standards

Conflict of interest We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work; there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, “*Fusion rates for odontoid fractures after treatment by anterior odontoid screw versus posterior C1–C2 arthrodesis: A meta-analysis*”.

Ethical approval The study was approved by the Medical Ethics Committee of Tian Jin 4th Center Hospital, Tianjin, China.

Consent to publish All authors Li Baogui and Chen Juwen of this paper “*Fusion rates for odontoid fractures after treatment by anterior odontoid screw versus posterior C1–C2 arthrodesis: A meta-analysis*” consent to publish on *BMC Musculoskeletal Disorders* once it is accepted.

References

- Chutkan NB, King AG, Harris MB (1997) Odontoid fractures: evaluation and management. *J Am Acad Orthop Surg* 5(4):199
- Maak TG, Grauer JN (2006) The contemporary treatment of odontoid injuries. *Spine* 31(11 Suppl):S53
- Bohlman HH (1979) Acute fractures and dislocations of the cervical spine. An analysis of three hundred hospitalized patients and review of the literature. *J Bone Jt Surg Am Vol* 61(8):1119–1142
- Clark CR (1985) Fractures of the dens. A multicenter study. *J Bone Jt Surg Am Vol* 67(9):1340–1348
- Song KJ, Lee KB, Kim KN (2007) Treatment of odontoid fractures with single anterior screw fixation. *J Clin Neurosci* 14(9):824–830
- Graziano G, Jaggars C, Lee M, Lynch W (1993) A comparative study of fixation techniques for type II fractures of the odontoid process. *Spine* 18(16):2383–2387
- Lee SH, Sung JK (2006) Anterior odontoid fixation using a 4.5-mm Herbert screw: the first report of 20 consecutive cases with odontoid fracture. *Surg Neurol* 66(4):361
- Hou Y, Yuan W, Wang X (2011) Clinical evaluation of anterior screw fixation for elderly patients with type II odontoid fractures. *J Spinal Disord Tech* 24(8):E75
- Smith HE, Vaccaro AR, Maltenfort M, Albert TJ, Hilibrand AS, Anderson DG, Harrop J, Fehlings MG, Kopjar B, Brodke DS (2008) Trends in surgical management for type II odontoid fracture: 20 years of experience at a regional spinal cord injury center. *Orthopedics* 31(7):650–650
- Ni B, Guo Q, Lu X, Xie N, Wang L, Guo X, Chen F (2015) Posterior reduction and temporary fixation for odontoid fracture—a salvage maneuver to anterior screw fixation. *Spine* 40(3):168–174
- Grob D, Jeanneret B, Aebi M, Markwalder TM (1991) Atlantoaxial fusion with transarticular screw fixation. *J Bone Jt Surg Br Vol* 73(6):972–976
- Elsaghir H, Böhm H (2000) Anderson type II fracture of the odontoid process: results of anterior screw fixation. *J Spinal Disord* 13(6):527–530
- Ochoa G (2005) Surgical management of odontoid fractures. *Inj Int J Care Inj* 36(2):S54–S64
- Polin RS, Szabo T, Bogaev CA, Replogle RE, Jane JA (1996) Nonoperative management of Types II and III odontoid fractures: the Philadelphia collar versus the halo vest. *Neurosurgery* 38(3):456–457
- Shen Y, Miao J, Li C, Fang L, Cao S, Zhang M, Yan J, Kuang Y (2015) A meta-analysis of the fusion rate from surgical treatment for odontoid fractures: anterior odontoid screw versus posterior C1–C2 arthrodesis. *Eur Spine J* 24(8):1649–1657
- Sawarkar DP, Singh PK, Siddique SA, Agrawal D, Satyarthee GD, Gupta DK, Sinha S, Kale SS, Sharma BS (2015) Surgical management of odontoid fractures at level one trauma center: a single-center series of 142 cases. *Neurol India* 63(1):40–48
- Wells GA, Shea BJ, O’Connell D, Peterson J, Welch V, Losos M, Tugwell P (2014) The Newcastle–Ottawa Scale (NOS) for assessing the quality of non-randomized studies in meta-analysis. *Appl Eng Agric* 18(6):págs. 727–734
- Higgins JP, Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. *Stat Med* 21(11):1539
- Higgins JP, Thompson SG, Deeks JJ, Altman DG (2003) Measuring inconsistency in meta-analyses. *BMJ* 327(7414):557–560
- Sterne JAC, Egger M (2001) Funnel plots for detecting bias in meta-analysis: guidelines on choice of axis. *J Clin Epidemiol* 54(10):1046–1055
- Andersson S, Rodrigues M, Olerud C (2000) Odontoid fractures: high complication rate associated with anterior screw fixation in the elderly. *European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical. Spine Res Soc* 9(1):56
- Chiba K, Fujimura Y, Toyama Y, Fujii E, Nakanishi T, Hirabayashi K (1996) Treatment protocol for fractures of the odontoid process. *J Spinal Disord* 9(4):267
- Fujii E, Kobayashi K, Hirabayashi K (1988) Treatment in fractures of the odontoid process. *Spine* 13(6):604–609
- Kim SK, Shin JJ, Kim TH, Shin HS, Hwang YS, Park SK (2011) Clinical outcomes of halo-vest immobilization and surgical fusion of odontoid fractures. *J Korean Neurosurg Soc* 50(1):17–22

25. Konieczny MR, Gstrein A, Müller EJ (2012) Treatment algorithm for dens fractures: non-halo immobilization, anterior screw fixation, or posterior transarticular C1–C2 fixation. *J Bone Jt Surg Am* Vol 94(19):e144(141)
26. Mashhadinezhad H, Samini F, Mashhadinezhad A, Birjandinejad A (2012) Clinical results of surgical management in type II odontoid fracture: a preliminary report. *Turk Neurosurg* 22(5):583–587
27. Platzer P, Thalhammer G, Oberleitner G, Schuster R, Vécsei V, Gaebler C (2007) Surgical treatment of dens fractures in elderly patients. *J Bone Jt Surg Am* Vol 89(8):1716–1722
28. Ziai W, Hurlbert R (2000) A six year review of odontoid fractures: the emerging role of surgical intervention. *Can J Neurol Sci* 27(4):297–301
29. Joaquim AF, Patel AA (2015) Surgical treatment of type II odontoid fractures: anterior odontoid screw fixation or posterior cervical instrumented fusion? *Neurosurg Focus* 38(4):E11
30. Fagin AM, Cipolle MD, Barraco RD, Eid S, Li PM, Pasquale MD (2010) Odontoid fractures in the elderly: should we operate? *J Trauma* 68(3):583
31. Guo Q, Zhang M, Wang L, Lu X, Guo X, Ni B (2015) Comparison of atlantoaxial rotation and functional outcomes of two non-fusion techniques in the treatment of Anderson-D’Alonzo type II odontoid fractures. *Spine* 41:1
32. Omeis I, Duggal N, Rubano J, Cerabona F, Abrahams J, Fink M, Das K (2009) Surgical treatment of C2 fractures in the elderly: a multicenter retrospective analysis. *Spine J* 22(2):91–95
33. Smith HE, Kerr SM, Maltenfort M, Chaudhry S, Norton R, Albert TJ, Harrop J, Hilibrand AS, Anderson DG, Kopjar B (2008) Early complications of surgical versus conservative treatment of isolated type II odontoid fractures in octogenarians: a retrospective cohort study. *J Spinal Disord Tech* 21(8):535–539
34. Platzer P, Thalhammer G, Sarahrudi K, Kovar F, Vekszler G, Vécsei V, Gaebler C (2007) Nonoperative management of odontoid fractures using a halothoracic vest. *Neurosurgery* 61(3):522–529
35. Th KC, Mirza SK, Jarell AD, Chapman JR, Shaffrey CI, Newell DW (2000) Type II odontoid fractures in the elderly: early failure of nonsurgical treatment. *Neurosurg Focus* 8(6):e7
36. Schoenfeld AJ, Bono CM, Reichmann WM, Warholc N, Wood KB, Losina E, Katz JN, Harris MB (2011) Type II odontoid fractures of the cervical spine: do treatment type and medical comorbidities affect mortality in elderly patients? *Spine* 36(11):879
37. Platzer P, Thalhammer G, Ostermann R, Wieland T, Vécsei V, Gaebler C (2007) Anterior screw fixation of odontoid fractures comparing younger and elderly patients. *Spine* 32(16):1714–1720
38. Aldrian S, Erhart J, Schuster R, Wernhart S, Domaszewski F, Ostermann R, Widhalm H, Platzer P (2012) Surgical vs nonoperative treatment of Hadley type IIA odontoid fractures. *Neurosurgery* 70(3):676
39. Chaudhary A, Drew B, Orr RD, Farrokhyar F (2010) Management of type II odontoid fractures in the geriatric population: outcome of treatment in a rigid cervical orthosis. *J Spinal Disord Tech* 23(5):317
40. Pepin JW, Bourne RB, Hawkins RJ (1985) Odontoid fractures, with special reference to the elderly patient. *Clin Orthop Relat Res* 193(193):178
41. Bednar DA, Parikh J, Hummel J (1995) Management of type II odontoid process fractures in geriatric patients; a prospective study of sequential cohorts with attention to survivorship. *J Spinal Disord* 8(2):166–169
42. Seybold EA, Bayley JC (1998) Functional outcome of surgically and conservatively managed dens fractures. *Spine* 23(17):1837–1845

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