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# Conservative versus surgical treatment for odontoid fracture: Is the surgical treatment harmful? Systematic review and meta-analysis

## *Surgery or orthosis for odontoid fracture*

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## Abstract

**Background:** Odontoid fracture is a common injury especially in elderly people. Despite some recent studies arguing in favor of surgery, the best treatment is still being debated.

**Objective:** Here we systematically review and analyze the comparative literature between surgical and conservative treatments of odontoid fractures.

**Method:** We systematically searched Medline and Cochrane library for studies published from January 1990 to May 2019 in English language. Comparative studies evaluating the results of surgical and conservative treatments for odontoid fractures were eligible for inclusion. Combined relative risks (RR) for mortality at last follow-up, union or non-union rates, and complications were calculated. Methodological quality was assessed using the Newcastle-Ottawa scale. Influence of age, year of publication on treatment effect was explored using a meta-regression analysis.

**Results:** A total of 1438 articles were identified, of which 30 articles with 2463 patients were eligible for inclusion. There was a trend toward lower mortality in the surgical group (RR: 0.80; CI: 0.63-1.02). Non-union rates (RR: 0.41; CI: 0.28-0.6) were lower in the surgical group. Union rates were higher in the surgical group (RR: 1.26; CI: 1.11-1.45). No significant influence of age or year of publication on treatment effect was found.

**Conclusion:** Based on this meta-analysis of non-randomized comparative studies, surgical treatment seems not to be inferior to conservative treatments. The conclusions of this study remain limited by the low quality of the evidence currently available. Randomized controlled studies are required.

## Introduction:

The odontoid process is a bony structure projecting from the second cervical vertebra (C2). Because of its bone structure and biomechanical functions, it is the site of one of the most common cervical fracture: odontoid fracture accounts for up to 15% of the cervical spine injuries and its incidence increases with population ageing <sup>1,2</sup>. Anderson and D'alonzo proposed a classification of odontoid fractures <sup>3</sup>: Type I involves the apex of the odontoid peg and is often considered as stable and treated with cervical orthosis<sup>4,5</sup>; Type II involves the base of the dens; and Type III implicates the odontoid and the lateral mass of C2. These fractures can occur in young patients in case of high-kinetic traumatism, but often affect the ageing population, following minor trauma. Of the three types, type II fractures are associated with a high risk of nonunion due to the weaknesses of blood supply and bone density associated to the high amount of biomechanical constraints in the dens. <sup>6,7</sup>

Two major kinds of management have been presented to treat odontoid fractures. On the one hand, the conservative treatment consists in immobilizing the neck with an external orthosis. This treatment can be performed with either a halo-vest, or a kind of cervical collar <sup>8,9</sup>. On the other hand, the surgical treatment aims to stabilize the fracture using screws and rods through an anterior or a posterior approach <sup>6</sup>. As the condition usually arises among fragile patients, the treatment of choice has long been the conservative treatment, using some external immobilization devices. It constitutes an easy and minimally invasive treatment. Nevertheless, several studies have highlighted a non-negligible rate of delayed complications associated with the conservative treatment, especially respiratory and cutaneous <sup>8,10</sup>. Immobilizing the neck with an orthosis using a conservative treatment in such cases could be falsely reassuring. Meanwhile, the improvement of surgical procedures in elderly patients and the development of new techniques have resulted in

a huge increase of surgeries for this indication. Some authors argue in favor of a reduced mortality<sup>11,12</sup>.

Despite a large interest among spine surgeons and a broad panel of treatments reported, the best management remains under debate, especially because of the variability of described results of each treatment. To date, no systematic study has been conducted to determine the optimal treatment in such cases<sup>7,13,14</sup>. Moreover, some recent meta-analyses about this topic are already of low value because of newer published relevant studies, or because of excessively restrictive inclusion criteria. Here we propose to systematically review and analyze the available literature and to summarize the results of the studies comparing surgical and conservative treatments of odontoid fractures for both efficacy and security endpoints. All comparative studies are considered (randomized or non-randomized, prospective or retrospective studies).

## Material and Methods:

### Search strategy

Literature searches were conducted in MEDLINE and Cochrane Collaboration Library from January 1990 to January 2019. The following search terms were used for the procedure (1) “Fracture OR Injury”, (2) “C2 or Axis” and (3) “Odontoid or Dens”. Only english-language studies were reviewed. An extensive search among cited bibliographies was also performed.

Two reviewers independently reviewed titles and abstracts of the publications. Subsequently, the full-text of studies that potentially met the inclusion criteria were read to determine the papers to be included. In the event of discrepancies between the reviewers, disagreements were resolved by discussion. No review protocol was registered.

## Inclusion and exclusion criteria

The following inclusion criteria were applied. Search studies focused on comparison of conservative and surgical treatment of acute odontoid fracture. It included randomized controlled studies, prospective or retrospective comparative cohort studies. Only adult samples were enrolled and studies should have reported information about mortality, union or pseudarthrosis rates, or complications.

The following exclusion criteria were applied. Studies with less than 10 cases reported. Review or meta-analysis publications. Studies assessing congenital abnormalities or pathological fractures.

## Data extraction and quality analysis

Two of the authors independently extracted the relevant data from each selected full-text using a standardized form. In the event of discrepancies between the reviewers, a consensus was reached by discussion. The following information were collected: authors, year of publication, study design, total sample size, sample size for each group, follow-up time, mean age and gender for each group, post-operative procedural and medical complications, pseudarthrosis rate, mortality rate.

Methodological quality of the randomized studies was assessed using the Cochrane tool. Methodological quality of non-randomized studies was assessed using the Newcastle-Ottawa Scale (NOS)<sup>15</sup>. This scale assesses the quality of non-randomized studies for meta-analyses with a maximum of 9 points. It includes 3 categories comprising 4 points for selection of the study groups, 2 points for the comparability and 3 points for ascertainment of the outcome of interest. All these variables are indicated in table 1.

## Statistical analysis

The summary statistics for the effect size of surgical treatment compared with conservative treatment were generated using a random-effect model and a relative risk (RR) with the corresponding 95% confidence intervals (95% CIs). Weighted incidences were also assessed. We explored the publication bias of the studies included in the final analysis using Begg's funnel plot.

For each meta-analysis, statistical heterogeneity among studies was explored using Cochrane's  $Q$  statistic, study consistency being quantified by means of the  $I^2$  statistic. In the event of significant heterogeneity ( $P$ -value  $<0.10$ ) with no clear explanation for this, a random-effect model was used for data analysis.

A  $P$ -value for the association  $<0.05$  was considered statistically significant. Combined effect estimates were calculated globally, and according to the study design. Interaction was systematically tested for retrospective and prospective studies and was considered as significant at  $p < 0.05$ . The results of the meta-analysis are presented graphically, including the effect size expressed as RR with the corresponding 95% CI. An RR equal to 1 indicates no difference between the treatments, of  $<1$  indicates that Surgery is better and of  $>1$  indicates that conservative treatment is better except for the fracture healing analysis. Influence of age and year of publication on treatment effect were investigated using a meta-regression analysis.

All statistical analyses were performed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria), version 3.3.1 with the meta-packages (version 4.7).

## Results

### Study selection

The initial search retrieved 1457 publications (Medline = 1438; Cochrane library = 16; Other sources = 3). 1313 duplicates and publications unrelated to the topic were excluded through title and abstract screening. Among the remaining 142 articles, 112 studies were excluded because of their specifications (Fig. 1). 30 papers were finally included in the study as shown in table 1<sup>11,12,16-43</sup>.

### Enrolled studies

The baseline characteristics of the included studies are shown in table 1. The enrolled 30 studies included a total of 2470 patients. There was no randomized controlled study. All included studies were cohort studies. 4 were prospective and 26 retrospective. The individual samples ranged from 19 to 322. On the one hand, a total of 1037 patients were treated surgically: 324 underwent an anterior and 334 a posterior surgery. The kind of surgery was unspecified for 379 patients. On the other hand, 1426 were treated in a conservative manner: 843 were treated with an orthosis and 368 with a halo-vest. The kind of conservative treatment was unspecified for 215 patients.

The mean follow-up time was 22.3 months (range = 0.3-60 months). 2 studies<sup>19,40</sup> were limited to the in-hospital period with restricted follow-up. The mean age was 72.9 years (+/- 12.3).

The mean NOS score was 4.97 (range 4-7), in favor of moderate quality studies.



## Mortality

26 studies reported mortality at different end-points (Fig. 2). The pooled results showed that last follow-up mortality rates were not significantly different, though there was a tendency toward a lower mortality in the surgical group (RR: 0.80; CI: 0.63-1.02)(Fig. 2). There was significant heterogeneity ( $I^2=30\%$ ,  $\tau^2=0.0892$ ,  $p=0.07$ ).

The mortality rates at 3 and 12 months were reported in 9 studies. At 3 months the weighted mortality incidences were 6% (CI: 6-10) and 12% (CI: 8-17) for surgical and conservative treatment. There was no significant difference, (RR: 1.13; CI: 0.52-2.48). At 12 months, the weighted mortality incidences were 14% (CI: 8-20) and 18% (CI: 12-26). There was still no significant difference (RR: 0.96; CI: 0.62-1.48). A funnel plot to detect publication bias is provided in the appendix. No significant influence of age or year of publication on treatment effect was observed (digital supplementary content).

## Union / Non-union

20 studies reported non-union rates (Fig 3.A). The pooled results were in favor of a lower non-union rate in the surgical group (RR: 0.41; CI: 0.28-0.6). There was significant heterogeneity ( $I^2=45\%$ ,  $\tau^2=0.2526$ ,  $p=0.02$ )(Fig. 3). Among these studies, the weighted incidences of non-union were 9% (CI: 6-14) and 30% (CI: 23-38) for surgical and conservative treatments.

16 studies reported union rates (Fig 3.B). The pooled results were in favor of a higher fracture-healing rate in the surgical group (RR: 1.26; CI: 1.11-1.45). There was significant heterogeneity ( $I^2=65\%$ ,  $\tau^2=0.0324$ ,  $p<0.01$ ). Among these studies, the weighted incidences of fracture union were 81% (CI: 74-87) and 53% (CI: 43-68) for surgical and conservative

treatments. Funnel plots to detect publication bias are provided in the digital supplementary content. Funnel plots for both union and non-union rates were asymmetrical with a lack of low power studies in favor of conservative treatment. Existence of a publication bias cannot be excluded. No significant influence of age or year of publication on treatment effect was observed (digital supplementary content).

## Complications

9 studies reported systemic complications. The pooled results showed a higher systemic complication rate in the surgical group (RR: 1.43; CI: 1.02-1.99). There was a significant heterogeneity ( $I^2=42\%$ ,  $\tau^2=0.0940$ ,  $p=0.09$ ).

13 studies reported procedural complications (i.e. attributable to treatment). The pooled results showed that patients had less procedural complications in the surgical group (RR: 0.71; CI: 0.53-0.95). There was no significant heterogeneity ( $I^2=37\%$ ,  $\tau^2=0.1981$ ,  $p=0.08$ ).

15 studies reported the rate of secondary surgery (i.e. because of first treatment failure). The pooled results showed a tendency for patients in the surgical group to be less at risk for secondary surgery (RR: 0.57; CI: 0.24-1.35). There was significant heterogeneity ( $I^2=61\%$ ,  $\tau^2=1.5610$ ,  $p<0.01$ ).

## Discussion

Odontoid fractures represent up to 15% of all cervical spine fractures <sup>1,2</sup> and Type II odontoid fractures are the most common fractures of the cervical spine in people aged 70 years or older. As the population is ageing, the incidence of these fractures is likely to continue increasing <sup>44</sup>. The best treatment of this condition remains unclear, especially in geriatric patients, because of comorbidities, poor bone quality and impaired physiological reserves. Treatment options for odontoid fractures are either conservative or surgical. Surgical options include mainly anterior odontoid screw fixation and posterior atlantoaxial arthrodesis <sup>45</sup>. Nonsurgical management techniques mostly consist of cervical orthosis and halo-vest <sup>46</sup>. Although conservative treatment was preferred in the 1990's, surgery has become more prominent in the last two decades. This might reduce mortality and increase rates of fusion <sup>11,12</sup>. However, the treatment decision remains highly dependent on patient and institutional factors, leading to heterogeneous treatment strategies.

Although geriatric patients generally sustain odontoid fracture without neurological damage, several prior studies have documented important morbidity and 1-year mortality, independent of management strategy. Odontoid fracture is indeed associated with in-hospital death of more than 10% <sup>47</sup> and reported 1-year mortality rates that can reach more than 20% <sup>11,48</sup>. Long-term mortality rates can be even worse with more than 40% related <sup>49</sup>. Recent and valuable studies suggested that surgical treatment could reduce this mortality <sup>7,11,12</sup>. For example, Chapman and al <sup>11</sup> compared 157 patients treated non operatively and 165 patients treated operatively. The 30-days and maximal follow-up mortality were 14% and 44%, respectively. The surgically treated patients had respective 30-day and 12- month follow-up

mortality rates of 7% and 38%, compared to 22% and 57% with conservative treatment. After adjusting for the effects of patient age, sex, and Charlson comorbidity index, the results suggested that surgical treatment of type II odontoid fracture in this elderly population did not negatively impact survival, and, that operative treatment might be associated with a significant better 30-day survival rate compared with non-operatively treated patients. Consistent with this study and some previous meta-analysis using different inclusion criteria <sup>7,14</sup>, our meta-analysis shows no increased mortality at last follow-up in the surgical group. There was even a trend toward reduced mortality rate with surgery. Nevertheless, the paucity of data concerning the comparability of surgical and non-surgical groups constitutes one of the major sources of biases of this work. As a matter of fact, the studies offer moderate to poor proof-level with no controlled trial, which makes these conclusions of limited value because of a high risk of bias. Moreover, some studies have pointed out the influence of the old age on these results. It seems that the surgery loses its protector effect for patients 80 years old or older. For example, Schoenfeld et al. <sup>37</sup> compared 112 non operatively treated with 44 operatively treated type II odontoid fractures in elderly patients. This study suggested that surgical treatment was associated with reduced mortality for patients aged from 65 to 74. After 75, this association decreased and the survival curves nearly coincided for patients aged 85 and older. Other studies<sup>26,40</sup> did not consider the benefits of surgery after 80. In our study, the heterogeneity and the quality of studies prevent us from drawing any conclusions regarding a specific age subclasses.

Data about mortality is closely linked to morbidity. Surgical treatment in frail patients is also associated with major complication rates, especially in octogenarians. Some authors suggest that conservative treatment may be more adequate in elderly people, despite a high rate of non-union. Others recommend surgical stabilization, because of the risk of residual C1–C2 instability that may cause pain and late myelopathy<sup>3,27,28,50</sup>. Conservative treatments reported in the

literature were not uniform and ranged from soft collars to halo-devices. In elderly patients, halo-vest seems to be inappropriate because of significant pain, psychological distress, complications, associated to a limited fusion rate<sup>10</sup>. The morbidity rates associated with halo-vest treatment seem comparable or worse than those with surgical treatment<sup>19,28</sup>. The major complications reported for the halo-vest include acute respiratory distress syndrome (ARDS) and pneumonia, dysphagia, pins failure and infection. Previous publications also suggested that, from a biomechanical standpoint, immobilization with a Philadelphia cervical collar is equivalent to halo-vest immobilization for stable fractures of the dens<sup>29,51</sup>. Because of all these reasons, cervical orthosis may be preferred to a halo-vest. .

Complications rates are also high in the surgical group, which is consistent with the literature. Medical complications are comparable those found with the halo-vest (i.e., ARDS, Pneumonia, Decubitus ulcer, dysphagia). However, we found significantly fewer procedural complications in the surgical group, and we noted a trend toward less revision surgery. Neurological complications and delayed myelopathy remain rare in both cases<sup>34,52,53</sup>. Our conclusions remain limited by the heterogeneity of the included records, as the complications types and rates are different between anterior and posterior surgery. Mechanical complications are more common after anterior surgery in elderly patients, with more frequent revision surgeries (between 3.6 and 13.6%) compared to posterior fusion<sup>54-56</sup>. This is likely due to poor bone quality for this group of patients. According to this, the recommended approach could be to favor surgical treatment as much as possible, especially for patients of age 80 or younger. In case of surgery, anterior screwing would be recommenced for young patients, with the aim of preserving motion as this technique can provide good results through a rapid intervention. In elderly people, posterior fusion would be favored to limit the risk of biomechanical failure, dysphagia and pulmonary complications. Moreover, similarly to what has been proposed for hip fractures, these

patients should be managed in a multidisciplinary way, in collaboration with geriatric specialists, to decrease perioperative morbidity.<sup>57,58</sup>

The last parameter studied was fracture union, which has often been considered as the main goal of these treatments. Because of its limited vascular supply, its cortical nature, and the age of occurrence, odontoid fracture pseudarthrosis is a frequent condition<sup>59-61</sup>. Bone quality and degree of displacement are predisposing factors. The non-union rate in the elderly is high, ranging between 20 and 85%<sup>27,33,62</sup>. It is found to be especially high in the case of conservative management and more limited for surgical treatment. For example, Di Paolo et al.<sup>20</sup> reported 91.7% of fusion with surgical treatment, compared to 46.7% with conservative treatment. Once again, our data seems consistent with this information, as we report strongly inferior rates of pseudarthrosis and superior rates of fusion in the surgical group. It is important to note that we separated “union” and “non-union” parameters as the provided data varied among studies, including for deceased or lost-to-follow-up patients. These data are probably heterogeneous because of the variety of techniques used. Concerning conservative treatments, more and more studies are in favor of the use of a collar instead of a halo-vest<sup>29,46,51</sup>. However, collars provide the same amount of fusion without comorbidities. That seems different for surgical treatment with no clear evidence, although the data seems to suggest slightly increased union rates using posterior fusion<sup>45</sup>.

As mentioned above, bony union has long been considered as the main goal to achieve. While this aim remains unchanged for young patients, things have changed for elderly patients. The main ambition is now to keep patients mobile and promote respiratory function and mental health. To this aim, achieving fracture stability with only fibrous union can be sufficient<sup>59,60</sup>. In fact, non-union does not systematically result in instability, and neurological consequences are very rare<sup>59</sup>. Some authors underlined the potential risk of delayed myelopathy as an unequivocal

surgical indication. But studies showed that delayed myelopathy rarely occurs<sup>3,27,28,50</sup>. Furthermore, in rare cases delayed myelopathy has been observed after type II odontoid fractures, occurrence could be many years, frequently a decade or more, after the injury. This is far beyond the lifespan of the majority of older patients who sustain such an injury. The persistence of neck pain and instability on dynamic radiographs constitute clues that can indicate a real instability, which can lead to a new treatment. Our results are coherent with that, showing a tendency toward delaying surgery if necessary after initial conservative treatment. This parameter has rarely been assessed, leaving our study unconfirmed on this point. The data collected argue in favor of focusing on symptomatic non-union rather than radiological non-union, especially in the elderly. These are not that frequent in the non-surgical group and even rarer in the surgical group, where pseudarthrosis is stabilized by the osteosynthesis

Because of a bigger heterogeneity of the data, and to limit the risk of methodological bias, we deliberately chose to exclude non-comparative studies. This parameter can probably dilute the information. Nonetheless our study is, to our knowledge, the biggest to date, summarizing data of 30 previous studies comparing surgical and non-surgical treatment of odontoid fractures. None of these studies can be considered as high-level proof and a huge heterogeneity among samples and kind of treatments used should be noted. For instance, mortality data mainly driven by the only few studies that could be included because of their weight in the analysis. We tried to limit this issue by using a random effect model, but these characteristics make the study at high risk of bias. Therefore, these records should be interpreted with caution. Though, it provides data in agreement with previously published records: surgical treatment of odontoid fracture is not riskier than conservative treatment and seems to provide better results in term of fracture union. Some of our results, such as the complications rates, suggest that surgical treatment is slightly harder to tolerate in the initial phase but is probably more efficient on the long-term, as shown by

293 mortality and fusion rates. All these results should be confirmed with a controlled randomized  
294 trial.

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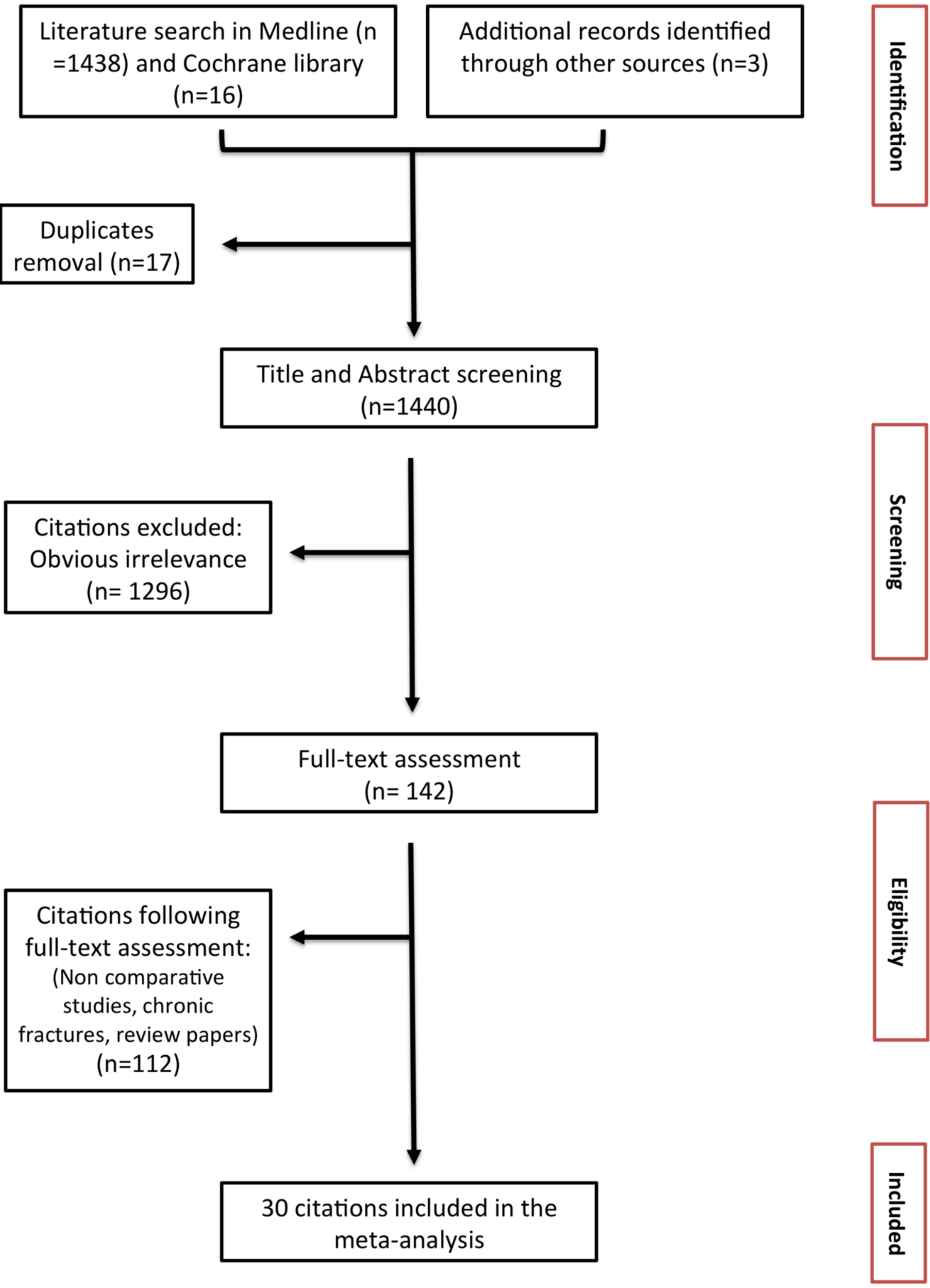
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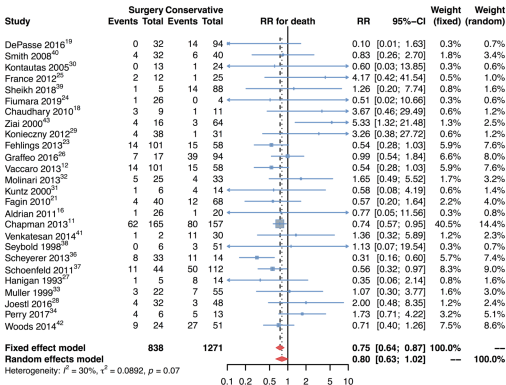
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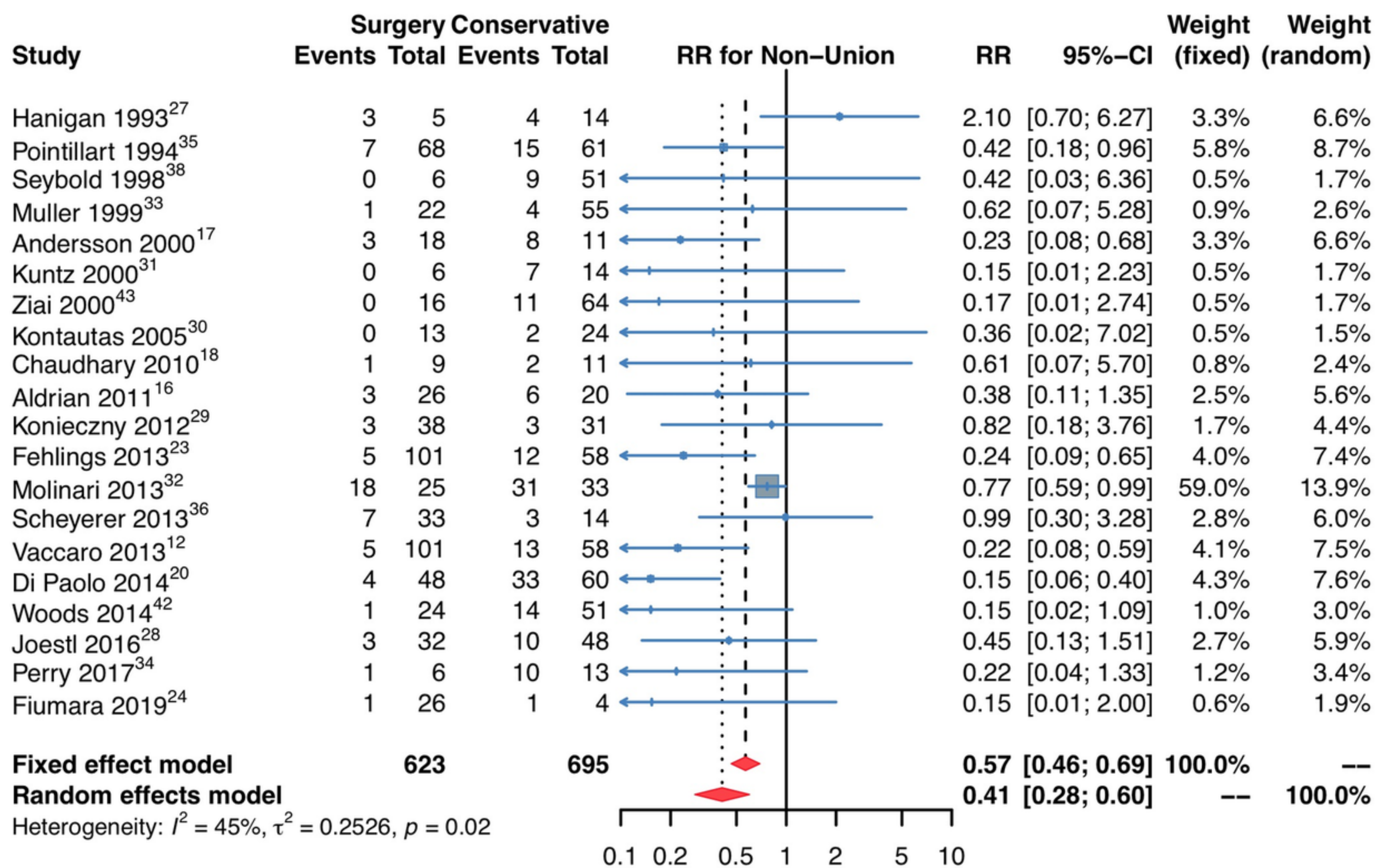
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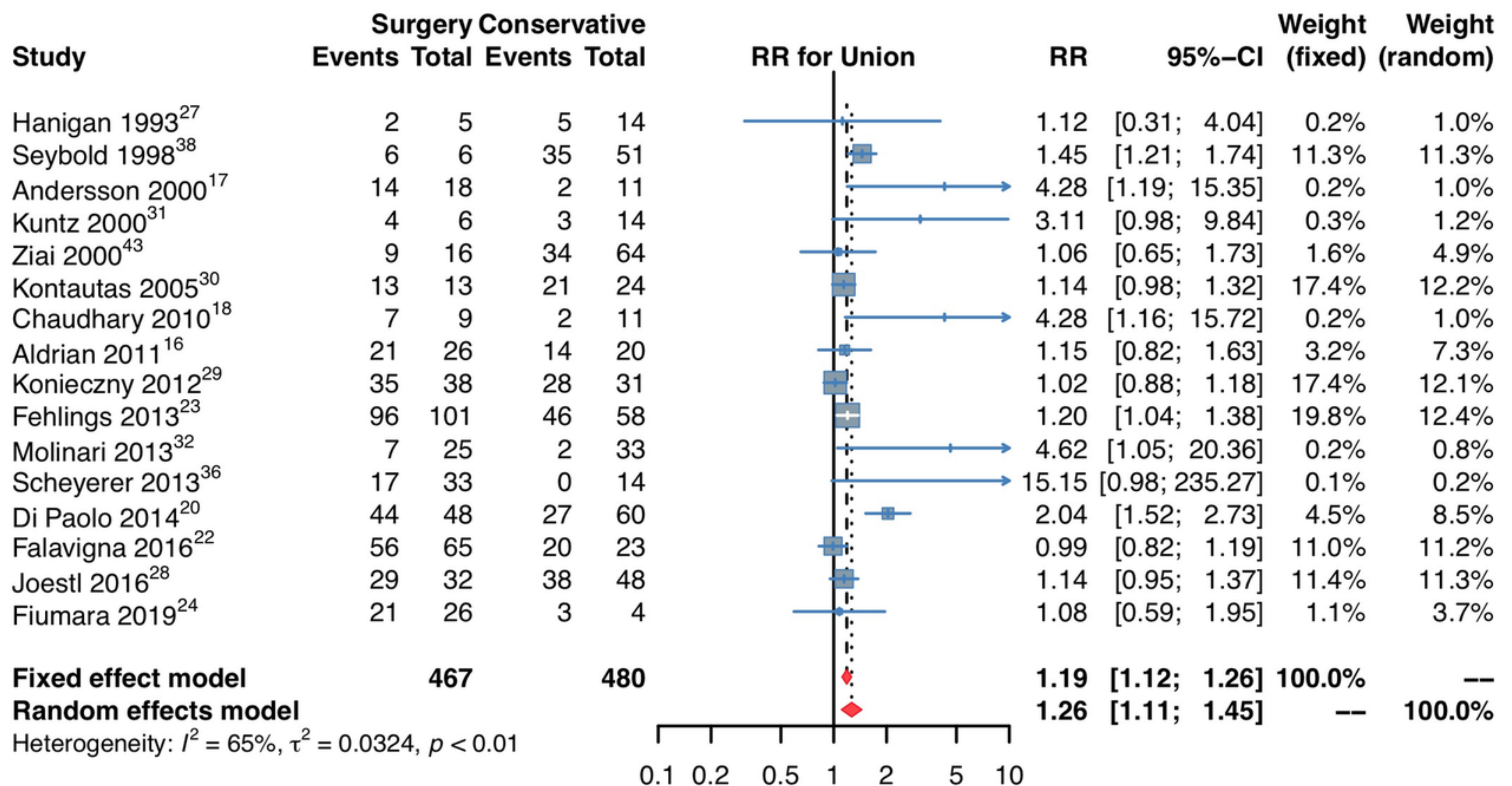








**A.**



**B.**



Author	Study design	NOS			Inclusion criteria	Exclusion criteria	Surgery		Conservative treatment		Follow-up (months)
		S	C	O			N	Technique	N	Technique	
<i>Aldrian 2011</i> <sup>16</sup>	Retrospective monocentric	3	1	2	<ul style="list-style-type: none"> <li>• Type IIa fractures</li> <li>• 2 years follow-up</li> </ul>	<ul style="list-style-type: none"> <li>• Type III</li> <li>• Incomplete data sets</li> </ul>	25	Odontoid screw	21	Halo-vest	24
<i>Andersson 2000</i> <sup>17</sup>	Retrospective monocentric	3	1	1	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;65 years</li> </ul>		18	Odontoid screw (11) Posterior fusion (7)	11	Cervical orthosis (10) Halo-vest (1)	51
<i>Chapman 2013</i> <sup>11</sup>	Retrospective multicentric	3	1	1	<ul style="list-style-type: none"> <li>• Type II fractures</li> <li>• &gt;65 years</li> </ul>		165	NS	157	NS	25
<i>Chaudhary 2010</i> <sup>18</sup>	Retrospective multicentric	3	1	0	<ul style="list-style-type: none"> <li>• Type II fractures</li> <li>• &gt;70 years</li> </ul>	<ul style="list-style-type: none"> <li>• Displacement &gt;4mm</li> <li>• Posterior displacement</li> <li>• Neurological impairment</li> <li>• Halo vest</li> <li>• Multiple cervical injuries</li> </ul>	11	Odontoid screw Transarticular screw	9	Cervical orthosis	5.5
<i>DePasse 2017</i> <sup>19</sup>	Retrospective monocentric	3	1	1	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;65 years</li> </ul>	<ul style="list-style-type: none"> <li>• GCS 3 at presentation</li> <li>• 48h mortality</li> </ul>	32	Odontoid screw Posterior fusion	94	Cervical orthosis (84) Halo-vest (10)	0.3
<i>Di Paolo 2014</i> <sup>20</sup>	Retrospective monocentric	3	1	0	<ul style="list-style-type: none"> <li>• Type II</li> </ul>		48	Odontoid screw (20) Posterior fusion (16) Occipito-cervical fusion (12)	60	Cervical orthosis (20) Halo-vest (40)	4.43
<i>Fagin 2010</i> <sup>21</sup>	Retrospective monocentric	3	1	0	<ul style="list-style-type: none"> <li>• &gt;60 years</li> </ul>		40	Odontoid screw (23) Posterior fusion (12)	68	Cervical orthosis (64) Halo-vest (4)	20
<i>Falavigna 2016</i> <sup>22</sup>	Retrospective multicentric	3	2	1	<ul style="list-style-type: none"> <li>• Type II</li> </ul>	<ul style="list-style-type: none"> <li>• Incomplete data set</li> </ul>	65	Odontoid screw (42) Posterior fusion (13)	23	Cervical orthosis (15) Halo-vest (8)	23.4
<i>Fehlings 2013</i> <sup>23</sup>	Retrospective multicentric	4	1	2	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;65 years</li> </ul>	<ul style="list-style-type: none"> <li>• Previous odontoid fracture</li> <li>• Mental incapacity</li> </ul>	101	Odontoid screw Anterior transarticular screws Posterior fusion	58	Cervical traction Cervical orthosis Halo-vest	12
<i>Fiumara 2019</i> <sup>24</sup>	Retrospective multicentric	3	1	0	<ul style="list-style-type: none"> <li>• Type II</li> </ul>		26	Odontoid screw (18) Odontoid and transarticular screws (7) Posterior fusion (1)	4	Cervical orthosis (4)	4
<i>France 2012</i> <sup>25</sup>	Retrospective monocentric	3	1	0	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;65 years</li> </ul>	<ul style="list-style-type: none"> <li>• Pathological fractures</li> </ul>	12	Odontoid screw (7) Posterior fusion (5)	25	Cervical orthosis (9) Halo-vest (16)	7.2
<i>Grafteo 2017</i> <sup>26</sup>	Retrospective monocentric	3	1	1	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;80 years</li> </ul>	<ul style="list-style-type: none"> <li>• Halo vest</li> </ul>	17	Odontoid screw (2) Posterior fusion (15)	94	Cervical orthosis	22
<i>Hanigan 1993</i> <sup>27</sup>	Retrospective monocentric	3	1	1	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;80 years</li> </ul>	<ul style="list-style-type: none"> <li>• Pathological fractures</li> </ul>	5	Posterior fusion	14	Cervical orthosis (11) Halo-vest (2) Cervical traction (1)	42
<i>Joestl 2016</i> <sup>28</sup>	Retrospective monocentric	3	1	2	<ul style="list-style-type: none"> <li>• Type II</li> <li>• &gt;65 years</li> <li>• ASA&gt;1</li> <li>• 5 years F-U</li> </ul>	<ul style="list-style-type: none"> <li>• Type III</li> <li>• Incomplete data set</li> </ul>	32	Odontoid screw	48	Halo-vest	60

<i>Konieczny 2012</i> <sup>29</sup>	Prospective monocentric	4	1	1			38	Odontoid screw (13) Posterior fusion (25)	31	Cervical orthosis	9.7
<i>Kontautas 2005</i> <sup>30</sup>	Prospective monocentric	3	2	1			13	Posterior fusion	23	Halo-vest	2
<i>Kuntz 2000</i> <sup>31</sup>	Retrospective monocentric	3	1	1	• >65 years		6	Posterior fusion	14	Cervical orthosis (6) Halo-vest (6)	14
<i>Molinari 2013</i> <sup>32</sup>	Retrospective monocentric	3	1	0	• Type II • >65 years		25	Posterior fusion	33	Cervical orthosis	14
<i>Müller 1999</i> <sup>33</sup>	Retrospective monocentric	3	2	1			22	Odontoid screw (21) Posterior fusion (5)	55	Cervical orthosis (26) Halo-vest (29)	47
<i>Perry 2018</i> <sup>34</sup>	Retrospective monocentric	3	1	0	• Type II • >80 years • 1 year follow-up		6	Posterior fusion	13	Cervical orthosis	60
<i>Pointillart 1994</i> <sup>35</sup>	Retrospective monocentric	3	1	0			68	Odontoid screw (19) Posterior fusion (43)	61	Cervical orthosis	6
<i>Scheyerer 2013</i> <sup>36</sup>	Retrospective monocentric	3	1	1	• Type II • >65 years	• Multiple cervical injuries	33	Odontoid screw (17) Posterior fusion (16)	14	Cervical orthosis	31.1
<i>Schoenfeld 2011</i> <sup>37</sup>	Retrospective monocentric	3	1	2	• Type II • >65 years		44	NS	112	Cervical orthosis (84) Halo-vest (28)	36
<i>Seybold 1998</i> <sup>38</sup>	Retrospective monocentric	3	0	1			6	Posterior fusion	51	Cervical orthosis (5) Halo-vest (46)	29
<i>Sheikh 2017</i> <sup>39</sup>	Retrospective monocentric	3	0	1	• Type II • >65 years		5	Occipito-cervical fusion	88	Cervical orthosis	3
<i>Smith 2008</i> <sup>40</sup>	Retrospective monocentric	3	1	1	• Type II • >80 years	• Associated spine fractures • Neurological impairment	32	Odontoid screw (10) Posterior fusion (22)	40	Cervical orthosis (24) Halo-vest (16)	0,5
<i>Vaccaro 2013</i> <sup>12</sup>	Prospective multicenter	4	1	2	• Type II • >65 years	• No previous fracture treatment • No cognitive impairment	101	Odontoid screw (12) Posterior fusion (88) Occipito-cervical fusion (1)	58	Cervical orthosis (52) Halo-vest (6)	12
<i>Venkatesan 2014</i> <sup>41</sup>	Retrospective monocentric	3	1	1	• >65 years	• Neurological impairment	2	Posterior fusion	30	Cervical orthosis (26) Halo-vest (4)	29
<i>Woods 2014</i> <sup>42</sup>	Retrospective monocentric	3	0	1	• >65 years	• Incomplete data set	24	Odontoid screw (8) Posterior fusion (16)	51	Cervical orthosis (21) Halo-vest (30)	60
<i>Ziai 2000</i> <sup>43</sup>	Retrospective multicentric	3	1	0			16	Odontoid screw (11) Posterior fusion (5)	64	Cervical orthosis (35) Halo-vest (29)	6

**Table 1:** Main characteristics of the 30 studies enrolled in the meta-analysis. **NOS:** Newcastle-Ottawa scale with 3 subclasses (**S:** Selection, **C:** Comparability, **O:** Outcome)