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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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1 Abstract

2

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

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

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

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

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

23 Introduction:

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

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

46 a huge increase of surgeries for this indication. Some authors argue in favor of a reduced
47 mortality^{11,12}.

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

57 **Material and Methods:**

58 **Search strategy**

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

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

67

68 **Inclusion and exclusion criteria**

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

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

77

78 **Data extraction and quality analysis**

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

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

91 **Statistical analysis**

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

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

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

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

111 Results

112 Study selection

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

118 Enrolled studies

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

127 The mean follow-up time was 22.3 months (range = 0.3-60 months). 2 studies ^{19,40} were
128 limited to the in-hospital period with restricted follow-up. The mean age was 72.9 years (+/-
129 12.3).

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

131

132 Mortality

133 26 studies reported mortality at different end-points (Fig. 2). The pooled results showed
134 that last follow-up mortality rates were not significantly different, though there was a tendency
135 toward a lower mortality in the surgical group (RR: 0.80; CI: 0.63-1.02)(Fig. 2). There was
136 significant heterogeneity ($I^2=30%$, $\tau^2=0.0892$, $p=0.07$).

137
138 The mortality rates at 3 and 12 months were reported in 9 studies. At 3 months the
139 weighted mortality incidences were 6% (CI: 6-10) and 12% (CI: 8-17) for surgical and
140 conservative treatment. There was no significant difference, (RR: 1.13; CI: 0.52-2.48). At 12
141 months, the weighted mortality incidences were 14% (CI: 8-20) and 18% (CI: 12-26). There was
142 still no significant difference (RR: 0.96; CI: 0.62-1.48). A funnel plot to detect publication bias is
143 provided in the appendix. No significant influence of age or year of publication on treatment
144 effect was observed (digital supplementary content).

145

146 Union / Non-union

147 20 studies reported non-union rates (Fig 3.A). The pooled results were in favor of a lower
148 non-union rate in the surgical group (RR: 0.41; CI: 0.28-0.6). There was significant heterogeneity
149 ($I^2=45%$, $\tau^2=0.2526$, $p=0.02$)(Fig. 3). Among these studies, the weighted incidences of non-union
150 were 9% (CI: 6-14) and 30% (CI: 23-38) for surgical and conservative treatments.

151 16 studies reported union rates (Fig 3.B). The pooled results were in favor of a higher
152 fracture-healing rate in the surgical group (RR: 1.26; CI: 1.11-1.45). There was significant
153 heterogeneity ($I^2=65%$, $\tau^2=0.0324$, $p<0.01$). Among these studies, the weighted incidences of
154 fracture union were 81% (CI: 74-87) and 53% (CI: 43-68) for surgical and conservative

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

160

161 **Complications**

162 9 studies reported systemic complications. The pooled results showed a higher systemic
163 complication rate in the surgical group (RR: 1.43; CI: 1.02-1.99). There was a significant
164 heterogeneity ($I^2=42%$, $\tau^2=0.0940$, $p=0.09$).

165 13 studies reported procedural complications (i.e. attributable to treatment). The pooled
166 results showed that patients had less procedural complications in the surgical group (RR: 0.71;
167 CI: 0.53-0.95). There was no significant heterogeneity ($I^2=37%$, $\tau^2=0.1981$, $p=0.08$).

168 15 studies reported the rate of secondary surgery (i.e. because of first treatment failure).
169 The pooled results showed a tendency for patients in the surgical group to be less at risk for
170 secondary surgery (RR: 0.57; CI: 0.24-1.35). There was significant heterogeneity ($I^2=61%$,
171 $\tau^2=1.5610$, $p<0.01$).

172

173

174 Discussion

175
176 Odontoid fractures represent up to 15% of all cervical spine fractures ^{1,2}and Type II
177 odontoid fractures are the most common fractures of the cervical spine in people aged 70 years or
178 older. As the population is ageing, the incidence of these fractures is likely to continue increasing
179 ⁴⁴. The best treatment of this condition remains unclear, especially in geriatric patients, because
180 of comorbidities, poor bone quality and impaired physiological reserves. Treatment options for
181 odontoid fractures are either conservative or surgical. Surgical options include mainly anterior
182 odontoid screw fixation and posterior atlantoaxial arthrodesis ⁴⁵. Nonsurgical management
183 techniques mostly consist of cervical orthosis and halo-vest ⁴⁶. Although conservative treatment
184 was preferred in the 1990's, surgery has become more prominent in the last two decades. This
185 might reduce mortality and increase rates of fusion ^{11,12}. However, the treatment decision remains
186 highly dependent on patient and institutional factors, leading to heterogeneous treatment
187 strategies.

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

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

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

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

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

245 patients should be managed in a multidisciplinary way, in collaboration with geriatric specialists,
246 to decrease perioperative morbidity. ^{57,58}

247 The last parameter studied was fracture union, which has often been considered as the
248 main goal of these treatments. Because of its limited vascular supply, its cortical nature, and the
249 age of occurrence, odontoid fracture pseudarthrosis is a frequent condition ⁵⁹⁻⁶¹. Bone quality and
250 degree of displacement are predisposing factors. The non-union rate in the elderly is high,
251 ranging between 20 and 85%^{27,33,62}. It is found to be especially high in the case of conservative
252 management and more limited for surgical treatment. For example, Di Paolo et al. ²⁰ reported
253 91.7% of fusion with surgical treatment, compared to 46.7% with conservative treatment. Once
254 again, our data seems consistent with this information, as we report strongly inferior rates of
255 pseudarthrosis and superior rates of fusion in the surgical group. It is important to note that we
256 separated “union” and “non-union” parameters as the provided data varied among studies,
257 including for deceased or lost-to-follow-up patients. These data are probably heterogeneous
258 because of the variety of techniques used. Concerning conservative treatments, more and more
259 studies are in favor of the use of a collar instead of a halo-vest ^{29,46,51}. However, collars provide
260 the same amount of fusion without comorbidities. That seems different for surgical treatment
261 with no clear evidence, although the data seems to be suggest slightly increased union rates using
262 posterior fusion⁴⁵.

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

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

280 Because of a bigger heterogeneity of the data, and to limit the risk of methodological bias,
281 we deliberately chose to exclude non-comparative studies. This parameter can probably dilute the
282 information. Nonetheless our study is, to our knowledge, the biggest to date, summarizing data of
283 30 previous studies comparing surgical and non-surgical treatment of odontoid fractures. None of
284 these studies can be considered as high-level proof and a huge heterogeneity among samples and
285 kind of treatments used should be noted. For instance, mortality data mainly driven by the only
286 few studies that could be included because of their weight in the analysis. We tried to limit this
287 issue by using a random effect model, but these characteristics make the study at high risk of
288 bias. Therefore, these records should be interpreted with caution. Though, it provides data in
289 agreement with previously published records: surgical treatment of odontoid fracture is not
290 riskier than conservative treatment and seems to provide better results in term of fracture union.
291 Some of our results, such as the complications rates, suggest that surgical treatment is slightly
292 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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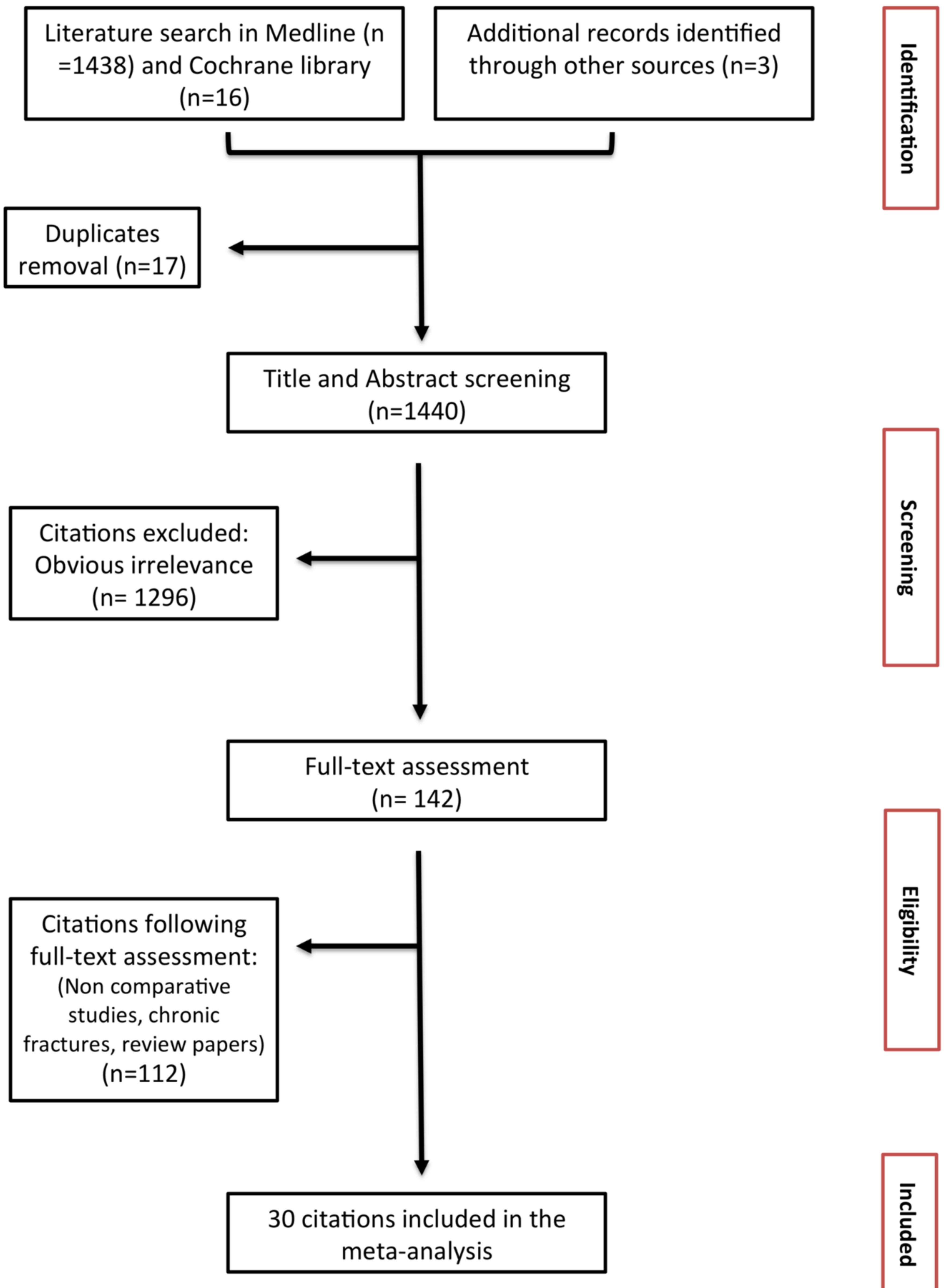
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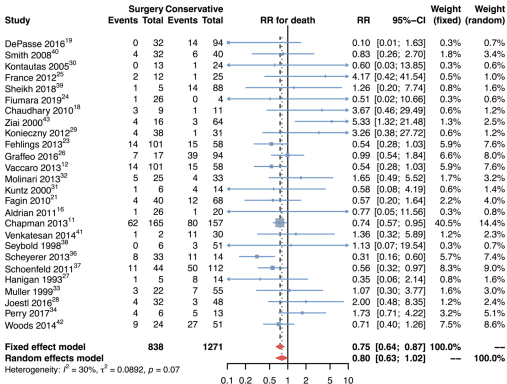
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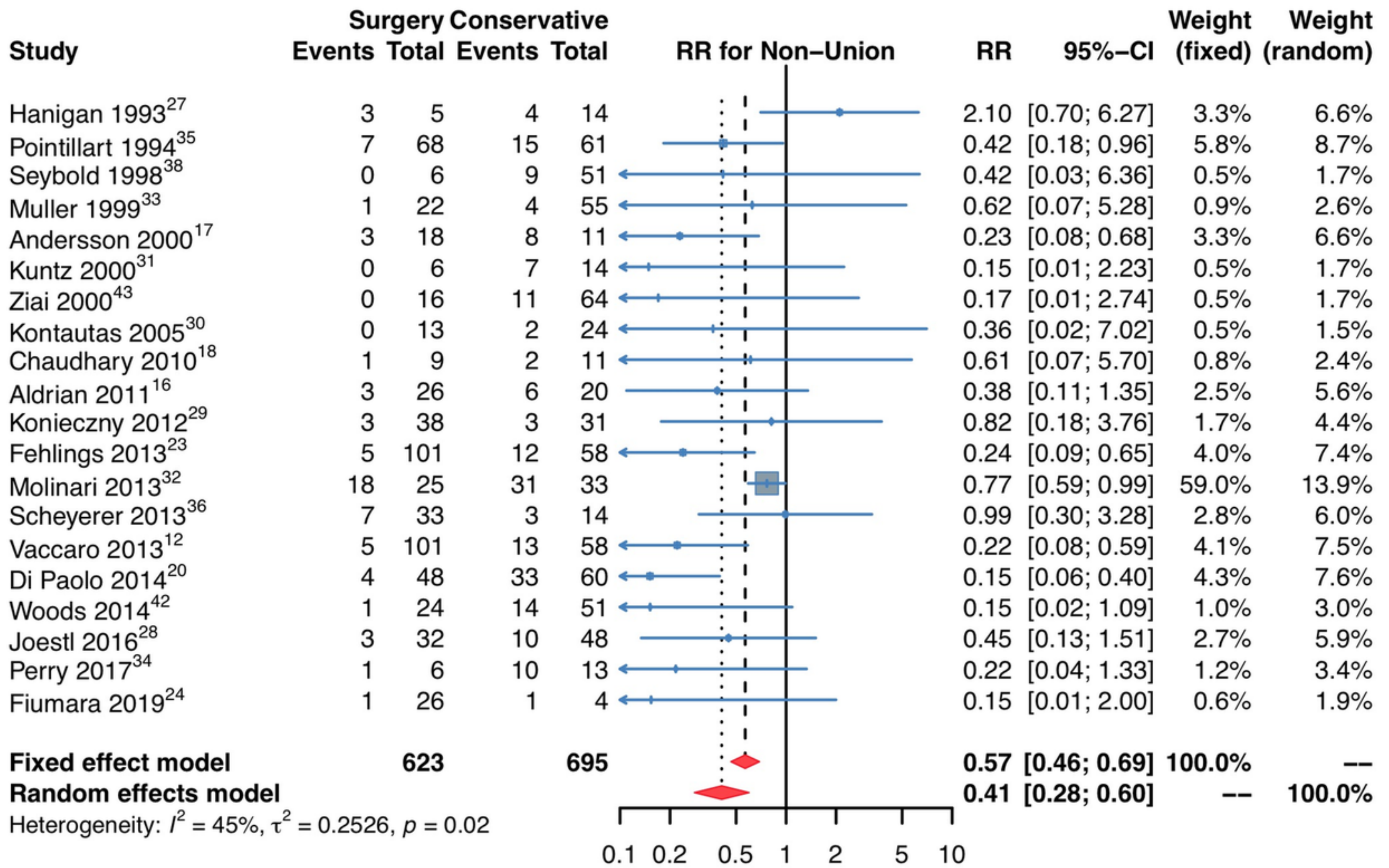
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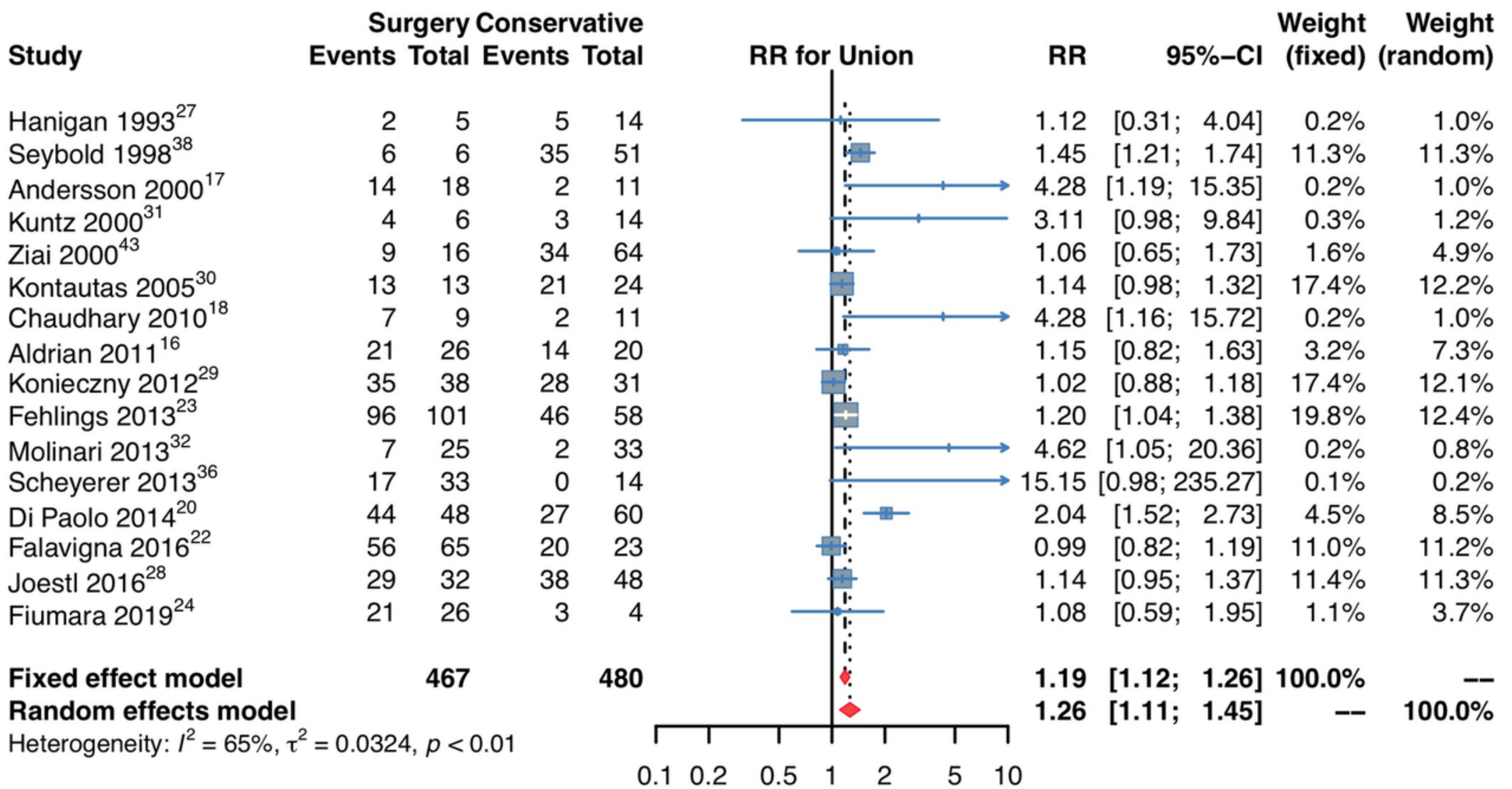
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A.



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

<i>Konieczny 2012</i> ²⁹	Prospective monocentric	4	1	1			38	Odontoid screw (13) Posterior fusion (25)	31	Cervical orthosis	9.7
<i>Kontautas 2005</i> ³⁰	Prospective monocentric	3	2	1			13	Posterior fusion	23	Halo-vest	2
<i>Kuntz 2000</i> ³¹	Retrospective monocentric	3	1	1	• >65 years		6	Posterior fusion	14	Cervical orthosis (6) Halo-vest (6)	14
<i>Molinari 2013</i> ³²	Retrospective monocentric	3	1	0	• Type II • >65 years		25	Posterior fusion	33	Cervical orthosis	14
<i>Müller 1999</i> ³³	Retrospective monocentric	3	2	1			22	Odontoid screw (21) Posterior fusion (5)	55	Cervical orthosis (26) Halo-vest (29)	47
<i>Perry 2018</i> ³⁴	Retrospective monocentric	3	1	0	• Type II • >80 years • 1 year follow-up		6	Posterior fusion	13	Cervical orthosis	60
<i>Pointillart 1994</i> ³⁵	Retrospective monocentric	3	1	0			68	Odontoid screw (19) Posterior fusion (43)	61	Cervical orthosis	6
<i>Scheyerer 2013</i> ³⁶	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> ³⁷	Retrospective monocentric	3	1	2	• Type II • >65 years		44	NS	112	Cervical orthosis (84) Halo-vest (28)	36
<i>Seybold 1998</i> ³⁸	Retrospective monocentric	3	0	1			6	Posterior fusion	51	Cervical orthosis (5) Halo-vest (46)	29
<i>Sheikh 2017</i> ³⁹	Retrospective monocentric	3	0	1	• Type II • >65 years		5	Occipito-cervical fusion	88	Cervical orthosis	3
<i>Smith 2008</i> ⁴⁰	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> ¹²	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> ⁴¹	Retrospective monocentric	3	1	1	• >65 years	• Neurological impairment	2	Posterior fusion	30	Cervical orthosis (26) Halo-vest (4)	29
<i>Woods 2014</i> ⁴²	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> ⁴³	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)