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REVIEW ARTICLE

Potential intraoperative factors of screw-related complications following posterior transarticular C1–C2 fixation: a systematic review and meta-analysis

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Abstract

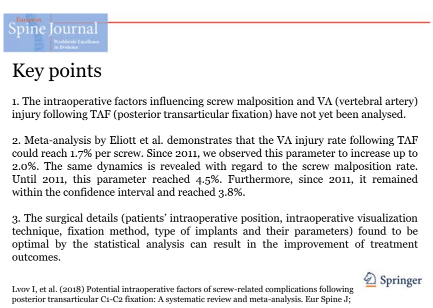
Purpose This study aimed to evaluate the impact of several factors, including patients' intraoperative position, intraoperative visualization technique, fixation method, and type of screws and their parameters, on the frequency of intraoperative screw-associated complications in posterior transarticular C1–C2 fixation.

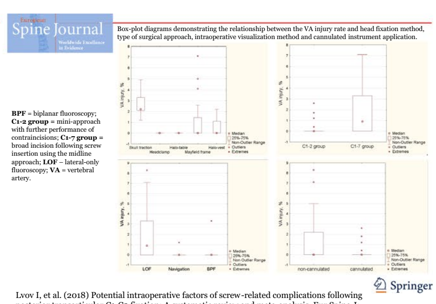
Methods A systematic review of the PubMed database between January 1986 and March 2018 was performed. The key inclusion criteria comprised detailed descriptions of the surgical technique and post-operative screw-associated complications.

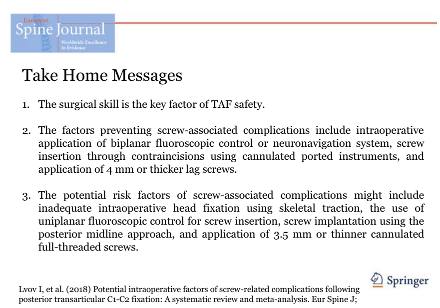
Results The initial search resulted in 1041 abstracts, and a total of 54 abstracts were included in the present study. The overall number of operated patients was 2306. In this group, 4439 screws were inserted. The rate of screw-associated complications during the different time periods was estimated upon meta-analysis. Statistical analysis of the screw malposition rate, vertebral artery injury rate, screw breakage rate based on patients' intraoperative position, intraoperative visualization technique, fixation method, and type of implants and their parameters was also performed.

Conclusions The factors that help reduce the rate of screw-associated complications include the intraoperative application of biplanar fluoroscopy or neuronavigation system, the use of 4 mm or thicker lag screws, and screw insertion through contraincisions using cannulated ported instruments. On the other hand, the potential risk factors of screw-associated complications include inadequate intraoperative head fixation using skeletal traction, uniplanar fluoroscopy-guided screw insertion, screw insertion using the posterior midline approach, and the use of 3.5 mm or thinner full-threaded screws.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.







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Keywords Screw-related complications · C1–C2 transarticular fixation · Vertebral artery injury · Screw breakage · Screw malposition

Introduction

Rationale

Transarticular fixation (TAF) using the Magerl technique is one of the most common methods of C1–C2 vertebrae fixation [1]. The meta-analysis performed by Eliott et al. demonstrated clear fusion development in 94.6% of operated patients [2]. However, the posterior fusion technique using screw-rod constructions has currently become more popular. This might be attributed to the lower risk of screw-associated complications [3]. A comparison on the outcomes of the Magerl and Harms technique revealed a higher frequency of vertebral artery (VA) injury (3.1% and 2.0% per patient, respectively) and a significant screw malposition rate (7.1% and 2.4% per patient, respectively) in patients who underwent TAF [4]. It was also shown that the risk of VA injury by screw insertion in TAF patients reached 1.7% per screw, while the screw malposition rate reached 4.5% per screw based on X-ray imaging [5]. Literature analyses performed by Eliott et al. [2, 4, 5] and Akinduro et al. [6] not only demonstrated the epidemiology of these complications but also revealed the surgery stages associated with the highest risk of VA injury. Authors suggest detailed preoperative VA anatomy assessment, careful surgical planning, and adequate surgical experience to be the major factors preventing VA injury and screw malposition. Despite the availability of these data, the intraoperative factors influencing screw malposition and VA injury have not yet been analysed.

Objectives

This study aimed to conduct a systematic review and meta-analysis of selected articles focusing on posterior transarticular C1–C2 fixation. We evaluated the impact of individual surgical factors, including patients' intraoperative position, intraoperative visualization technique, fixation method, and type of implants and their parameters, on the rate of screw-associated complications.

Methods

Article selection

A systematic review of the PubMed database was performed following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The selection included English articles released between January 1986 and March 2018. The search query included the following key words: ((“C1” AND “C2”) or “C1” or “C2” or “C1-2” or “C1–C2” or “atlas” or “axis” or “atlantoaxial” or “atlanto-axial” or (“atlas” AND “axis”) or “upper cervical” or “craniovertebral”) AND (“stabilization” or “fusion” or “fixation” or “instrumentation” or “transarticular” or “trans-articular” or “Magerl”) NOT “anterior.”

The criteria for article inclusion were as follows: (a) availability of full-text English version, (b) patients older than 18 years, (c) case series consisting of at least 6 patients who underwent TAF, (d) obligatory insertion of at least 1 transarticular screw, (e) availability of highly detailed descriptions of the surgical technique (head fixation technique, intraoperative visualization method, projection of skin incision, potential cannulated instrument application) and/or the type of implants (screw type and diameter), and (f) detailed description of screw-associated complications (screw breakage, implant malposition, VA injury). All articles that did not meet these criteria were excluded from the study.

If we found several articles of one study group with the same data released in different years and/or in different journals, we used the latest version.

Data collection

Data from each article were transferred to their corresponding cells in Microsoft Excel (Office 2016 for Mac). If required information was absent in the text, the table cells were labelled n/a (not available). Basic information included the years when the study started and ended, number of included patients, sex, age, diagnosis, and frequency of fusion and non-union. Surgical technique details included the intraoperative head fixation method, screw insertion method (the midline approach or contraincisions), intraoperative visualization method (lateral fluoroscopy, biplanar fluoroscopy (BPF), or navigation), and cannulated instrument application. Implant characteristics included the type of inserted screw (lag screw or full-threaded screw), screw diameter, and number of inserted screws. Outcomes were analysed using the following indicators: screw malposition following the same criteria as that of Madawi et al. [7] (too high, too low, medial, or lateral malposition), VA injury (symptomatic or asymptomatic), and screw failure. However, the length of inserted screws was not assessed according to the classification of Madawi et al. [7]: this aspect is dependent upon preoperative planning only and does not correlate with the surgical technique.

Statistical analysis

The raw data were transferred to Microsoft Excel (Office 2016 for Mac). Statistical analysis and data processing were performed using PC STATISTICA program version 10.0 (StatSoft Inc., Tulsa, OK, USA). Demographic data were summarized using descriptive statistics. Only mean values were reported for patient age at surgery. Differences between groups were estimated using the Mann–Whitney (M–W) test and Kruskal–Wallis (K–W) test. Microsoft Excel (Office 2016 for Mac) was used for Gantt chart creation.

Meta-analysis was performed using Comprehensive Meta-analysis software version 2.2.064 (Biostat, Englewood, NJ, USA) to assess the rates of screw malposition, VA injury, and screw breakage. The rates of screw malposition and VA injury were estimated for two time periods: (a) between April 2011 and May 2018 to determine the dynamics of indicators compared to the previous meta-analysis results [5] and (b) between January 1989 and May 2018 to obtain the relevant level of current complication rate. The screw breakage rate was not evaluated in previous meta-analyses. Therefore, we assessed this parameter throughout all time periods of the study. A fixed-effects model was used if there was no evidence of statistical heterogeneity amongst the studies. A random-effects model (Der Simonian and Laird) was used otherwise. All *P* values were two-sided, and a *P* value of <0.05 was considered statistically significant.

Results

Article selection and patient demographics

The initial selection resulted in 1041 abstracts. A total of 85 full texts were chosen for detailed study based on the selected abstracts. A flowchart of the search parameters and article selection process is shown in Fig. 1. Consequently, 54 articles satisfying the inclusion criteria were used for the analysis [7–60]. A Gantt chart showing the years when the surgeries were performed is shown in Fig. 2. The majority

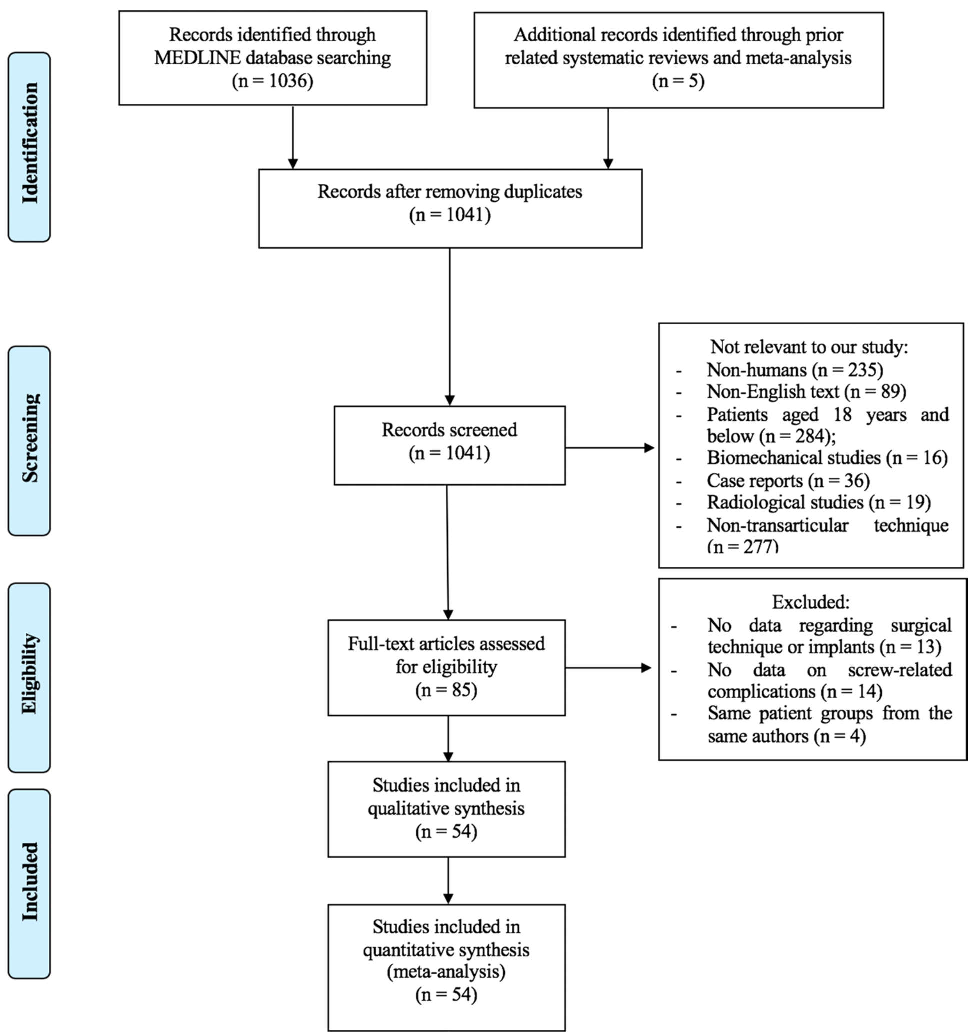

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart for search and study selection

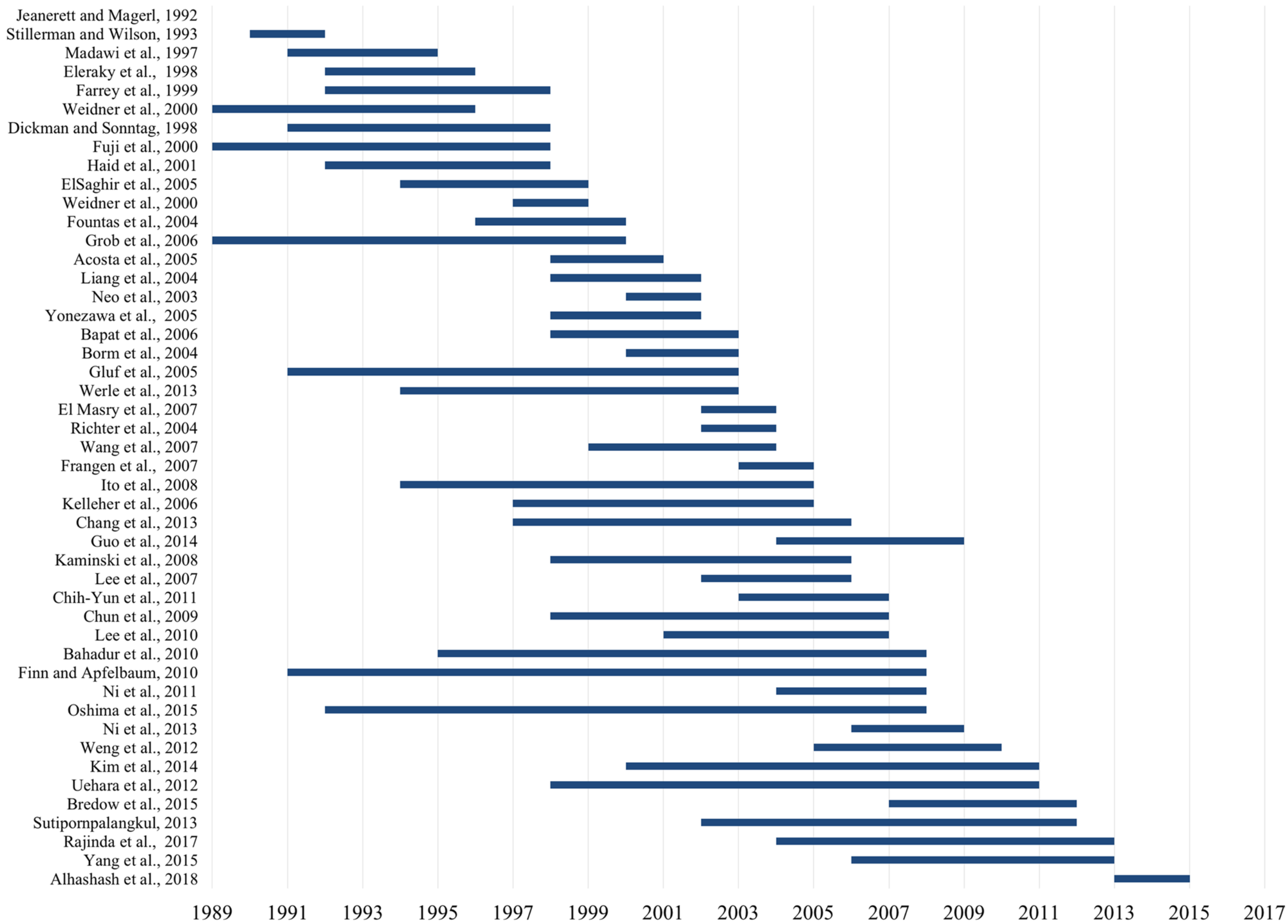

Fig. 2 Gantt chart demonstrating the dates of performed surgeries in selected studies

of articles included groups of patients who underwent surgery between 1993 and 2007. Outcomes of patient treatment were analysed in 2306 cases. The mean age was 52 years. Most patients were female (54.1%). In most cases, the indications for surgery included atlantoaxial instability following traumatic injury or rheumatoid arthritis exacerbation. Patient demographics are shown in Table 1. In all 2306 cases, 4406 screws were inserted. The number of patients who underwent insertion of additional 33 screws [13] was not determined. In 2100 patients (91.1%), the screws were inserted bilaterally, whereas in 206 patients (8.9%), they were inserted unilaterally. The original data used for the analysis are shown in Table 2.

Meta-analysis of screw malposition, VA injury, and screw failure rate

Figure 3 is a forest plot demonstrating the point estimates and confidence intervals (CIs) for the screw malposition rate between 1989 and 2018. The point estimate of the screw malposition frequency was 3.2% (95% CI 2.3–4.4%). Heterogeneity amongst the studies was identified by *Q* tests ($P<0.0001$). The point estimate of the screw malposition rate between April 2011 and May 2018 was 3.8% (95% CI 2.4–5.8%) (Fig. 4). There was no significant difference between the study groups according to *Q* tests ($P=0.478$).

Figure 5 is a forest plot demonstrating the point estimates and CI for the VA injury rate revealed amongst studies released between 1989 and 2018. The point estimate of the VA injury rate was 1.8% (95% CI 1.4–2.3%) per screw. There was no significant difference between the study groups according to *Q* tests ($P=0.960$). The point estimate for the VA injury rate amongst articles released between April 2011 and 2018 was 2.0% (95% CI 1.2–3.5%) per screw (Fig. 6). There was no significant difference between the study groups according to *Q* tests ($P=0.968$).

Figure 7 is a forest plot demonstrating the point estimates and CI for the screw breakage rate amongst studies released between 1989 and 2018. The point estimate of the screw breakage rate was 2.2% (95% CI 1.7–2.8%). There was no significant difference between the study groups according to *Q* tests ($P=0.954$).

Table 1 Summary of demographic data, diagnosis distribution, and complications in patients with atlantoaxial transarticular screw fixation

Demographic data, no of patients (percentage)	
Total	2306 (100%)
Mean age (years)	52
Male/female/unidentified	962/1249/95 (41.7%/54.2%/4.1%)
Diagnosis, no of patients (percentage)	
Rheumatoid arthritis	973 (42.2%)
Trauma	759 (32.9%)
Congenital anomaly	122 (5.3%)
Os odontoideum	134 (5.8%)
Non-union after conservative treatment	84 (3.6%)
Non-traumatic instability	66 (2.9%)
Osteoarthritis	64 (2.8%)
Previously failed surgery	52 (2.3%)
Tumour	33 (1.4%)
Tuberculosis	12 (0.5%)
Infection	7 (0.3%)
Post-operative screw-related complications, no of screws (percentage)	
Total number of screws	4439 (100%)
Screw malposition	
Total	168 (3.8%)
Too high/too low (Madawi et al. [40])	14/29
Too lateral/too medial (Madawi et al. [40])	49/24
C2 malposition	10
Other type/unidentified malposition	42
Vertebral artery injury asymptomatic/symptomatic	34 (0.8%)/8 (0.2%)
Arteriovenous fistula	5 (0.1%)
Screw breakage	51 (1.1%)
Screw cut out	16 (0.4%)
Screw backed out	1 (0.02%)

Detailed surgical technique description

The intraoperative head fixation method was described in 36 articles. In most cases, authors employed the Mayfield clamp (23 articles, 2202 inserted screws). However, skeletal tractions (5 articles, 293 inserted screws), halo devices (2 articles, 83 inserted screws), halo rings fixed to the operating Table (2 articles, 366 inserted screws), and head clamps (2 articles, 122 inserted screws) were less commonly used. In 2 articles, both the halo device and skeletal traction [44] or the halo device and Mayfield clamp [26] were used together.

The patients were divided into 2 groups depending on the location of skin incision: the mini-approach group with subsequent implant insertion through contraincisions (C1-2 group) and the open group (C1-7 group) with screw insertion using the midline approach. The surgical technique was described in 47 articles. Overall, 2748 screws were inserted using the C1-2 approach (27 articles) and 1165 screws through the C1-7 approach (18 articles). Both techniques were applied in 1 study [40], and in 1 case, the surgery was fully percutaneous [9].

The intraoperative visualization method was indicated in 40 articles. A total of 2385 screws were inserted using lateral-only fluoroscopy (LOF), 390 screws using BPF, and 747 screws using navigation.

Cannulated screws were used in 1509 cases, non-cannulated in 2647 cases. Both types of screws were used in 1 study [7], but the number of screws was not indicated in the text. No data with regard to cannulated instrument application was provided in 2 articles.

Two types of screws were used for C1–C2 fixation: partially threaded lag screws and full-threaded screws. This aspect was described in 47 articles. Overall, 2444 full-threaded screws were inserted, whereas the number of inserted lag screws reached 595. Both screw types were used in 9 studies, but the number of screws was not provided in 3 articles [28, 33, 36].

The screw diameter was specified in 43 articles. Different screws were used ranging from 2.7 to 4.5 mm. The most frequently used were those with a diameter of 3.5 and 4.0 mm.

Analysis of surgical technique details and screw malposition rate

Post-operative screw malposition was revealed in 168 cases. The most common types of malposition were too lateral (49 screws, 29.2%), too low (29 screws, 17.3%), and too medial (24 screws, 14.3%). In some studies, the malposition of 42 screws was not classified [17, 21, 23, 25, 27, 49] or was determined but not for all screws [10, 34, 38].

Both screw malposition and the intraoperative head fixation method were provided in 35 studies. No significant differences between these parameters were revealed (K–W test, $P = 0.723$).

The skin incision location along with the respective screw insertion method and the screw malposition rate were provided in 46 studies. No significant differences between these parameters were revealed (M–U test, $P = 0.168$). However, we determined a tendency for a lower screw malposition rate in the C1-2 group (Fig. 8).

Both the intraoperative visualization method and the screw malposition rate were described in 38 studies. No significant differences between these indicators were revealed (K–W test, $P = 0.317$). However, we determined a strong tendency for a lower screw malposition rate in patients who underwent surgery using intraoperative BPF (Fig. 9).

Both the type of applied instruments and the screw malposition rate were provided in 48 articles. No significant

Table 2 Surgical technique and implant-related complications for published series of patients with atlantoaxial transarticular screw fixation

Author(s)	No of patients	No of screws	Head fixation	Skin incision	Visualization	Screw type	Cannulated instruments	Screws diameter, mm	Screw malposition (per screw)	VA injury asymptomatic/symptomatic (per screw)	Screw breakage (per screw)
Acosta et al. [7]	20	36	Mayfield frame	C1-2	Navigation	FTS	No	4	3 (8.3%)	0	0
Alhashash et al. [8]	20	40	Head clamp	MIS	Biplanar fluoroscopy	FTS	No	3.5	0	0	1 (2.5%)
Bahadur et al. [9]	38	75	N/A	C1-7	LOF	LS	No	N/A	4 (5.3%)	3 (4.0%) 0	0
Bapat et al. [10]	11	22	N/A	N/A	N/A	FTS	No	N/A	0	0	0
Borm et al. [11]	14	28	N/A	C1-2	Navigation	FTS	Yes	4	1 (3.6%)	0	0
Bredow et al. [12]	N/A	33	Mayfield frame	C1-2	Navigation	FTS	Yes	3.5 or 4	1 (3.0%)	0	0
Campanelli et al. [13]	7	13	Mayfield frame	C1-7	LOF	FTS	No	3.5	0	1 (7.7%) 0	0
Chang et al. [14]	30	60	N/A	N/A	N/A	FTS	No	3.5	8 (13.3%)	2 (3.3%) 0	4 (6.7%)
Chih-Yun et al. [15]	11	19	Mayfield frame	C1-2	LOF	FTS	No	4	0	0	0
Chun et al. [16]	55	82	Head clamp	C1-7	N/A	FTS	No	N/A	1 (1.2%)	0	0
Cornefjord et al. [17]	26	52	N/A	N/A	N/A	FTS	No	4.5	0	0	0
Dickman and Sonntag. [18]	121	226	N/A	C1-2	LOF	LS	Yes	3.5 or 4	5 (2.2%)	1 (0.4%) 0	0
Eleraky et al. [19]	36	58	Mayfield frame	C1-7	LOF	FTS or LS	No	N/A	0	0	0
ElSaghir et al. [20]	57	114	N/A	C1-2	Biplanar fluoroscopy	FTS	No	2.7	2 (1.7%)	0	1 (0.9%)
Farrey et al. [21]	15	30	Skull traction	C1-7	Biplanar fluoroscopy	FTS	No	3.5	0	1 (3.3%) 0	0
Finn and Apfelbaum [22]	269	491	Mayfield frame	C1-2	LOF	FTS	No	3.5 or 4	13 (2.6%)	5 (1.0%) 3 (0.6%)	11 (2.2%)
Fountas et al. [23]	23	44	N/A	C1-7	Biplanar fluoroscopy	FTS	Yes	3.5	2 (4.5%)	0	2 (4.5%)
Frangen et al. [24]	27	54	Mayfield frame	N/A	N/A	FTS	Yes	3.5	1 (1.8%)	0	0

Table 2 (continued)

Author(s)	No of patients	No of screws	Head fixation	Skin incision	Visualization	Screw type	Cannulated instruments	Screws diameter, mm	Screw malposition (per screw)	VA injury asymptomatic/ symptomatic (per screw)	Screw breakage (per screw)
Fuji et al. [25]	56	111	Halo vest or Mayfield frame	C1-7	LOF	FTS or LS	Yes	3.5 or 4 or 4.5	5 (4.5%)	0	0
Gluf et al. [26]	191	353	Mayfield frame	C1-2	LOF	FTS	No	4	5 (1.4%)	3 (0.8%) 3 (0.8%)	9 (2.5%)
Grob et al. [27]	161	322	Head Halo-ring	C1-7	LOF	FTS or LS	No	3.5	49 (15.2%)	0	3 (0.9%)
Grob et al. [28]	35	61	N/A	N/A	N/A	FTS	No	N/A	N/A	0	1 (1.6%)
Guo et al. [29]	36	72	N/A	C1-2	N/A	FTS	No	4	0	0	0
Haid et al. [30]	75	141	Mayfield frame	C1-2	LOF	LS	Yes	3.5 or 4	0	0	0
Ito et al. [31]	38	76	N/A	C1-2	N/A	LS	Yes	4	0	0	0
Jeanerett and Magerl [32]	12	24	N/A	C1-7	LOF	FTS or LS	No	3.5 or 4	0	0	0
Kaminski et al. [33]	47	94	Mayfield frame	C1-2	Biplanar fluoroscopy	FTS	No	2.7 or 3.5	3 (3.2%)	0	5 (5.3%)
Kelleher et al. [34]	60	109	Mayfield frame	C1-2	Navigation and LOF	N/A	Yes	N/A	0	0	0
Kim et al. [35]	14	28	Mayfield frame	C1-7	LOF	FTS or LS	Yes	3.5	3 (10.7%)	0	1 (3.6%)
Lee et al. [36]	12	24	N/A	N/A	LOF	N/A	No	3.5	N/A	2 (8.3%) 0	0
Lee et al. [37]	28	55	Mayfield frame	C1-7	LOF	FTS	Yes	3.5 or 4	4 (7.3%)	1 (1.8%) 0	3 (5.4%)
Liang et al. [38]	23	45	Halo vest	C1-7	LOF	FTS	No	3.5 or 4	1 (2.2%)	1 (2.2%) 0	0
Madawi et al. [39]	61	121	Mayfield frame	C1-7 or C1-2	LOF	FTS or LS	In some cases	3.5	17 (14.0%)	5 (4.1%) 1 (0.8%)	5 (4.1%)
Marcotte et al. [40]	18	35	Mayfield frame	C1-7	LOF	FTS	No	3.5	2 (5.7%)	0	0
El Masry et al. [41]	24	48	Skull traction	C1-7	N/A	FTS	No	N/A	0	1 (2.1%) 0	0
Nagaria et al. [42]	37	70	Mayfield frame	C1-2	Navigation	N/A	N/A	N/A	0	0	0
Naseer and Bailey [43]	11	22	Halo vest or skull traction	C1-2	N/A	LS	Yes	N/A	0	0	0

Table 2 (continued)

Author(s)	No of patients	No of screws	Head fixation	Skin incision	Visualization	Screw type	Cannulated instruments	Screws diameter, mm	Screw malposition (per screw)	VA injury asymptomatic/symptomatic (per screw)	Screw breakage (per screw)
Neo et al. [44]	27	54	Mayfield frame	C1-2	LOF	FTS or LS	Yes	4	8 (14.8%)	0	0
Ni et al. [45]	12	24	N/A	C1-2	Biplanar fluoroscopy or Navigation	FTS	No	4	0	0	0
Ni et al. [46]	72	144	N/A	C1-2	N/A	FTS	No	4	6	0	0
Oshima et al. [47]	20	39	Mayfield frame	C1-2	LOF	LS	Yes	N/A	0	1 (2.6%) 0	0
Panjasee [48]	10	20	Mayfield frame	C1-7	LOF	N/A	No	N/A	1 (5.0%)	1 (5.0%) 0	0
Rajinda et al. [49]	45	90	Skull traction	C1-7	LOF	FTS	No	3.5	3 (3.3%)	2 (2.2%) 0	0
Richter et al. [50]	12	22	Mayfield frame	C1-2	Navigation	FTS	Yes	4	0	0	0
Stillerman and Wilson [51]	22	44	Head Halo-ring	C1-7	Biplanar fluoroscopy	FTS	No	3.5	0	0	0
Sutipornpalangkul and Thanapipatsiri [52]	23	41	Skull traction	C1-7	LOF	FTS	No	3.5 or 4 or 4.5	N/A	2 (4.9%) 0	0
Uehara et al. [53]	20	38	Halo vest	C1-2	Navigation	FTS or LS	Yes	4	1 (2.6%)	0	0
Wang et al. [54]	57	114	Mayfield frame	C1-2	N/A	FTS	No	3.5	2 (1.7%)	0	0
Weidner et al. [55]	115	227	Mayfield frame	C1-2	Navigation or LOF	FTS or LS	Yes	4	8 (3.5%)	1 (0.4%) 1 (0.4%)	N/A
Weng et al. [56]	8	16	Mayfield frame	C1-2	Navigation	LS	Yes	3.5	1 (6.2%)	0	0
Werle et al. [57]	46	92	N/A	N/A	N/A	N/A	N/A	2.7	2 (2.2%)	0	4 (4.3%)
Wigfield and Bolger [58]	46	84	N/A	C1-2	Navigation	N/A	Yes	4	0	0	0
Yang et al. [59]	42	84	Skull traction	C1-2	Navigation	FTS	Yes	3.5 or 4	5 (5.9%)	1 (1.2%) 0	1 (1.2%)
Yonezawa et al. [60]	10	18	N/A	C1-2	N/A	N/A	Yes	3.5	1 (5.6%)	0	0

FTS full-threaded screws, *LOF* lateral-only fluoroscopy, *LS* lag screws, *N/A* not available, *VA* vertebral artery

Study name	Statistics for each study				
	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Acosta et al., 2005	0,083	0,027	0,228	-3,976	0,000
Alhashash et al., 2018	0,012	0,001	0,167	-3,088	0,002
Bahadur et al., 2010	0,053	0,020	0,133	-5,594	0,000
Bapat et al., 2006	0,022	0,001	0,268	-2,662	0,008
Borm et al., 2004	0,035	0,005	0,214	-3,225	0,001
Bredow et al., 2015	0,030	0,004	0,186	-3,406	0,001
Campanelli et al., 1999	0,033	0,002	0,366	-2,341	0,019
Chang et al., 2013	0,033	0,008	0,123	-4,674	0,000
Chih-Yun et al., 2011	0,025	0,002	0,298	-2,558	0,011
Chun et al., 2009	0,012	0,002	0,081	-4,349	0,000
Cornefjord et al., 2003	0,009	0,001	0,134	-3,275	0,001
Dickman and Sonntag, 1998	0,022	0,009	0,052	-8,367	0,000
El Masry et al., 2007	0,010	0,001	0,143	-3,218	0,001
Eleraky et al., 1998	0,008	0,001	0,121	-3,353	0,001
ElSaghir et al., 2005	0,017	0,004	0,067	-5,600	0,000
Farrey et al., 1999	0,016	0,001	0,211	-2,883	0,004
Finn and Apfelbaum, 2010	0,026	0,015	0,044	-12,777	0,000
Fountas et al., 2004	0,045	0,011	0,164	-4,201	0,000
Frangen et al., 2007	0,018	0,002	0,120	-3,907	0,000
Fuji et al., 2000	0,045	0,019	0,104	-6,672	0,000
Gluf et al., 2005	0,014	0,006	0,033	-9,392	0,000
Grob et al., 1991	0,152	0,117	0,195	-11,074	0,000
Guo et al., 2014	0,007	0,000	0,100	-3,507	0,000
Haid et al., 2001	0,004	0,000	0,054	-3,985	0,000
Ito et al., 2008	0,006	0,000	0,095	-3,545	0,000
Jeanerett and Magerl, 1992	0,020	0,001	0,251	-2,724	0,006
Kaminski et al., 2008	0,031	0,010	0,093	-5,784	0,000
Kelleher et al., 2006	0,005	0,000	0,068	-3,802	0,000
Kim et al., 2014	0,107	0,035	0,284	-3,471	0,001
Lee et al., 2010	0,073	0,028	0,179	-4,903	0,000
Liang et al., 2004	0,022	0,003	0,142	-3,734	0,000
Madawi et al., 1997	0,124	0,076	0,196	-7,088	0,000
Marcotte et al., 1993	0,057	0,014	0,201	-3,849	0,000
Nagaria et al., 2009	0,007	0,000	0,103	-3,487	0,000
Naseer and Bailey, 2001	0,022	0,001	0,268	-2,662	0,008
Neo et al., 2003	0,130	0,063	0,248	-4,698	0,000
Ni et al., 2011	0,020	0,001	0,251	-2,724	0,006
Ni et al., 2013	0,003	0,000	0,053	-4,000	0,000
Oshima et al., 2015	0,013	0,001	0,171	-3,070	0,002
Panjasee, 2001	0,050	0,007	0,282	-2,870	0,004
Rajinda et al., 2017	0,033	0,011	0,098	-5,724	0,000
Richter et al., 2004	0,022	0,001	0,268	-2,662	0,008
Stillerman and Wilson, 1993	0,011	0,001	0,154	-3,156	0,002
Uehara et al., 2012	0,026	0,004	0,164	-3,554	0,000
Wang et al., 2007	0,018	0,005	0,068	-5,677	0,000
Weidner et al., 2000	0,035	0,018	0,069	-9,184	0,000
Weng et al., 2012	0,063	0,009	0,336	-2,624	0,009
Werle et al., 2013	0,022	0,006	0,083	-5,339	0,000
Wigfield and Bolger, 2001	0,006	0,000	0,087	-3,617	0,000
Yang et al., 2015	0,060	0,025	0,136	-5,989	0,000
Yonezawa et al., 2005	0,055	0,008	0,306	-2,751	0,006
POINT ESTIMATE	0,032	0,023	0,044	-20,070	0,000

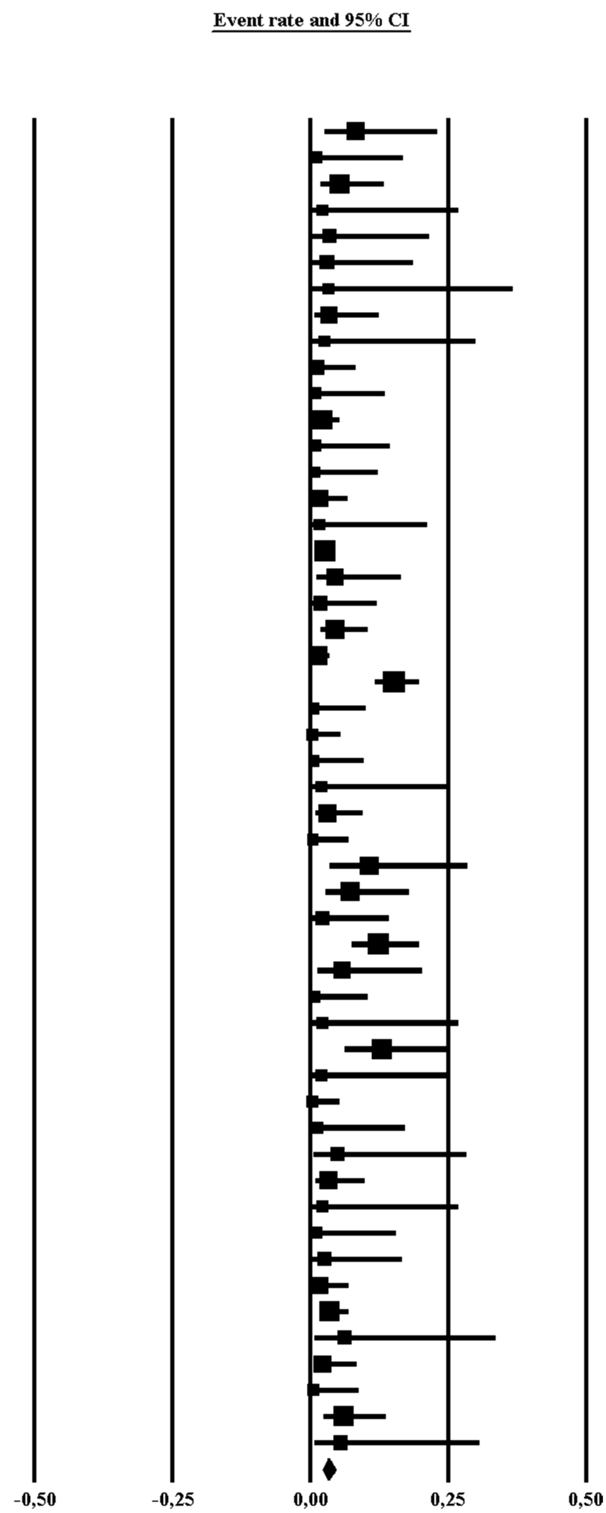

Fig. 3 Point estimates with 95% confidence intervals and forest plot of all included studies reporting on screw malposition rates following posterior transarticular screw fixation

Study name	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Alhashash et al., 2018	0,012	0,001	0,167	-3,088	0,002
Chang et al., 2013	0,033	0,008	0,123	-4,674	0,000
Chih-Yun et al., 2011	0,025	0,002	0,298	-2,558	0,011
Guo et al., 2014	0,007	0,000	0,100	-3,507	0,000
Kim et al., 2014	0,107	0,035	0,284	-3,471	0,001
Ni et al., 2011	0,020	0,001	0,251	-2,724	0,006
Ni et al., 2013	0,003	0,000	0,053	-4,000	0,000
Oshima et al., 2015	0,013	0,001	0,171	-3,070	0,002
Rajinda et al., 2017	0,033	0,011	0,098	-5,724	0,000
Uehara et al., 2012	0,026	0,004	0,164	-3,554	0,000
Weng et al., 2012	0,063	0,009	0,336	-2,624	0,009
Werle et al., 2013	0,022	0,006	0,083	-5,339	0,000
Yang et al., 2015	0,060	0,025	0,136	-5,989	0,000
POINT ESTIMATE	0,038	0,024	0,058	-14,148	0,000

Statistics for each study

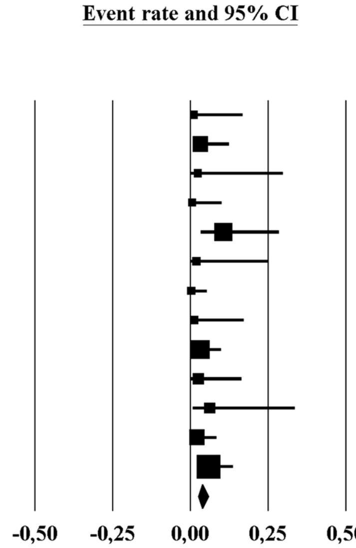

Fig. 4 Point estimates with 95% confidence intervals and forest plot of studies reporting on screw malposition rates following posterior transarticular screw fixation in the last 7 years

differences between the screw malposition rate and cannulated instrument application were revealed (M–U test, $P=0.313$).

Analysis of surgical technique details and VA injury rate

A total of 34 VA injury episodes were revealed in 32 patients from 54 studies. Symptomatic injuries were recorded in 8 cases (0.3% of all patients). In 5 patients, VA injury resulted in arteriovenous fistula formation.

Analysis of patient demographics demonstrated a significantly higher risk of VA injury in younger patients (mean age less than 55 years) (M–W test, $P=0.016$).

Both the intraoperative head fixation methods and the VA injury rate were provided in 36 studies. The VA injury rate was significantly higher in patients who underwent head fixation using skeletal traction (K–W test, $P=0.035$) (Fig. 10).

The size of skin incision and the VA injury rate were provided in 45 studies. The VA injury rate was significantly higher in patients with a larger skin incision (projection of C1–C7 vertebrae with subsequent screw insertion using the midline approach) (M–W test, $P=0.008$) (Fig. 11).

Both the intraoperative visualization method and the VA injury rate were provided in 40 studies. The VA injury rate was significantly higher in patients who underwent surgery under LOF (K–W test, $P=0.0049$) (Fig. 12).

The type of applied instruments and the VA injury rate were provided in 51 studies. No significant differences between the VA injury rate and the type of applied instrument (cannulated or non-cannulated) were revealed (M–W test, $P=0.087$). However, we found a strong tendency for a lower complication rate in patients who underwent cannulated screw insertion (Fig. 13).

Analysis of screw types and screw breakage rate

The total number of screw breakage was 51. Both the fusion development rate and screw failure rate were provided in 42 studies. The screw failure rate was significantly lower in patients with 100% fusion rate (M–W test, $P=0.039$) (Fig. 14).

Both the type of inserted screws and the screw breakage frequency were described in 46 articles. Moreover, both types of screws were used in 9 studies. No screw failure episodes were observed in patients who underwent lag screw insertion. There were no significant differences in the screw failure rate between groups of patients who underwent insertion using both screw types and full-threaded screw insertion only (M–W test, $P=0.718$) (Fig. 15).

The screw diameter and screw breakage rate were provided in 43 studies. The breakage rate was higher in 3.5 mm or thinner screws. Thicker screws (4 mm or more) failed much rarely (K–W test, $P=0.003$) (Fig. 16).

Both the screw breakage rate and the type of inserted screws (cannulated or non-cannulated) were provided in 50 studies. Cannulated screws failed slightly more often (Fig. 17), but the difference was insignificant (M–W test, $P=0.874$).

Discussion

In recent decades, the wide application of TAF, significant advancement in spinal surgery, implementation of modern tools for neurovisualization, and development of new implants took place. However, the rate of screw-associated complications remains to be high. The most recent meta-analysis [5] demonstrates that the VA injury rate following TAF could reach 1.7% per screw. Since 2011, we observed

Study name	Statistics for each study				
	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Acosta et al., 2005	0,014	0,001	0,182	-3,013	0,003
Alhashash et al., 2018	0,012	0,001	0,167	-3,088	0,002
Bahadur et al., 2010	0,040	0,013	0,117	-5,393	0,000
Bapat et al., 2006	0,022	0,001	0,268	-2,662	0,008
Born et al., 2004	0,017	0,001	0,223	-2,834	0,005
Bredow et al., 2015	0,015	0,001	0,196	-2,951	0,003
Campanelli et al., 1999	0,071	0,010	0,370	-2,472	0,013
Chang et al., 2013	0,033	0,008	0,124	-4,682	0,000
Chih-Yun et al., 2011	0,025	0,002	0,298	-2,558	0,011
Chun et al., 2009	0,006	0,000	0,089	-3,600	0,000
Cornefjord et al., 2003	0,009	0,001	0,134	-3,275	0,001
Dickman and Sonntag, 1998	0,004	0,001	0,031	-5,404	0,000
El Masry et al., 2007	0,021	0,003	0,134	-3,810	0,000
Eleraky et al., 1998	0,008	0,001	0,121	-3,353	0,001
ElSaghir et al., 2005	0,004	0,000	0,066	-3,834	0,000
Farrey et al., 1999	0,033	0,005	0,202	-3,311	0,001
Finn and Apfelbaum, 2010	0,012	0,006	0,027	-10,693	0,000
Fountas et al., 2004	0,011	0,001	0,154	-3,156	0,002
Frangen et al., 2007	0,009	0,001	0,129	-3,302	0,001
Fuji et al., 2000	0,004	0,000	0,067	-3,815	0,000
Gluf et al., 2005	0,017	0,008	0,037	-9,854	0,000
Grob et al., 1991	0,002	0,000	0,024	-4,571	0,000
Grob et al., 2006	0,008	0,001	0,116	-3,389	0,001
Guo et al., 2014	0,007	0,000	0,100	-3,507	0,000
Haid et al., 2001	0,004	0,000	0,054	-3,985	0,000
Ito et al., 2008	0,006	0,000	0,095	-3,545	0,000
Jeanerett and Magerl, 1992	0,020	0,001	0,251	-2,724	0,006
Kaminski et al., 2008	0,005	0,000	0,079	-3,697	0,000
Kelleher et al., 2006	0,005	0,000	0,068	-3,802	0,000
Kim et al., 2014	0,017	0,001	0,223	-2,834	0,005
Lee et al., 2007	0,083	0,021	0,279	-3,247	0,001
Lee et al., 2010	0,018	0,003	0,118	-3,953	0,000
Liang et al., 2004	0,022	0,003	0,142	-3,742	0,000
Madawi et al., 1997	0,041	0,017	0,095	-6,884	0,000
Marcotte et al., 1993	0,014	0,001	0,187	-2,993	0,003
Nagaria et al., 2009	0,007	0,000	0,103	-3,487	0,000
Naseer and Bailey, 2001	0,022	0,001	0,268	-2,662	0,008
Neo et al., 2003	0,009	0,001	0,129	-3,302	0,001
Ni et al., 2011	0,020	0,001	0,251	-2,724	0,006
Ni et al., 2013	0,003	0,000	0,053	-4,000	0,000
Oshima et al., 2015	0,026	0,004	0,161	-3,591	0,000
Panjasee, 2001	0,050	0,007	0,282	-2,870	0,004
Rajinda et al., 2017	0,022	0,006	0,085	-5,292	0,000
Richter et al., 2004	0,022	0,001	0,268	-2,662	0,008
Stillerman and Wilson, 1993	0,011	0,001	0,154	-3,156	0,002
Sutipornpalangkul and Thanapipatsiri, 2013	0,049	0,012	0,175	-4,097	0,000
Uehara et al., 2012	0,013	0,001	0,175	-3,052	0,002
Wang et al., 2007	0,004	0,000	0,066	-3,834	0,000
Weidner et al., 2000	0,004	0,001	0,031	-5,409	0,000
Weng et al., 2012	0,029	0,002	0,336	-2,436	0,015
Werle et al., 2013	0,005	0,000	0,080	-3,681	0,000
Wigfield and Bolger, 2001	0,006	0,000	0,087	-3,617	0,000
Yang et al., 2015	0,012	0,002	0,080	-4,392	0,000
Yonezawa et al., 2005	0,026	0,002	0,310	-2,519	0,012
POINT ESTIMATE	0,018	0,014	0,023	-29,678	0,000

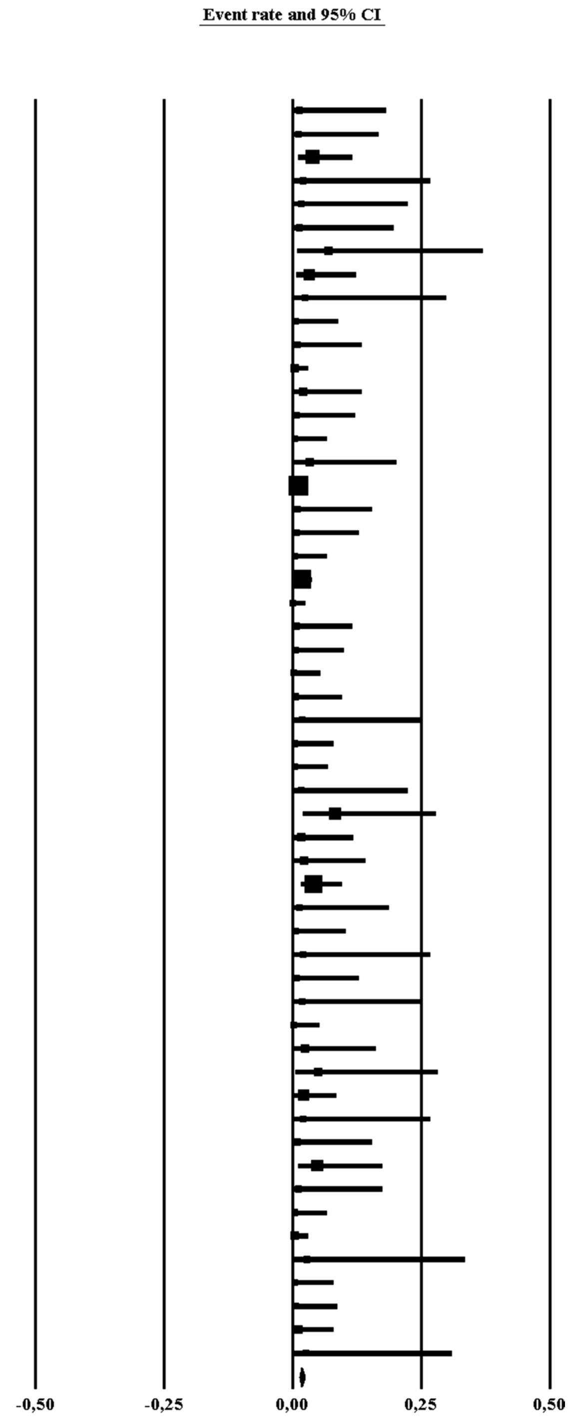

Fig. 5 Point estimates with 95% confidence intervals and forest plot of all included studies reporting on vertebral artery injury rates following posterior transarticular screw fixation

this parameter to increase up to 2.0%. The same dynamics is revealed with regard to the screw malposition rate. Until 2011, this parameter reached 4.5% [5]. Furthermore, since 2011, it remained within the CI and reached 3.8%. Eliott et al. [2, 4, 5] and Akinduro et al. [6] specify clearly the surgery stages associated with the most episodes of VA injury and correlate the development of implant-associated complications with severe degeneration of lateral joints, incomplete reduction of C1 and C2 lateral masses, or abnormal VA anatomy in the atlantoaxial segment. However, a systematic detailed analysis of surgery technique elements is not provided in their studies. VA injury can

Study name	Statistics for each study				
	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Alhashash et al., 2018	0,012	0,001	0,167	-3,088	0,002
Bredow et al., 2015	0,015	0,001	0,196	-2,951	0,003
Chang et al., 2013	0,033	0,008	0,124	-4,682	0,000
Chih-Yun et al., 2011	0,025	0,002	0,298	-2,558	0,011
Guo et al., 2014	0,007	0,000	0,100	-3,507	0,000
Kim et al., 2014	0,017	0,001	0,223	-2,834	0,005
Ni et al., 2011	0,020	0,001	0,251	-2,724	0,006
Ni et al., 2013	0,003	0,000	0,053	-4,000	0,000
Oshima et al., 2015	0,026	0,004	0,161	-3,591	0,000
Rajinda et al., 2017	0,022	0,006	0,085	-5,292	0,000
Sutipornpalangkul and Thanapipatsiri, 2013	0,049	0,012	0,175	-4,097	0,000
Uehara et al., 2012	0,013	0,001	0,175	-3,052	0,002
Weng et al., 2012	0,029	0,002	0,336	-2,436	0,015
Werle et al., 2013	0,005	0,000	0,080	-3,681	0,000
Yang et al., 2015	0,012	0,002	0,080	-4,392	0,000
POINT ESTIMATE	0,020	0,012	0,035	-13,796	0,000

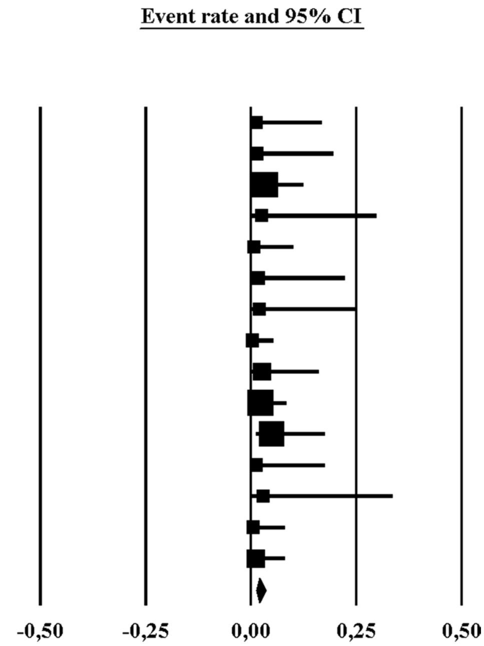

Fig. 6 Point estimates with 95% confidence intervals and forest plot of studies reporting on vertebral artery injury rates following posterior transarticular screw fixation in the last 7 years

result in catastrophic outcomes for the patient. The high incidence rate of this life-threatening complication and critical necessity of its prevention were the key grounds for our study.

Besides the fact that the studies demonstrated a high rate of post-operative complications, we also found large observational series providing the level of implant-associated complications comparable to that of the Goel–Harms technique. These suggest the transarticular technique to be reasonably safe. The highest rate of implant-associated complications was reported by Vergara et al. [61]. There was a high frequency of VA injury reaching 13.2%, and the total rate of post-operative complications reached 21%. However, a detailed description of the surgical technique was not provided, so we did not include these data in our study. Finn et al. [23] performed an analysis on 269 patients and reported a 3.9% rate of implant-associated complications (e.g. screw malposition, VA injury, and screw failure). The VA injury rate in this study reached 1.2%. Authors claim that most complications were observed with emerging surgical techniques. Since then, the significant improvement in surgical skills helped reduce the complication rate. Same results were demonstrated by other groups: Dickman and Sonntag [19], Gluf et al. [27], and others.

We analysed the potential intraoperative factors affecting the development of screw-associated complications. We found that the least effective method of intraoperative head fixation is skeletal traction. The highest rate of VA injury was noted in studies applying skeletal traction. This could be attributed to inadequate cervical immobilization and the high mobility of the cervical vertebrae during drilling and implant insertion. The most efficient head fixation can be achieved using the halo device. However, the use of the Mayfield clamp or halo device can result in the same rate of screw malposition and VA injury.

The size of the skin incision also affected the accuracy of screw insertion. A small incision made through the C1–C2 projection suggested the application of ported instruments placed through contraincisions into the entry point of the C2 vertebra. In contrast to the open screw insertion, a significantly more acute angle is achievable in the C1-2 group [62]. This can result in the reduction of the screw malposition rate. Literature analysis demonstrated a lower rate of screw malposition and VA injury in the C1-2 group.

Intraoperative visualization of screw insertion trajectory was also substantial. It was performed using lateral intraoperative fluoroscopy in the LOF group, but with a visual frontal control. This required broad opening of the C2 arc, pedicle, and lateral atlantoaxial joint. In the BPF group, intraoperative visualization was biplanar. In some cases, a navigation system was applied. Screw insertion using either biplanar fluoroscopic control or navigation control was found to be safer. Despite the obvious disadvantages of uniplanar fluoroscopy, the LOF method was used during the insertion of 2/3 of all screws.

Cannulated instruments were applied during the insertion of 1/3 of all screws. The application of cannulated screws

Study name	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Alhashash et al., 2018	0,025	0,004	0,157	-3,617	0,000
ElSaghir et al., 2005	0,009	0,001	0,060	-4,741	0,000
Grob et al., 2006	0,016	0,002	0,107	-4,037	0,000
Kim et al., 2014	0,036	0,005	0,214	-3,241	0,001
Yang et al., 2015	0,028	0,004	0,173	-3,511	0,000
Dickman and Sonntag, 1998	0,009	0,002	0,035	-6,675	0,000
Fountas et al., 2004	0,045	0,011	0,164	-4,201	0,000
Lee et al., 2010	0,036	0,009	0,134	-4,542	0,000
Grob et al., 1991	0,009	0,003	0,028	-7,967	0,000
Chang et al., 2013	0,067	0,025	0,165	-5,101	0,000
Werle et al., 2013	0,043	0,016	0,110	-6,037	0,000
Kaminski et al., 2008	0,053	0,022	0,121	-6,262	0,000
Madawi et al., 1997	0,041	0,017	0,095	-6,876	0,000
Gluf et al., 2005	0,025	0,013	0,048	-10,746	0,000
Finn and Apfelbaum, 2010	0,022	0,012	0,039	-12,333	0,000
Acosta et al., 2005	0,014	0,001	0,182	-3,013	0,003
Bahadur et al., 2010	0,007	0,000	0,097	-3,536	0,000
Bapat et al., 2006	0,022	0,001	0,268	-2,662	0,008
Borm et al., 2004	0,017	0,001	0,223	-2,834	0,005
Bredow et al., 2015	0,015	0,001	0,196	-2,951	0,003
Campanelli et al., 1999	0,033	0,002	0,366	-2,341	0,019
Chih-Yun et al., 2011	0,025	0,002	0,298	-2,558	0,011
Chun et al., 2009	0,006	0,000	0,089	-3,600	0,000
Cornefjord et al., 2003	0,009	0,001	0,134	-3,275	0,001
El Masry et al., 2007	0,010	0,001	0,143	-3,218	0,001
Eleraky et al., 1998	0,008	0,001	0,121	-3,353	0,001
Farrey et al., 1999	0,016	0,001	0,211	-2,883	0,004
Frangen et al., 2007	0,009	0,001	0,129	-3,302	0,001
Fuji et al., 2000	0,004	0,000	0,067	-3,815	0,000
Guo et al., 2014	0,007	0,000	0,100	-3,507	0,000
Haid et al., 2001	0,004	0,000	0,054	-3,985	0,000
Ito et al., 2008	0,006	0,000	0,095	-3,545	0,000
Jeanerett and Magerl, 1992	0,020	0,001	0,251	-2,724	0,006
Kelleher et al., 2006	0,005	0,000	0,068	-3,802	0,000
Lee et al., 2007	0,020	0,001	0,251	-2,724	0,006
Liang et al., 2004	0,011	0,001	0,151	-3,172	0,002
Marcotte et al., 1993	0,014	0,001	0,187	-2,993	0,003
Nagaria et al., 2009	0,007	0,000	0,103	-3,487	0,000
Naseer and Bailey, 2001	0,022	0,001	0,268	-2,662	0,008
Neo et al., 2003	0,009	0,001	0,129	-3,302	0,001
Ni et al., 2011	0,020	0,001	0,251	-2,724	0,006
Ni et al., 2013	0,003	0,000	0,053	-4,000	0,000
Oshima et al., 2015	0,013	0,001	0,171	-3,070	0,002
Panjasee, 2001	0,024	0,001	0,287	-2,594	0,009
Rajinda et al., 2017	0,005	0,000	0,082	-3,666	0,000
Richter et al., 2004	0,026	0,002	0,310	-2,519	0,012
Stillerman and Wilson, 1993	0,011	0,001	0,154	-3,156	0,002
Sutipornpalangkul and Thanapipatsiri, 2013	0,012	0,001	0,164	-3,106	0,002
Uehara et al., 2012	0,013	0,001	0,175	-3,052	0,002
Wang et al., 2007	0,004	0,000	0,066	-3,834	0,000
Weng et al., 2012	0,029	0,002	0,336	-2,436	0,015
Wigfield and Bolger, 2001	0,006	0,000	0,087	-3,617	0,000
Yonezawa et al., 2005	0,026	0,002	0,310	-2,519	0,012
POINT ESTIMATE	0,022	0,017	0,028	-31,392	0,000

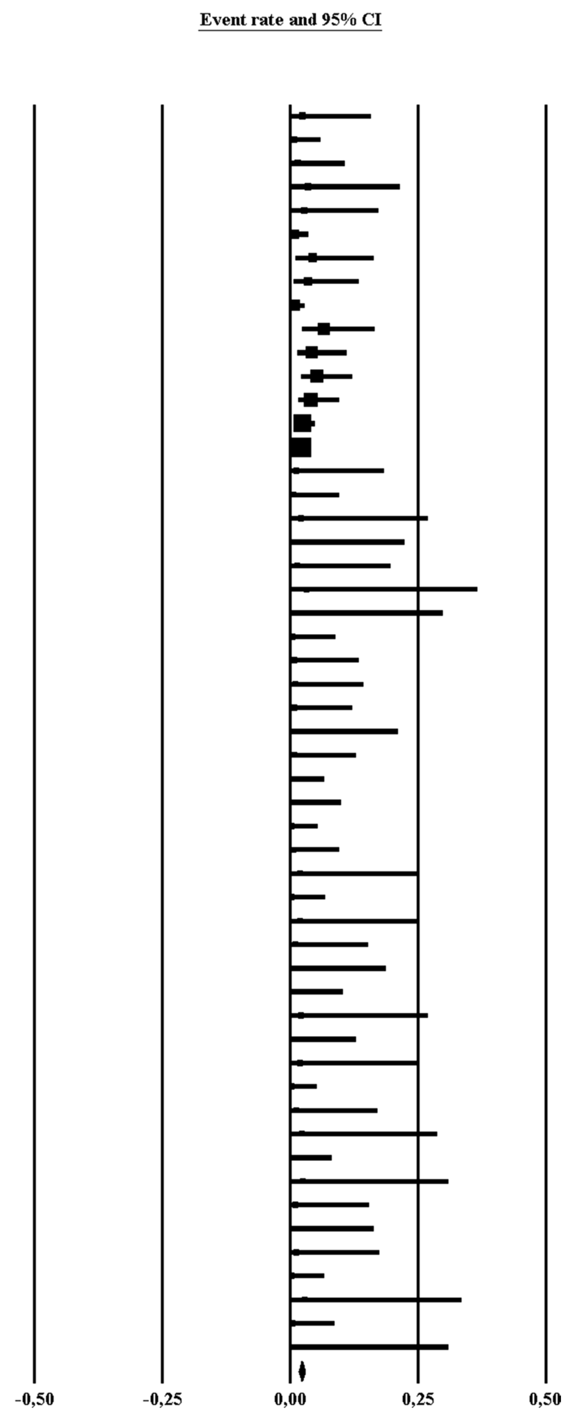

Fig. 7 Point estimates with 95% confidence intervals and forest plot of studies reporting on screw breakage rates following posterior transarticular screw fixation

and K-wires offers several significant advantages including the prevention of drill and screw migration at various surgery stages. This can result in safer screw implantation to craniovertebral segment (Fig. 13).

We also found a clear correlation between the screw breakage rate and C1–C2 non-unions. However, we could not identify the exact sequence of these events, that is, whether screw failure resulted in non-union formation or non-union development resulted in screw failure. Nevertheless, the highest failure rate was observed following the insertion of full-threaded screws. No failure of lag screws was observed. In the case of conventional screw insertion,

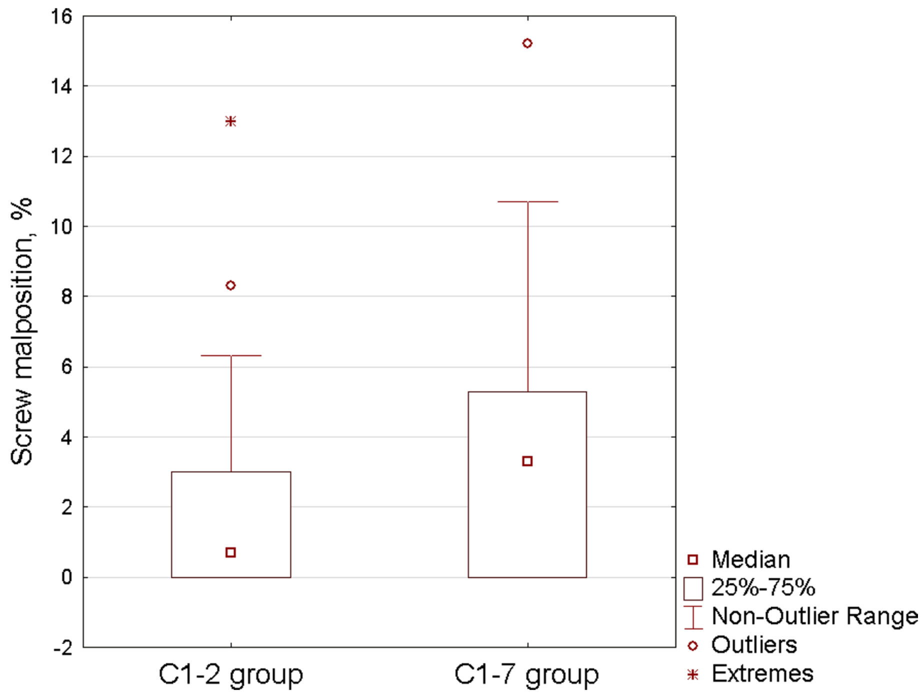

Fig. 8 Box-plot diagram demonstrating the relationship between the screw malposition rate and surgical approach selection. C1-2 group—mini-approach with further performance of contraincisions; C1-7 group—broad incision following screw insertion using the midline approach

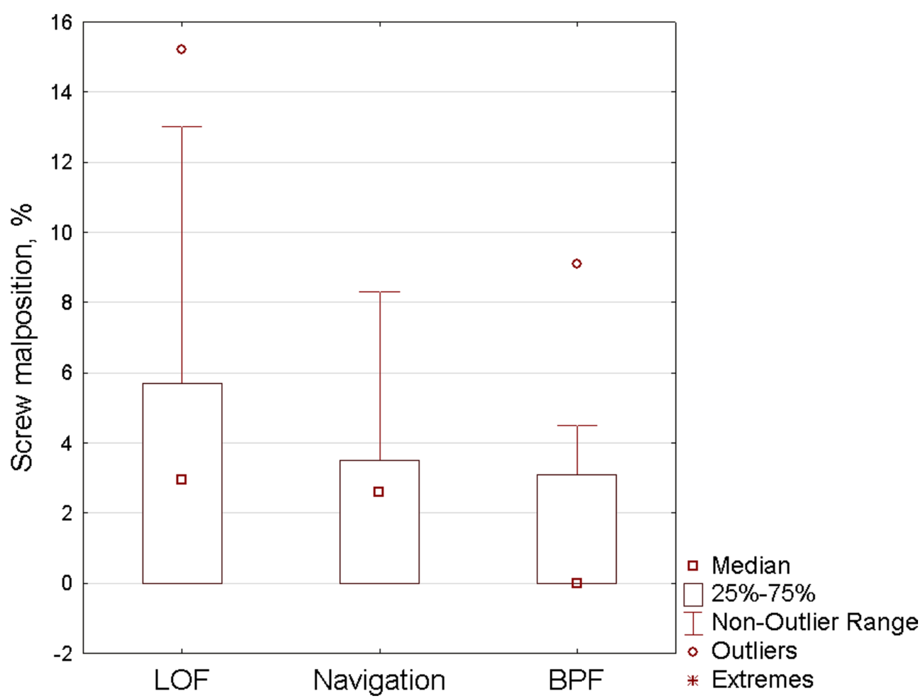

Fig. 9 Box-plot diagram demonstrating the relationship between the screw malposition rate and intraoperative visualization method. LOF—lateral-only fluoroscopy; BPF—biplanar fluoroscopy

major stress falls on the middle part of the screw located in the lateral atlantoaxial joint. The diameter of lag screws in this area was larger than that of full-threaded screws owing to the absence of thread. Lag screws also cause retraction of C1 and C2 lateral masses: this can be another factor of rigidity. The highest breakage rate was observed in 3.5 mm or thinner screws. In many cases screw diameter choice in conditioned by the size of bony corridor along the transarticular trajectory. In case of high-riding VA and narrow C2 isthmus, the surgeon should take in count higher risk of thin screw breakage. Perhaps in this case the one should avoid transarticular fixation, but rather use alternative methods of atlantoaxial stabilization. The failure rate was higher

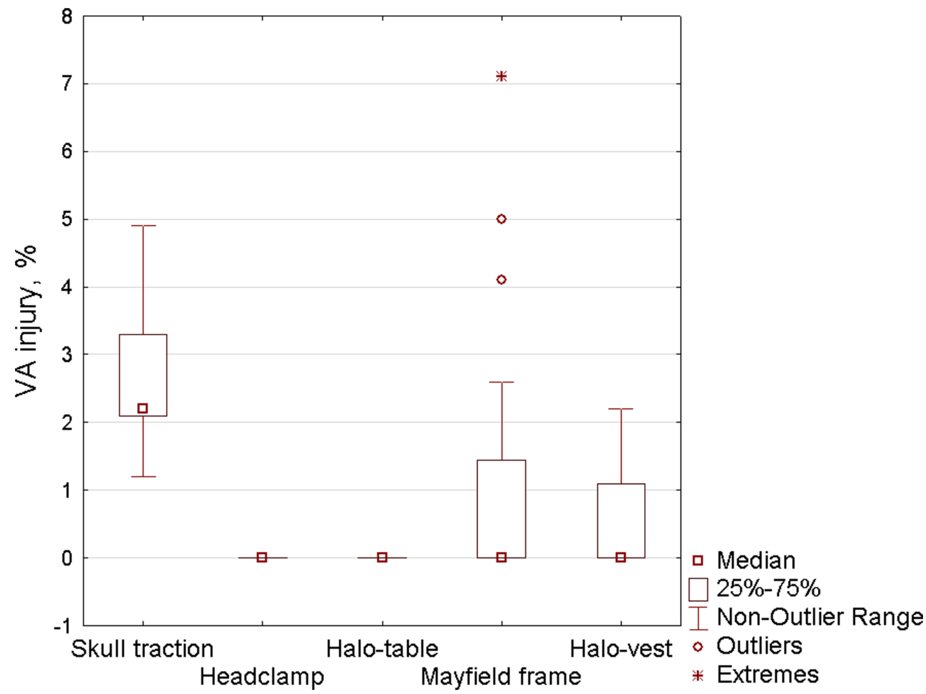

Fig. 10 Box-plot diagram demonstrating the relationship between the VA injury rate and head fixation method. VA—vertebral artery

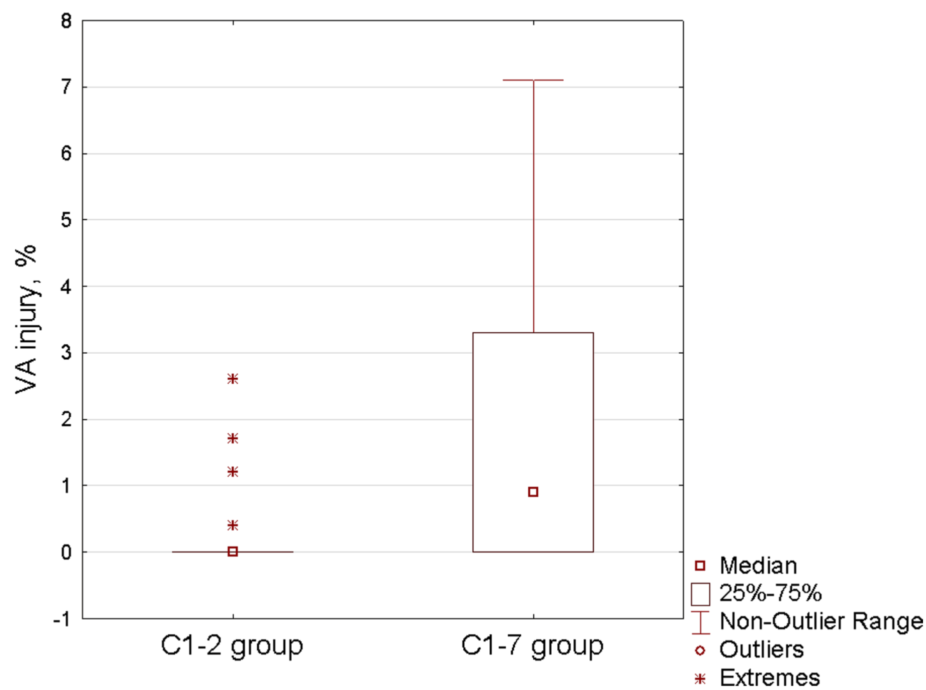

Fig. 11 Box-plot diagram demonstrating the relationship between the VA injury rate and type of surgical approach. VA—vertebral artery; C1-2 group—mini-approach with further performance of contraincisions; C1-7 group—broad incision following screw insertion using the midline approach

in cannulated screws than in non-cannulated ones, but the difference was insignificant.

Thus, literature analysis revealed the following factors preventing the development of screw-associated complications: (a) intraoperative application of BPF or neuronavigation system, (b) screw insertion through contraincisions using cannulated instruments, and (c) application of 4 mm or thicker lag screws. The factors influencing screw-associated complications include inadequate intraoperative cervical fixation using skeletal traction, the use of uniplanar fluoroscopic control during screw insertion, screw implantation using the posterior midline approach, and application of 3.5 mm or thinner cannulated full-threaded screws.

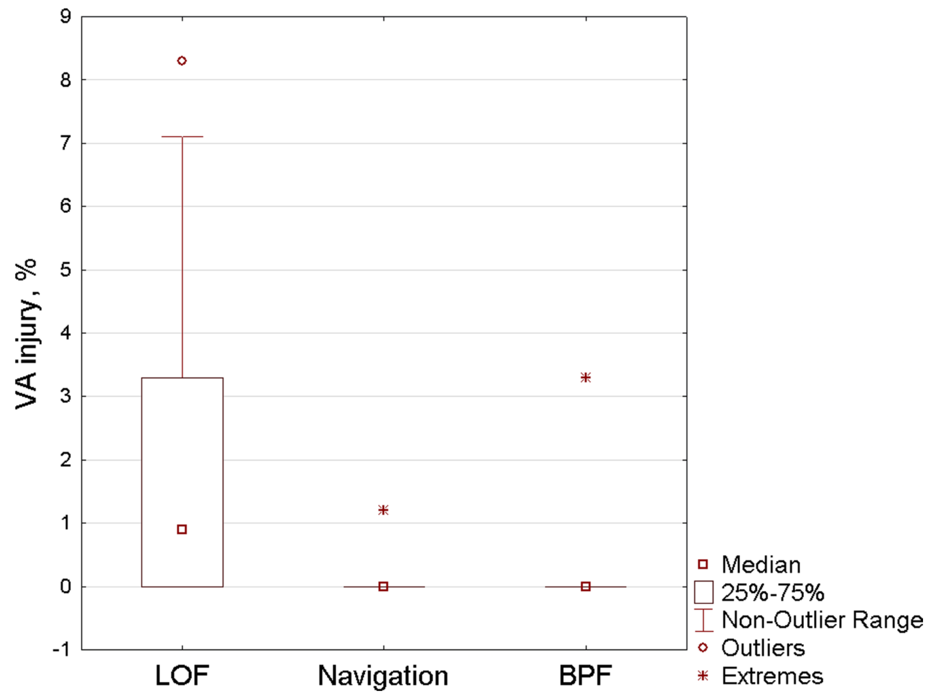

Fig. 12 Box-plot diagram demonstrating the relationship between the VA injury rate and intraoperative visualization method. VA—vertebral artery; LOF—lateral-only fluoroscopy; BPF—biplanar fluoroscopy

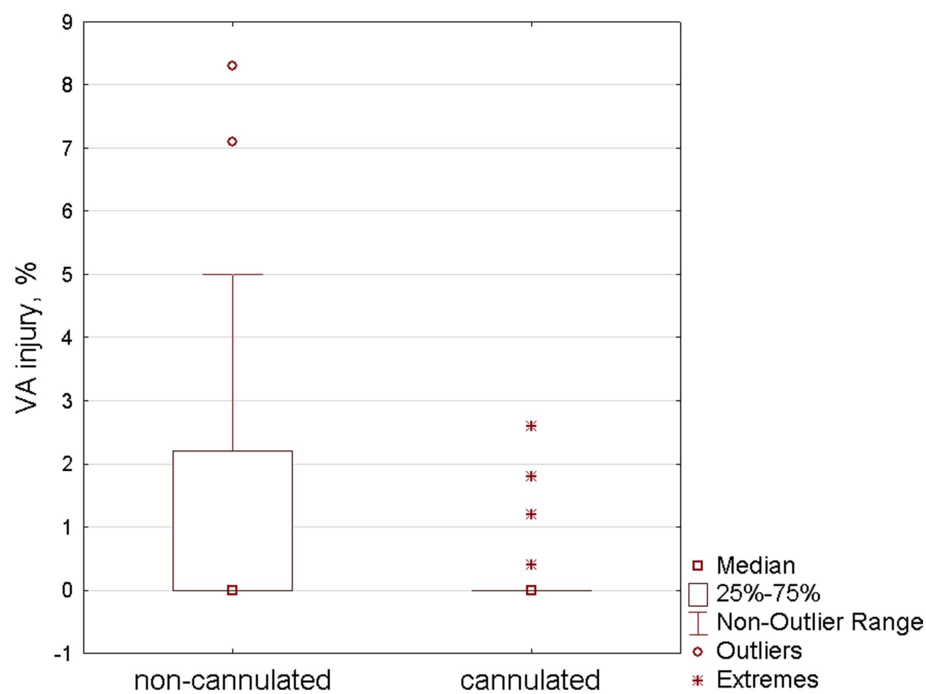

Fig. 13 Box-plot diagram demonstrating the relationship between the VA injury rate and cannulated instrument application. VA—vertebral artery

Study limitations

The limitations of the study need to be acknowledged. First, clinical and demographic data were either missing or could not be disaggregated in some studies. Second, no studies with a high level of significance were found. All our conclusions are based on studies with a level III significance. The obtained data are the outcomes of multiple surgeries, performed by differently skilled surgeons using various surgical techniques. This is indicated both by small groups of patients observed in some studies for a long period of time and large groups of more than 100 patients in others. The broad range of inclusion criteria for selected articles did not allow us to analyse outcomes in some studies providing observed screw-associated complications [61–66]. Unfortunately, in most studies,

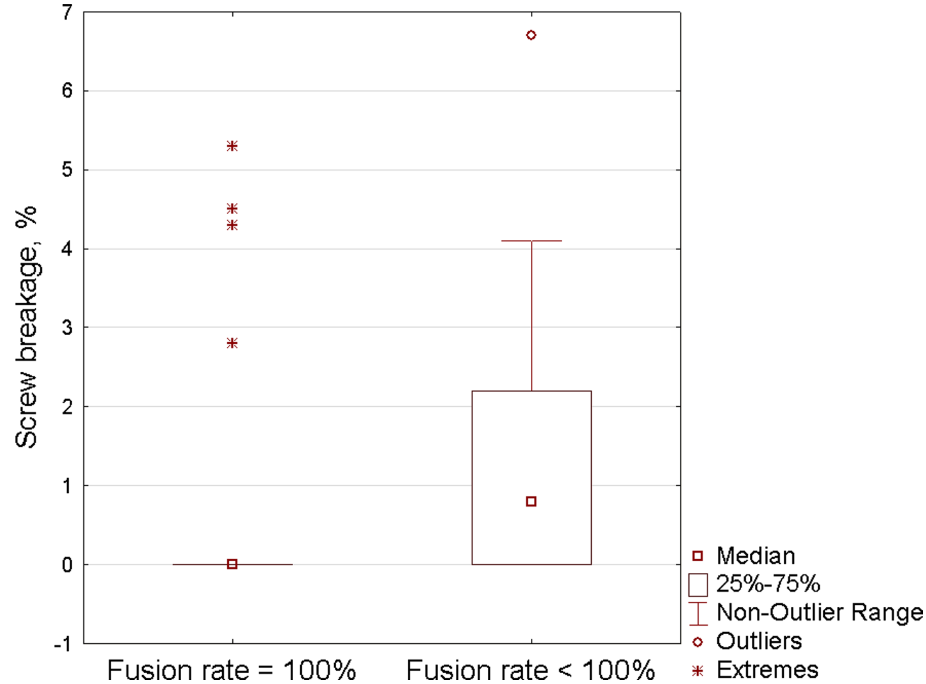

Fig. 14 Box-plot diagram demonstrating the relationship between the screw breakage rate and frequency of C1–C2 non-union development

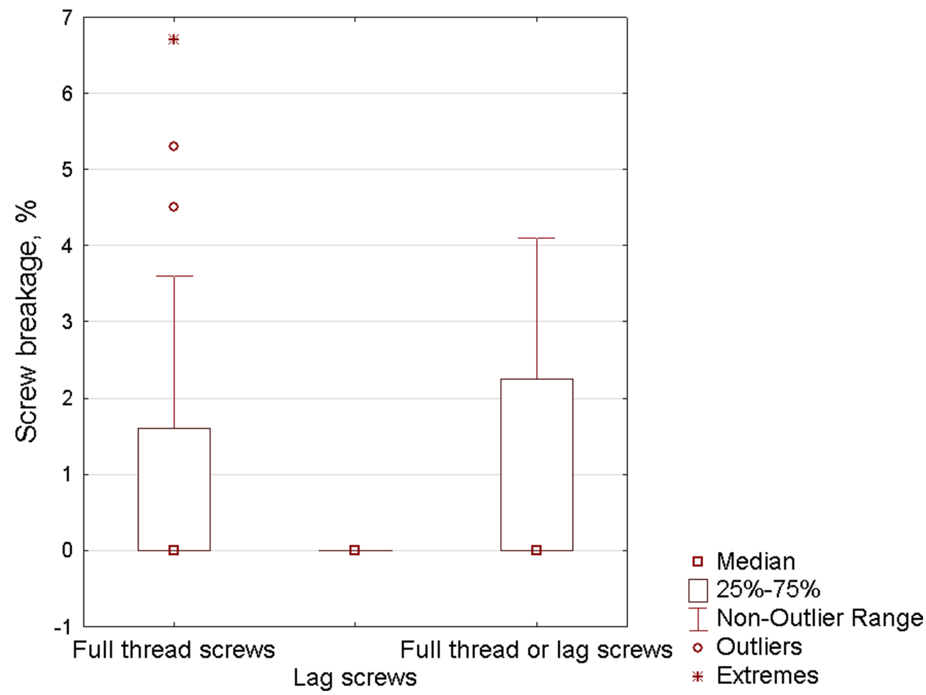

Fig. 15 Box-plot diagram demonstrating the relationship between the screw breakage rate and type of implanted screws (full-threaded or lag screws)

the potential causes of complications are not discussed, except for abnormal VA anatomy or incomplete reduction of C1 dislocation. The complication rate observed in large groups of patients (greater than 50) in different studies using both full-threaded and lag screws was relatively low; thus, we consider the surgical skill to be the key factor of TAF safety. The same observations can be found in previous systematic reviews [2, 4–6]. The surgical techniques found to be optimal by the statistical analysis are not strictly recommended, but rather optional and can result in the improvement of treatment outcomes. Further prospective randomized studies of different surgical techniques should be performed to determine factors of screw malposition following TAF.

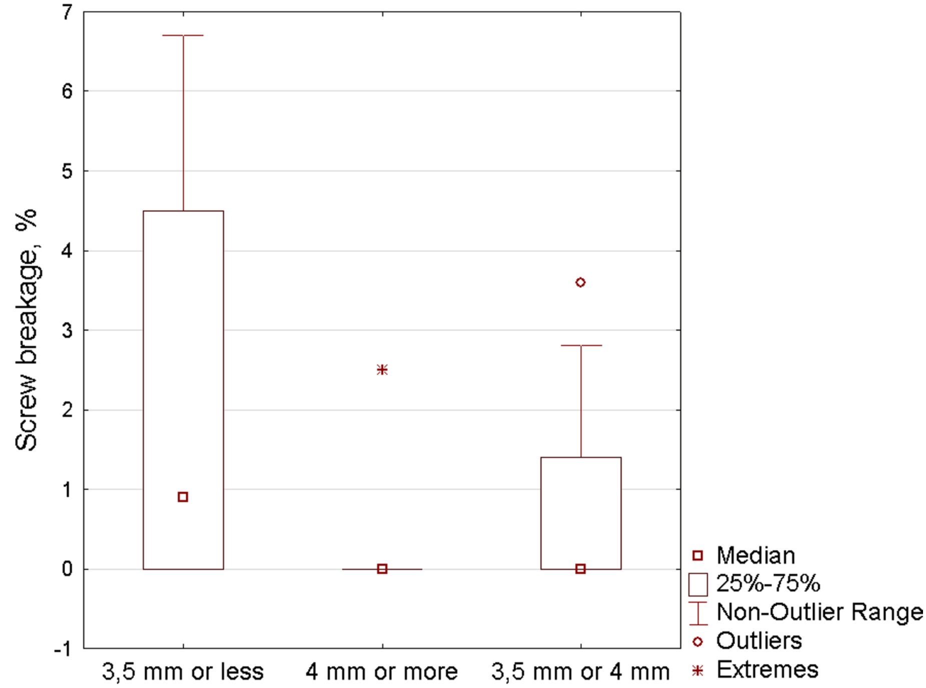

Fig. 16 Box-plot diagram demonstrating the relationship between the screw breakage rate and screw diameter

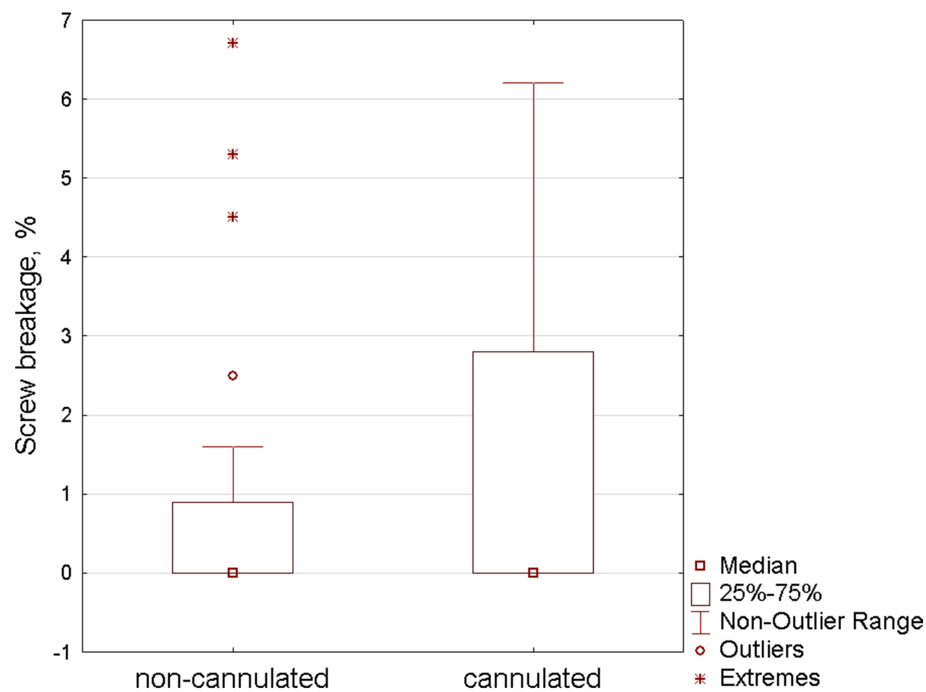

Fig. 17 Box-plot diagram demonstrating the relationship between the screw breakage rate and type of implanted screws (cannulated or non-cannulated)

Conclusions

The factors preventing screw-associated complications include intraoperative application of biplanar fluoroscopic control or neuronavigation system, screw insertion through contraincisions using cannulated ported instruments, and application of 4 mm or thicker lag screws. The potential risk factors of screw-associated complications might include inadequate intraoperative head fixation using skeletal traction, the use of uniplanar fluoroscopic control for screw insertion, screw implantation using the posterior midline approach, and application of 3.5 mm or thinner cannulated full-threaded screws.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no confict of interest.

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