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REVIEW ARTICLE

Incidence of postoperative symptomatic spinal epidural hematoma requiring surgical evacuation: a systematic review and meta-analysis

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Abstract
Purpose This systematic review and meta-analysis aimed to determine the incidence of symptomatic spinal epidural hematoma (SSEH) following spine surgery.
Methods We systematically searched for all relevant articles that mentioned the incidence of SSEH following the spine surgery published in the PubMed, Embase, and Cochrane Library databases through March 2022 and manually searched the reference lists of included studies. The Newcastle–Ottawa quality assessment scale (NOS) was used to assess the quality of the included studies. A fixed-effects or random-effects model was performed to calculate the pooled incidence of the totality and subgroups based on the heterogeneity. The potential publication bias was assessed by Egger's linear regression and a funnel plot. Sensitivity analysis was also conducted.
Results A total of 40 studies were included in our meta-analysis based on our inclusion and exclusion criteria. The overall pooled incidence of SSEH was 0.52% (95% CI 0.004–0.007). In the subgroup analysis, the pooled incidence of SSEH in males and females was 0.86% (95% CI 0.004–0.023) and 0.68% (95% CI 0.003–0.017). Among the different indications, a higher incidence (2.9%, 95% CI 0.006–0.084) was found in patients with deformity than degeneration (1.12%, 95% CI 0.006–0.020) and tumor (0.30%, 95% CI 0.006–0.084). For different surgical sites, the incidences of SSEH in cervical, thoracic and lumbar spine were 0.32% (95% CI 0.002–0.005), 0.84% (95% CI 0.004–0.017) and 0.63% (95% CI 0.004–0.010), respectively. The incidences of SSEH in anterior and posterior approach were 0.24% (95% CI 0.001–0.006) and 0.70% (95% CI 0.004–0.011), respectively. The pooled incidence of SSEH was five times higher with minimally invasive surgery (1.94%, 95% CI 0.009–0.043) than with open surgery (0.42%, 95% CI 0.003–0.006). Delayed onset of SSEH had a lower incidence of 0.16% (95% CI 0.001–0.002) than early onset. There were no significant variations in the incidence of SSEH between patients who received perioperative anticoagulation therapy and those who did not or did not report getting chemopreventive therapy (0.44%, 95% CI 0.006–0.084 versus 0.42%, 95% CI 0.003–0.006).
Conclusion We evaluated the overall incidence proportion of SSEH after spine surgery and performed stratified analysis, including sex, surgical indication, site, approach, minimally invasive surgery, and delayed onset of SSEH. Our research would be helpful for patients to be accurately informed of their risk and for spinal surgeons to estimate the probability of SSEH after spine surgery.

Keywords Spine surgery · Incidence · Symptomatic spinal epidural hematoma · Meta-analysis

Introduction

Spinal epidural hematoma (SEH) after spinal surgery is a common postoperative complication, and the incidence of different degrees of hematoma on imaging is about 33–100% [1–4]. However, most cases have no clinical symptoms. In a few patients, the postoperative hematoma compresses the dural sac, nerve roots or cauda equina, leading to the deterioration of nerve function, with sensory and motor dysfunction in the innervated area, which is called symptomatic

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spinal epidural hematoma (SSEH). Conservative treatment can be taken when the clinical manifestations are mild [5], but sometimes emergency surgery is needed to remove the hematoma because of severe neurological impairment like incomplete or complete paralysis [6–8]. The neurological recovery is related to the time of hematoma detection and surgical removal that the earlier the time, the better the recovery of neurological function [6, 9–11]. In the perioperative complications of spinal surgery, SSEH should be the focus of all spinal surgeons, given the potentially catastrophic prognosis.

According to previous studies, some risk factors were reported for the occurrence of SSEH, including older ages, obesity, history of hypertension, alcohol consuming, smoking, abnormal blood coagulation, multilevel surgery, revision surgery, low serum calcium level [5, 7, 10–22]. But these analyses remained limited because most of the studies were retrospective, owing to the rareness of this complication, so the level of evidence was not high enough. In addition, the criteria of SSEH in case group were different among these studies, for examples, some studies included case group mainly diagnosed by MRI, while others included case groups mainly diagnosed by postoperative clinical symptoms and whether surgery was conducted to remove hematoma, so the reported incidence is varied. Besides, the differences of surgical sites, spinal diseases, approaches and the development of minimally invasive surgery are also the causes of variable results. Determining more credible rates of incidence of SSEH following spine surgery and evaluating potential preventive risk factors is beneficial to patients and doctors that patients can be accurately informed of their risk, and doctors can make better medical decisions.

To our knowledge, a comprehensive meta-analysis has not been performed to study the incidence. In the present study, we defined postoperative SSEH cases to be limited to those patients who required surgical re-intervention. The primary objective aimed to review the related literature to investigate the overall and subgroup incidence of SSEH following spinal surgery requiring reoperation and to establish more robust conclusions about this rare but serious complication.

Materials and methods

Our study is based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines [23]. This study was registered with PROSPERO (ID#CRD42022322126).

Search strategies and information sources

Two authors (Q Chen, Xx Zhong) independently searched the databases PubMed, Embase, and Cochrane library from the date of inception to March 2022. The literature search strategy included: "Spinal Epidural Hematoma", "Symptomatic postoperative hematoma", "Hematomas", "Hemorrhages", and "Hemorrhage". The reference lists of selected essays were also screened to identify supplementary studies regarding the proportion of SSEH requiring the return to the operative room following spine surgery left out in the initial search.

The definition and selection criteria

The primary outcome was the incidence of postoperative SSEH, defined as postoperative SSEH requiring reoperation. The eligible studies were included if they mentioned the number of SSEH patients returning to the operating room and the number of total people in the study, even though the patients who were treated conservatively or assessed radiographically for SSEH were included in the study, retrospectively or prospectively, regardless of sample size. Studies were excluded if they were not published in English; from the same clinical centers with duplicate data or public database; not human subjects as participants; the patient only underwent vertebroplasty or kyphoplasty, Any disagreement was discussed to resolve by two authors.

Data extraction

For the individual included study, two reviewers extracted the data independently: the number of SSEH cases and total population enrolled in the study, the article information including the first author's name, publication year, study type, the country or region of study institute, and the demographic characteristics of the patient including age, sex, surgical indication, site, approach, minimally invasive.

Quality assessment

In order to limit the heterogeneity of hematoma severity, the inclusion criteria are strict that the definition of hematoma required reoperation, so the risk of bias reported in the studies we included was limited. In addition, the quality of included articles was measured by two reviewers with the Newcastle Ottawa Scale (NOS), ranging from 0 to 9 [24]. When the score of a study was <5, it was excluded for its low quality; otherwise, it was included [25].

Statistical analysis

Using the inconsistency index (I^2) and Q statistics, the heterogeneity test of included studies was measured. A random-effects model was used when the heterogeneity test indicated a significant difference ($P<0.10$ and $I^2>50\%$); otherwise, a fixed-effects model was used. The logarithmic transformation would make it obey or close to the normal distribution if the initial rate did not obey so as to improve the reliability of the combined results. We calculated the respective incident of SSEH with its 95% confidence interval (CI) for each study and further generated a pooled incidence and 95%CI [26, 27].

Subgroup analysis was performed referring to sex, surgical indication, site, approach, minimally invasive surgery, and delayed onset. Subgroup pooled incidence was compared between groups using the Chi-square test. A sensitivity analysis was performed to assess the robustness of the primary results. The potential publication and selective reporting bias were assessed using Egger's regression test and a funnel plot. All statistical analyses were conducted by *R* 4.02 software (http://www.r-project.org), and *P* value < 0.05 was considered statistical significance.

Results

Study selection

A total of 1702 studies were screened from the electronic databases. After the removal of duplicates (760), there were 942 unique citations. The remaining 37 articles are screened after reading abstracts. Finally, through reading the complete text, 40 studies were assessed for eligibility, including 15 articles identified by supplementary manual-searching of reference lists. Figure 1 illustrates the study selection process.

Study characteristics

The meta-analysis included 40 studies with a total of 164,934 patients enrolled, and SSEH demanding surgical intervention following spinal surgery was noted in 580 patients. The essential characteristics of the included articles in our study are presented in Table 1.

Meta-analysis of overall incidence

The incidence of SSEH among the studies varied from 0.07 to 5.71%. The overall pooled incidence of SSEH computed as 0.52% (95% CI 0.004–0.007) was described in the Forest plot (Fig. 2) using the random-effects model, with critical heterogeneity of incidence observed.

Subgroup analysis

The subgroup pooled SSEH incidence was summarized in Table 2 according to sex, surgical indication, surgical site, approach, minimally invasive surgery, delayed onset, anticoagulation. Moreover, the result of the heterogeneity test and Chi-square test was also shown.

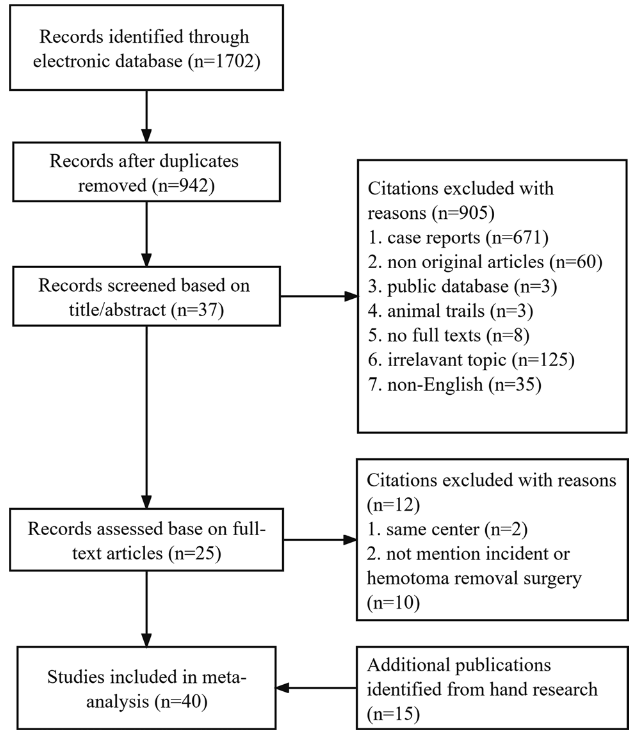

Fig. 1 Flow diagram of the search process in this meta-analysis

Sex

Seven studies [7, 9, 10, 14, 28–30] were included for the analysis of SSEH occurrence between males and females. There were 5868 males and 7044 females, 31 males and 25 females had SSEH, and the pooled incidence of SSEH was 0.86% (95% CI 0.003–0.023, $P < 0.01$, $I^2 = 87\%$) in males, 0.68% (95% CI 0.003–0.017, $P < 0.01$, $I^2 = 84\%$) in females. There was no statistical difference between the two groups ($\chi 2 = 0.11$, $P = 0.74$). (Fig S1).

Indication

A total of 33,583 patients with degenerative disease were included in 15 studies [9, 17–22, 29, 31–37], including 228 patients with SSEH, and the incidence of SSEH was 1.12% (95% CI 0.006–0.020, $P < 0.01$, $I^2 = 91\%$). There was only one study on tumor [38] and deformity [39], respectively, so the meta-analysis could not be carried out. The incidence of SSEH among degenerative disease, tumor and deformity patients was significantly different ($\chi 2 = 20.57$, $P < 0.01$) with 16 of the 5421 patients developing SSEH in tumor group (0.30%, 95% CI 0.002–0.005) and 3 of the 102

Table 1 The essential characteristics of the included studies

Author	Year	Total	Case	Ratio (%)	Type of study	NOS score	Country/Region	Age (mean)	Sex (M/F)	Surgery site	Indication	Approach	MI
Lawton	1995	10,500	12	0.11	Retrospective	6	USA	NA	NA	ALL	ALL	ALL	No
Kou	2002	12,000	12	0.10	Retrospective	6	USA	63.7	NA	ALL	ALL	ALL	No
Uribe	2003	4018	7	0.17	Retrospective	6	USA	62.0	4/3	ALL	ALL	POS	No
Gerlach	2004	1954	13	0.67	Retrospective	6	Germany	59.2	8/5	ALL	ALL	ALL	No
Awad	2005	14,932	32	0.21	Retrospective	6	USA	60.5	14/18	ALL	ALL	ALL	No
Yi	2006	3720	7	0.19	Retrospective	6	Korea	53.1	2/5	ALL	ALL	ALL	No
Schizas	2008	270	2	0.74	Prospective	7	Swit	NA	NA	ALL	ALL	ALL	No
Cramer	2009	11,817	8	0.07	Retrospective	6	USA	66.6	NA	ALL	ALL	ALL	No
Aono	2011	6356	26	0.41	Retrospective	6	Japan	NA	NA	ALL	ALL	ALL	No
Amiri	2013	4568	10	0.22	Retrospective	7	UK	59.5	6/4	ALL	ALL	ALL	No
Cox	2014	1933	10	0.52	Retrospective	7	USA	52.4	4/6	ALL	ALL	ALL	No
YIN	2014	2338	12	0.51	Retrospective	7	China	48.0	8/4	Cervical	ALL	ALL	No
Goldstein	2015	529	6	1.13	Retrospective	6	Canada	67.2	5/1	Cervical	ALL	ALL	No
Kao	2015	15,562	25	0.16	Retrospective	7	Taiwan	64.6	9/16	Lumbar	ALL	POS	No
Yamada	2015	8250	32	0.39	Retrospective	7	Japan	71.0	14/18	ALL	ALL	POS	No
Boudissa	2016	2319	7	0.30	Retrospective	7	France	55.0	4/3	Cervical	ALL	ANT	No
Fujiwara	2017	2468	15	0.61	Retrospective	6	Japan	71.7	7/8	Lumbar	ALL	ALL	Yes
Zeng	2017	4457	9	0.20	Retrospective	6	China	49.3	4/5	ALL	ALL	POS	No
Liu	2017	2715	31	1.14	Retrospective	7	China	59.4	19/12	Lumbar	DE	POS	No
Ohba	2017	1282	6	0.47	Retrospective	6	Japan	62.2	3/3	ALL	ALL	ALL	No
Kadri	2017	2870	30	1.05	Retrospective	6	Finland	63	17/13	ALL	ALL	ALL	No
Kulkarni	2017	381	1	0.26	Retrospective	6	India	NA	NA	Lumbar	DE	POS	Yes
Anno	2019	3371	14	0.42	Retrospective	6	Japan	66.1	NA	ALL	ALL	ALL	No
Fujita	2019	10,071	1	0.10	Retrospective	7	Japan	NA	NA	Lumbar	ALL	POS	No
Eguchi	2019	137	4	2.92	Retrospective	6	Japan	70.5	ALL male	Lumbar	DE	POS	No
Kim	2019	310	6	1.94	Retrospective	6	Korea	NA	NA	Lumbar	DE	POS	Yes
Gao	2019	5421	16	0.30	Retrospective	7	China	47	10/6	ALL	Tumor	ALL	No
Plano	2019	303	3	0.99	Retrospective	7	Spain	NA	NA	Cervical	DE	ALL	No
Wang	2020	9258	47	0.51	Retrospective	7	China	NA	23/24	Lumbar	DE	POS	No
Wang	2020	1612	24	1.49	Retrospective	7	China	53.3	16/6	Thoracic	DE	POS	No
Hohenberger	2020	6024	42	0.70	Retrospective	7	Germany	69.5	20/22	ALL	DE	ALL	No
Merter	2020	245	14	5.71	Prospective	7	Turkey	NA	NA	Lumbar	DE	POS	Yes
Liu	2020	102	3	2.94	Retrospective	6	China	56.3	2/1	ALL	Deformity	POS	No
Mueller	2020	1004	14	1.39	Retrospective	6	USA	NA	NA	Lumbar	DE	POS	Yes
Liao	2020	6890	5	0.07	Retrospective	6	China	59.6	4/1	Cervical	DE	ANT	No
Snopko P	2021	371	7	1.89	Retrospective	6	Slovakia	NA	NA	Lumbar	DE	POS	No

Table 1 (continued)

Author	Year	Total	Case	Ratio (%)	Type of study	NOS score	Country/Region	Age (mean)	Sex (M/F)	Surgery site	Indication	Approach	MI
Aikeremu	2021	3717	12	0.32	Retrospective	7	China	NA	4/8	Lumbar	DE	POS	No
Ahn	2021	237	10	4.22	Retrospective	7	Korea	64.7	5/5	Lumbar	DE	POS	Yes
Saitta	2022	9307	37	0.40	Retrospective	6	USA	66.1	20/17	TL	ALL	ALL	No
Bekki	2022	379	8	2.11	Retrospective	7	Japan	NA	NA	Lumbar	DE	POS	Yes

DE degeneration, *ANT* anterior, *POS* posterior, *MIS* minimally invasive surgery, *TL* thoracolumbar, *NA* data not available

patients occurring SSEH in deformity group (2.94%, 95% CI 0.006–0.084) (Fig S2).

Surgical site

The surgical sites were divided into cervical [8, 10, 11, 13, 14, 19, 28, 36, 37, 40–45], thoracic [8, 11, 13, 19, 28, 31, 40–42, 44–46] and lumbar [5, 8, 9, 11, 13, 16–22, 28, 29, 32–35, 40–42, 44–46] surgery with 15, 12 and 25 studies including 27,779, 16,897, 80,766 patients, respectively, and 72, 104 and 356 patients developed SSEH, respectively. The pooled incidence of SSEH was 0.32% (95% CI 0.002–0.005, $P<0.01$, $I^2=63\%$) for cervical surgery, 0.84% (95% CI 0.004–0.017, $P<0.01$, $I^2=88\%$) for thoracic surgery, and 0.63% (95% CI 0.004–0.010, $P<0.01$, $I^2=92\%$) for lumbar surgery. Statistical difference was found between the three groups ($\chi 2=7.84$, $P<0.05$) (Fig S3).

Approach

The surgical approach was divided into the anterior and posterior approach, and minimally invasive surgery was not included. Four studies [14, 37, 40, 43] mentioned 24 patients developed SSEH in a total of 11,700 patients after anterior approach surgery, and the pooled incidence was 0.24% (95% CI 0.001–0.006, $P<0.01$, $I^2=79\%$). The SSEH occurred in 235 of the 45,103 patients after posterior approach surgery with rate of 0.70% (95% CI 0.004–0.011, $P<0.01$, $I^2=89\%$) in a total of 17 studies [5, 8–11, 14, 16–18, 21, 22, 28, 29, 31, 35, 39, 40]. There was statistical difference between the two groups ($\chi 2=3.96$, $P<0.05$) (Fig S4).

Minimally invasive surgery

The patients were divided into 2 groups: the minimally invasive surgery group and open surgery group. The minimally invasive surgery group included seven studies [16, 20, 29, 32–35] among which of 4882 patients, 66 developed SSEH with a pooled incidence of 1.94% (95% CI 0.009–0.043, $P<0.01$, $I^2=90\%$). In the other group, 34 studies [5–15, 17–19, 21, 22, 28–31, 38–42, 46–49] were included, of 160,052 patients, 514 developed SSEH with a pooled incidence of 0.42% (95% CI 0.003–0.006, $P<0.01$, $I^2=90\%$). The difference between the two groups was statistically significant ($\chi 2=12.41$, $P<0.01$) (Fig S5).

Delayed onset

Delayed onset of SSEH was defined as a time of occurrence > 72 h [28]. There were five pieces of literatures [7, 22, 28, 30, 42] mentioning delayed hematoma, all of which are about open surgery, including 22,300 patients, 33 patients of SSEH, with a pooled incidence of 0.16% (95%

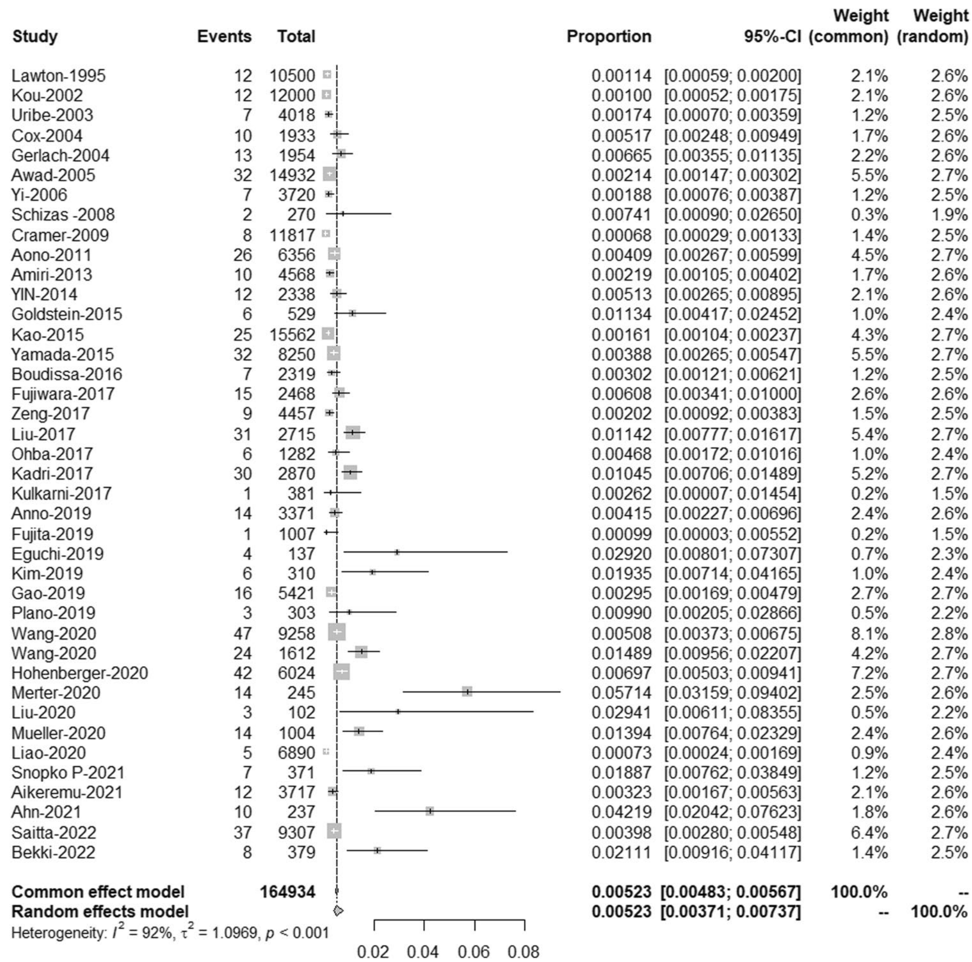

Fig. 2 Forest plot and the overall estimated of the incidence of SSEH by random-effects model

CI 0.001–0.002, $P = 0.65$, $I^2 = 0\%$). As a control, the other 33 studies reported the occurrence of 481 SSEH cases in a total population of 156,034 after open surgery without mentioning delayed hematoma, with a pooled incidence of 0.41% (95% CI 0.003–0.006, $P < 0.01$, $I^2 = 90\%$). There was a statistical difference between the two groups ($\chi 2 = 15.74$, $P < 0.01$) (Fig S6).

Perioperative anticoagulation

In three different studies, the incidence of SSEH in patients receiving perioperative anticoagulation was specifically highlighted. Of the 3216 patients in these studies, 16 had SSEH, with a pooled incidence of 0.44% (95% CI 0.003–0.007, $P = 0.73$, $I^2 = 0\%$). There were no significant differences ($\chi 2 = 0.06$, $P = 0.81$) compared with patients who did not receive chemopreventive therapy or did not report whether they received chemopreventive therapy after open surgery with a pooled incidence of 0.42% (95% CI 0.003–0.006, $P < 0.01$, $I^2 = 89\%$) (Fig S7).

Publication bias and sensitivity analysis

The funnel plot (Fig. 3) and the P-value of Egger's regression test ($P = 0.97$) have shown no publication bias among included studies in our meta-analysis. Sensitivity analysis validated the stability and reliability of the meta-analysis by consecutively omitting each eligible study, indicating that no individual study had an effect of more than 1% on the estimated overall incidence of SSEH.

Discussion

Symptomatic spinal epidural hematoma (SSEH) is one of the most threatening complications after spine surgery [50]. Our study calculated that the overall incidence proportion of SSEH was 0.52% by the random-effects model, with 40 studies included varying from 0.07% to 5.71%. Previous studies have shown that the female sex is a risk factor for SSEH [20]. In our study, the incidence rate was 0.86% in males and

Table 2 Subgroups analysis of the incidence of SSEH

Subgroups	No. of studies	No. of total patients	No. of SSHE	Pooled incidence (%)	95% CI	Q test P value*	I^2 (%)	χ^2 test P value**
Sex								$\chi^2=0.11$ $P=0.74$
male	7	5868	31	0.86	[0.003, 0.024]	<0.01***	87	
female	7	7044	25	0.68	[0.003, 0.017]	<0.01***	84	
Indication								$\chi^2=20.57$ $P<0.01$***
degeneration	15	33,583	228	1.12	[0.006, 0.020]	<0.01***	92	
tumor	1	5421	16	0.30	[0.002, 0.005]	NA	NA	
deformity	1	102	3	2.94	[0.006, 0.084]	NA	NA	
Surgical site								$\chi^2=7.84$ $P<0.05$***
cervical	15	27,779	72	0.32	[0.002, 0.005]	<0.01***	63	
thoracic	12	16,897	104	0.84	[0.004, 0.017]	<0.01***	88	
lumbar	25	80,766	356	0.63	[0.004, 0.010]	<0.01***	92	
Approach								$\chi^2=3.96$ $P<0.05$***
anterior	4	11,700	24	0.24	[0.001, 0.006]	<0.01***	79	
posterior	17	45,103	235	0.70	[0.004, 0.011]	<0.01***	89	
Minimally invasive								$\chi^2=12.41$ $P<0.01$***
Yes	7	4882	66	1.94	[0.009, 0.043]	<0.01***	90	
No	34	160,052	514	0.42	[0.003, 0.006]	<0.01***	90	
Delayed onset								$\chi^2=15.74$ $P<0.01$***
Yes	5	22,300	33	0.16	[0.001, 0.002]	=0.65	0	
No	33	156,034	481	0.41	[0.003, 0.006]	<0.01***	90	
Anticoagulation								$\chi^2=0.06$ $P=0.81$
Yes	3	3216	14	0.44	[0.003, 0.007]	=0.73	0	
No	32	160,052	495	0.42	[0.003, 0.006]	<0.01***	89	

NA data not available

*By Q test

**By Chi-square test

***Significant P value

0.68% in females in the subgroup analysis, indicating that sex is not associated with the incidence of SSEH ($P=0.74$).

For the different indications, the incidence of SSEH in tumor, degenerative disease, and deformity patients was 0.30%, 1.12%, 2.94%, respectively. The comparison among groups showed statistical differences ($P<0.01$). Degenerative disease mainly include spinal stenosis, spondylolisthesis, and disc herniation. Only one study was about the incidence of SSEH on spinal deformity and tumor, respectively. The spinal tumor surgeries in the single-center retrospective study included vertebral, extradural, intradural extramedullary, and partially intramedullary tumor and the deformities were adult spinal deformity (ASD) patients in another single-center retrospective study. Spinal deformities and tumors may cause a higher incidence of SSEH than degeneration, but this result may be biased and unreliable.

Among different surgical sites, the incidence of SSEH in cervical, thoracic and lumbar surgery was 0.32%, 0.84%, and 0.63%, with the statistical difference between the three groups ($P<0.05$). The surgical approach is simply divided into anterior and posterior, and we only included the literature on open surgery. The posterior approach is more common and routine than the anterior approach, and much works of the literature did not clearly distinguish the incidence of the anterior approach from all surgery, so only four studies of the anterior approach were included in the meta-analysis. The incidence of anterior versus posterior approach was different in our study (0.24% versus 0.70%, $P<0.05$). Anterior

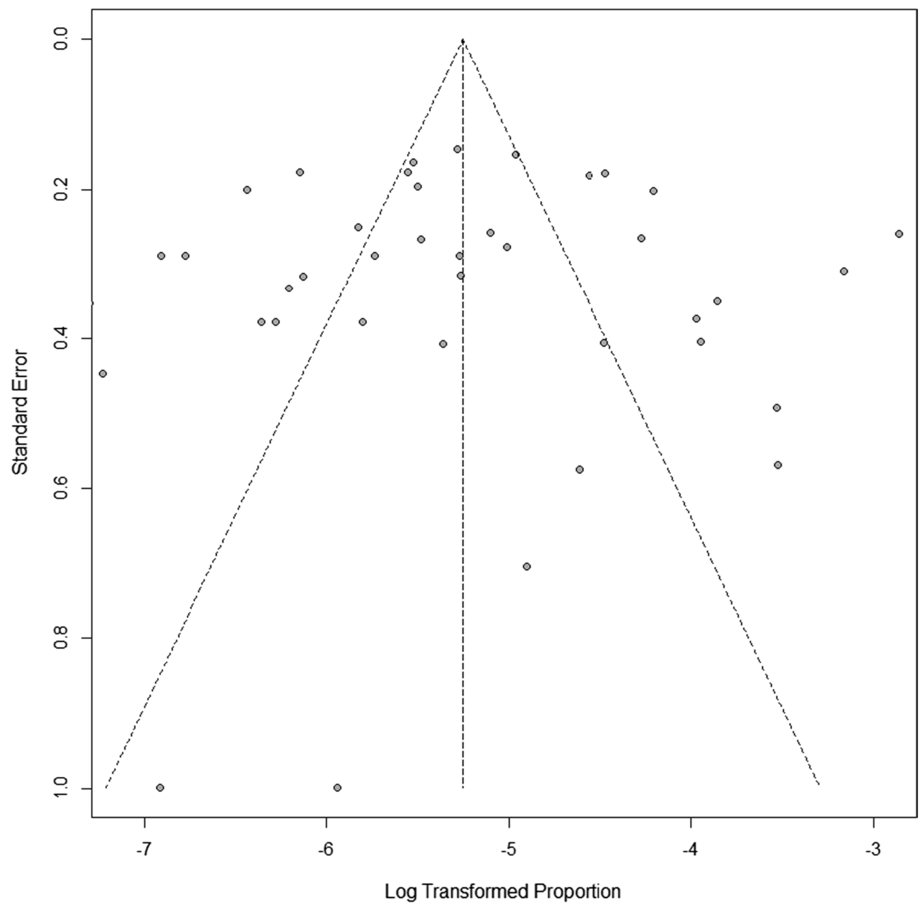

Fig. 3 Funnel plot of the citations referring to the incidence of SSEH

surgery is usually performed on the cervical spine, with little exposure and milder intraspinal venous plexus injury, which means minor bleeding than posterior approach. The same could be said for the low incidence of SSEH in cervical surgery.

In recent years, minimally invasive surgery has been widely used in spinal surgery, and it can reduce lengths of stay and accelerate recovery of function [51]. Some studies have pointed out that minimally invasive surgery cause higher incidence of SSEH than open surgery [29, 52, 53]. We also came to similar results. The prevalence of SSEH after minimally invasive surgery ranged from 0.26% to 8.41%, compared with 0.07% to 2.94% for open surgery. The pooled incidence of SSEH was about five times higher with minimally invasive surgery than with open surgery (1.94% versus 0.42%, $P<0.01$). On the one hand, the operation under microendoscopy or arthroscopy requires continuous saline irrigation, the pressure setting of which may be higher than the venous pressure to prevent venous bleeding so that surgeons may ignore the intraoperative bleeding [20, 29]. On the other hand, poor visualization due to smaller surgical fields increases the difficulty of observing the bleeding site adequately than in open surgery. So the bleeding during the minimally invasive procedure may be masked [32, 54]. In addition, bone bleeding is difficult to control intraoperatively because the usage of bone wax is affected by the saline flow. What is more, it is impossible to compress the surgical site by tightly suturing muscles and fascia intraoperatively [29]. In a word, the likelihood of SSEH was higher in minimally invasive surgery on the spine for various reasons leading to insufficient hemostasis during operation, which ultimately leads to the occurrence of SSEH following surgery, so spine surgeons should be more careful to control bleeding adequately.

According to the reported study [22, 28], SSEH is divided into early-onset (≤ 72 h) and delayed-onset (> 72 h) based on the time of postoperative onset. Delayed hematoma increases the difficulty in diagnosis [42]. In this meta-analysis, we found that the incidence of delayed onset of SSEH was just about 1/3 of other studies (0.16% versus 0.41%, $P<0.01$). Although the incidence is much lower, delayed onset of SSEH is still a severe complication that is impossible to ignore. Clinicians should be alert to the possibility of delayed hematoma [22].

It is well known that perioperative anticoagulation can reduce the incidence of deep venous thrombosis (DVT) and pulmonary embolism (PE). Whether perioperative anticoagulation therapy increases the risk of epidural hematoma is still controversial. In our study, we found that perioperative chemoprophylactic anticoagulation did not enhance the incidence of SSEH. Gerlach et al. [45] performed a retrospective study, where they investigated 1954 cases who all received anticoagulation therapy after spine surgery. A total of 13 cases of postoperative spinal hematoma occurred, among which 5 cases (0.26%) occurred before anticoagulation therapy and 8 cases (0.41%) occurred after anticoagulation therapy, indicating that there was no correlation between chemoprophylaxis and postoperative hematoma. A retrospective cohort study [30] was conducted to compare a group of patients who received postoperative chemical anticoagulation to a previous group of patients who did not get this regimen. There is no statistically significant difference in the incidence of SSEH between the preprotocol (n = 944, 0.6%) and postprotocol (n = 994, 0.4%) groups. Similarly, Sharpe et al. [55] found that increasing the dosage of chemoprophylactic anticoagulation in patients with surgically treated spinal fractures reduced the risk of PE (0.4% vs 2.2%), without increasing bleeding complications (2.1% vs 2.9%). However, there are no clear standards regarding the necessity of chemoprophylaxis following elective spine surgery.

Kreppel et al.[56] 's meta-analysis showed that SSEH occurred more frequently within 24 h after spinal surgery, especially 4–6 h after surgery. Early diagnosis and surgical intervention play an important role in neurological recovery [10, 15]. Amiri et al. [13] published research showed that decompression was performed within 6 h of the occurrence of SSEH, and Frankel's mean improvement was grade 2, while surgical decompression after 6 h, the mean improvement was just grade 1. Yamada et al. [11] reported that those patients who underwent the evacuation of hematoma within 24 h of the onset had significantly better improvement in clinical outcome and Frankel grade than those who did after 24 h. Early diagnosis requires careful evaluation of the patient's clinical manifestations. SSEH should be highly suspected if new neurological disorders (severe pain at the surgical site, radicular pain in the lower extremities, decreased muscle strength, and hypoesthesia) appear [7, 10]. In addition, the size and location of hematoma can be assessed by MRI [5, 20, 32]. A study in Germany showed that many doctors used drainage tubes in spinal surgery based on personal habits and experiences, which were inconsistent [57]. Some studies suggested that inadequate postoperative drainage or the absence of a drainage tube may be a risk factor for SSEH after spinal surgery [8, 9, 16]. Nevertheless, several studies suggested that the use of drainage tubes could not reduce the incidence of SSEH [12, 58, 59]. The necessity of postoperative drainage remains controversial, but recently more high-quality studies [57, 58, 60–64] have concluded that the usage of drainage tubes after spinal surgery cannot decrease postoperative complications, including the SSEH, even increase the need for perioperative blood transfusion. A similar conclusion was drawn by a meta-analysis [65].

To our knowledge, our study was the first meta-analysis focused on the incident of SSEH in spine surgery patients specifically. However, some limitations may exist in our meta-analysis. First, assessment of the incidence of SSEH varied from study to study due to the rarity of the incidence of this disease, resulting in increased heterogeneity, even though we conducted the subgroup analysis to explore the potential sources of heterogeneity. Second, few studies in some areas like tumor and deformity may increase bias. Third, some eligible literature was not designed for the incidence of SSEH after surgery requiring surgical re-intervention, which may result in the pooled data's inaccuracy.

In summary, the incidence of SSEH in the population was 0.52%, and we also assessed each subgroup in this meta-analysis to provide appropriate references for doctors and patients.

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Declarations

Conflict of interest All authors certify that they have no conflict of interest.

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