International Orthopaedics (SICOT) (2017) 41:1395–1403
DOI 10.1007/s00264-017-3506-2

ORIGINAL PAPER

Causes and preventive measures of symptomatic spinal epidural haematoma after spinal surgery

Xiao-Jun Zeng[1] · **Wei Wang**[1] · **Zhou Zhao**[1] · **Ming Li**[2]

Received: 12 March 2017 / Accepted: 7 May 2017 / Published online: 24 May 2017

Abstract
Study design This was a retrospective study to evaluate clinical characteristics of patients who developed symptomatic spinal epidural haematoma (SSEH) after spinal surgery.
Objective The objective was to determine clinical parameters associated with the development of SSEH after spinal surgery, and to discuss clinical management and possible preventive measures.
Summary of background data Although the incidence rate of SSEH is low, the neurological sequelae are devastating. There are limited reports which identify risk factors for SSEH because of the rarity of the condition.
Methods The 4,457 cases of spine operations performed in two medical centres were reviewed. Eleven of the cases developed postoperative spinal epidural haematomas, causing neurologic deterioration. The clinical manifestations of these 11 cases were described, and factors associated with the recovery of neurologic function were evaluated.
Results The causes of SSEH following spinal surgery included inadequate drainage (9 cases), administration of anticoagulants (6 cases) and complicated coagulation disorders (1 case). The main clinical manifestation was progressive neurological deterioration in the innervated area. Seven cases underwent MRI examination and compressions of dural sac and spinal cord were observed. High pressure haematomas were found in eight cases during haematoma evacuation. Statistical analyses showed that patients with mild nerve injury at the initial stage were associated with better recovery ($P<0.05$). Patients who recovered completely had shorter symptom duration on average.
Conclusions Post-operative bleeding in the wound and inadequate drainage are the primary causes of SSEH. The severity of neurologic injury before haematoma evacuation was associated with the treatment outcome; therefore, it is important to have early diagnosis of SSEH to prevent progression of the neurologic injury.

Keywords Spinal epidural haematoma · Spinal surgery · Low molecular weight heparin · Suction drainage · Bleeding

Introduction

Epidural haematoma is a complication of spinal surgery, with an incidence rate of approximately 0.1–3% [1–4]. Most epidural haematoma are asymptomatic and require no treatment [5–7]. However, on rare occasions, the conditions of epidural haematoma could become clinically evident and require immediate operation. Pain around the wound and/or the innervated area is the predominant initial symptom. The haematoma could cause compression of the spinal cord or nerve roots, leading to neurological consequences, such as urinary and fecal incontinency, motor and sensory loss [8]. We define such conditions as symptomatic spinal epidural haematoma (SSEH); and if not treated timely, irreversible neurological sequelea may occur.

Because of the rarity of the SSEH, are were only limited reports investigating the risk factors of the development of SSEH after spinal surgery [1, 4, 7, 9, 10]. The risk factors

Co-first authors: Xiao-Jun Zeng and Wei Wang

✉ Zhou Zhao
xianzhongliping@163.com

[1] Department of Spine Surgery, Renmin Hospital, Hubei University of Medicine, No. 39 Middle Chaoyang Road, Shiyan, Hubei 442000, People's Republic of China

[2] Department of Orthopaedic Surgery, Changhai Hospital, Second Military Medical University, Shanghai, People's Republic of China

include: advanced age (> 60 years old), use of pre-operative non-steroidal anti-inflammatories, high alcohol consumption (> 10 units/week), history of spinal surgery, pre-operative coagulation disorder, Rh-positive blood type, insertion of drain, multi-segmental operation, intra-operative hemoglobin <100 g/L, blood loss >1 L, and an international normalized ratio > 2.0 within the first 48 hours post-surgery. Most of these factors are uncontrollable. In this study, we carried out a detailed review of 11 cases that developed post-operative SSEH, aiming to explore if any other controllable clinical parameters are associated with SSEH; practical measures for the prevention of SSEH were also discussed.

Patients and methods

We retrospectively reviewed 4,457 cases that underwent spinal surgery in two medical centres between November 2009 and November 2012. Among the 4,457 cases, 11 developed post-operative SSEH. Demographic and clinical information was collected, including age, gender, medical history, coagulation function, blood type, surgical site, number of segments operated, intra-operative blood loss, peri-operative medication, drainage use, onset time and symptoms of SSEH, imaging features, SSEH symptom duration before haematoma evacuation, findings during re-operation, management and recovery results. Neurological state was assessed by using the American Spinal Injury Association (ASIA) grading system at the following time points: before and immediately after initial operation, before and two weeks after haematoma evacuation, the last follow-up.

The 11 SSEH cases included six male and five female patients. The age was from 21 to 82 years old (Table 1). The mean follow-time was 9.2 months (ranging from 3 to 16 months) (Table 2). All 11 cases had normal coagulation function, positive Rh blood type and had used post-operative drainage. The average blood loss was 972.7 ± 666.5 ml, and the mean number of segments operated was 2.18 ± 1.33. The first operation was performed for the following medical conditions: spine fracture for trauma (1 case), deformity (3 cases), degenerative diseases (6 cases), and angioma in spinal canal (1 case). All of the patients underwent posterior spinal surgery, except one case in which a combined procedure was performed. The sites of operation were: 18.2% cervical (2 cases), 9.1% cervicothoracic (1 case), 9.1% thoracic (1 case), 18.2% thoracolumbar (2 cases), 45.5% lumbar (5 cases). Tables 1 and 2 show the details of the cases.

Statistical analysis of the associations between clinical parameters and recovery was performed using SPSS Statistics 17.0 (Chicago, IL, USA). Independent sample *t*-test was used to compare the SSEH symptom duration between the complete recovery group and incomplete recovery/no improvement group. Mann-Whitney U-test was used to compare the neurological state at different time points between the two groups.

Results

Symptoms of SSEH

Neurological impairment was observed in patients with SSEH. All but one patient had the impairment emerge in bilateral lower limbs. Urinary or fecal incontinence was reported in three patients (27.3%). New deficits or deterioration of neurological function were found in all 11 cases (100%). Pain around the wound area occurred in two cases (18.2%), and radiating pain occurred in one patient (9.1%).

Medical history and findings during haematoma evacuation

Case number 6 had small volume platelet with a history of chronic lymphocytic leukemia, indicating a higher chance of haemorrhage. Six cases were administered with low molecular weight heparin (LMWH) post-surgery, and two of them developed SSEH after removal of the drain tube (3–4 days after surgery), suggesting the occurrence of re-bleeding after the drain tube was removed.

There were nine cases with SSEH developed before the drain tube was removed (average 10.0 ± 8.3 h after surgery), and uncoagulated blood was found during the haematoma evacuation, indicating an inadequate drainage. During the second operation, uncoagulated blood spewed out in eight cases, indicating the high blood pressure in the haematoma.

MRI findings

MRI examinations were performed in seven cases before haematoma evacuation. The typical manifestations of the haematoma were: heterogeneous hyperintense/isointense signal in T2-weighted images (Figs. 1 and 3) or isointense/slightly hyperintense signal in T1-weighted images (Figs. 2 and 3). The dural sac and spinal cord were compressed.

Treatment and outcome

In this cohort, SSHE was treated either conservatively (by suction drainage or sucking with a syringe) or by a second operation. Two cases, case numbers 2 and 3, were treated conservatively. The second operation was performed on the other nine cases to evacuate haematoma. Closed drainage container without vacuum was used postoperatively in case number 2, and the patient developed SSEH three hours after

Table 1 Patient profile

Patient number	Centre	Gender/ Age	Risk factor	Diagnosis	Operation (number of segments)	Blood loss (ml)	OTAIO (hours)	Management and findings
1	A	M/43	LMWH	L4/5 spondylolisthesis	Posterior L4–5 decompression, reduction and fusion (1)	600	96	Re-operation. High pressure haematoma of uncoagulated blood
2	B	M/57	None	Adjacent degeneration after cervical fusion	Posterior C3–6 laminectomy and fusion (4)	500	3	Conservative. No suction used for drain at first. Blood flow out when container was removed from the tube. 20 ml blood was aspirated through a syringe. Then, continuous suction drain was used instead
3	A	M/46	LMWH	C4 fracture	Combined anterior and posterior C3–4 decompression and fusion (2)	800	4	Conservative. Symptom disappeared after 30 ml blood was aspirated through a syringe
4	A	F/47	LMWH	lumbar spinal stenosis	Posterior L4-S1 decompression and fusion (2)	500	18	Re-operation. High pressure haematoma of uncoagulated blood
5	A	F/21	LMWH	T10 old fracture and segmental kyphosis	Posterior T10 PSO and fusion (1)	1200	19	The wound suture was removed immediately and uncoagulated blood spewed out
6	B	M/82	CLL for 16 years, small volume PLT	Cervicothoracic intraspinal angioma	Posterior C6-T2 laminectomy and resection of angioma (4)	300	5	Re-operation. 100 ml uncoagulated blood was evacuated. Active bleeding at muscular layer
7	B	F/54	None	T12 old fracture and segmental kyphosis	T12 PSO and fusion (1)	1800	3	Re-operation. 100 ml uncoagulated blood was evacuated
8	B	M/26	None	T11-L2 butterfly vertebra and segmental kyphosis	L2 PSO and fusion (1)	2500	3	Re-operation. 6 ml blood clot located in the left side of spinal canal
9	A	M/40	LMWH	Lumbar disc hernia and lumbar spinal stenosis	L4–5 discectomy and canal decompression and fusion (1)	500	72	Re-operation. High pressure haematoma of uncoagulated blood
10	A	F/69	LMWH	Lumbar spinal stenosis	L3–5 canal decompression and fusion (3)	800	11	Re-operation. High pressure haematoma of incoagulated blood
11	B	F/62	None	Lumbar spinal stenosis	L2-S1 laminectomy and fusion (4)	1200	24	Re-operation. 100 ml haematoma and clot compressing spinal cord

F female, *M* male, *LMWH* low molecular weight heparin, *PSO* pedicle subtraction osteotomy, *PLT* platelet, *CLL* chronic lymphocytic leukemia, *OTAIO* onset time after the initial operation

A = Renmin Hospital, Hubei University of Medicine, Shiyan, Hubei

B = Changhai Hospital of the Second Military Medical University, Shanghai

Table 2 Symptoms, symptom duration before haematoma evacuation and neurologic function

Number	Symptom	SDBHE (h)	ASIA grade					Followed up (months)	Recovery
			BIO	AIO	BHE	2WAHE	final follow-up		
1	Motor/sensory dysfunction	2.5	D	D	D	D	D	12.3	Complete
2	Motor/sensory dysfunction	1	D	D	C	D	E	3	Complete
3	Sensory dysfunction /dyspnea	1	E	E	D	E	E	4	Complete
4	Motor/sensory dysfunction	2	D	D	D	D	D	16	Complete
5	Pain around the wound, Motor/sensory dysfunction	1	E	E	D	E	E	13	Complete
6	Incontinence of urine, Motor/sensory	26	D	D	C	D	D	8	Complete
7	Motor/sensory dysfunction	3	D	D	B	B	C	10	Incomplete
8	Motor/sensory dysfunction	3.5	E	E	C	D	D	11.5	Incomplete
9	Radiating pain, motor/sensory dysfunction	3	D	D	C	D	D	12	Incomplete
10	Severe pain around the wound, incontinence, motor/sensory dysfunction	10	D	D	C	C	C	7.6	No change
11	Incontinence, motor/sensory dysfunction	288	D	D	C	C	C	4	No change

SDBHE symptom duration before haematoma evacuation, *BIO* before the initial operation, *AIO* after the initial operation, *BHE* before the haematoma evacuation, *2WAHE* two weeks after haematoma evacuation

Complete recovery: The neurologic state at the final follow-up recovered to at least the degree after the initial operation

No change: The neurologic state at the final follow-up was the same as the degree before haematoma evacuation

operation. His symptoms vanished after continuous suction drainage was used instead. Continuous suction drainage was used in case number 3, and the patient developed SSEH four hours after surgery. Syringe was used to aspirate 30 mL of uncoagulated blood, and the symptoms disappeared afterwards.

We defined a complete recovery as neurological state recovered to the state immediately after the first operation. In this cohort, six patients recovered completely, three incompletely, and two had no improvement (the neurological state at the final follow-up visit was the same as the state before haematoma evacuation) (Table 3). In the group of complete recovery, the mean time of symptom duration was 5.58 ± 10.02 hours before the haematoma evacuation, and the ASIA grades of the patients were D (n = 4) and C (n = 2). In the groups of incomplete recovery and no improvement, the mean time of symptom

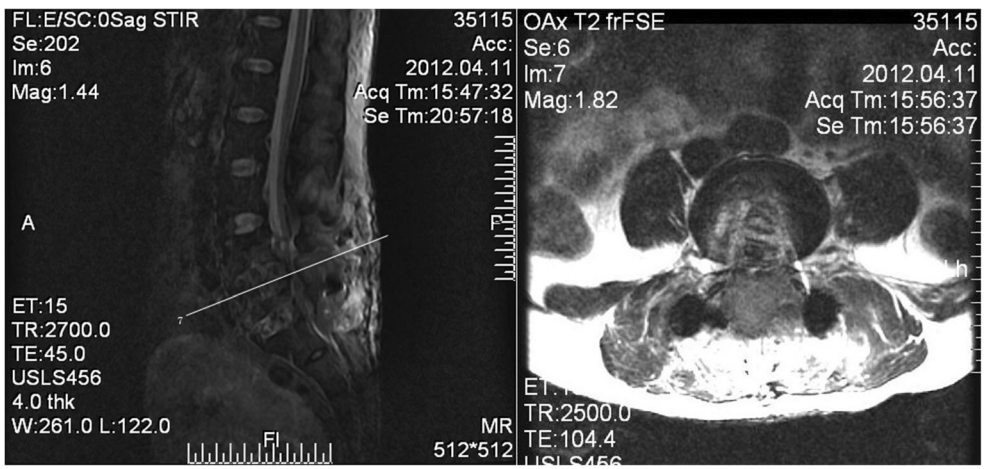

Fig. 1 A 43-year-old male, who suffered from L4/5 spondylolisthesis, was administered with low molecular weight heparin (LMWH) post-operatively for thromboprophylaxis. He complained of progressive motor and sensory dysfunction in bilateral lower limbs on the third day after the drain tube was removed (case number 1). T2-weighted image showed lumbar epidural haematoma which had heterogeneous isointense signal. The superficial area in the wound was hyperintense. The dural sac was compressed

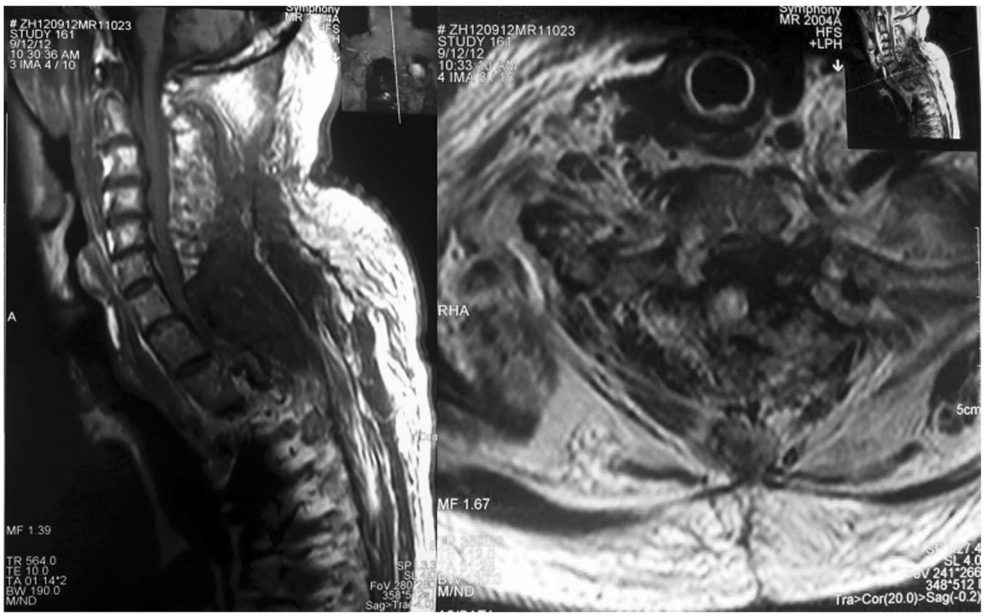

Fig. 2 A 82-year-old male who had small volume platelets with a history of chronic lymphocytic leukemia. He complained of progressive motor and sensory deterioration in his lower limb 5 hours after resection of the epidural angioma in the cervicothoracic spinal canal (case number 6). The T1-weighted image showed epidural haematoma, which had isointense or slightly hyperintense signal. The spinal cord was compressed

duration before haematoma evacuation was 61.50 ± 126.65 hours. Before haematoma evacuation, the ASIA grades were C (n = 4) and B (n = 1). We compared the symptom duration and ASIA grading of different time points between the complete and incomplete/no improvement groups. Statistical analyses showed significant differences of ASIA grading before haematoma evacuation, suggesting mild nerve injury at the initial state is more likely to have complete recovery (Table 3).

Discussion

It was reported that the incident rate of spinal epidural haematoma after spinal surgery was 0.1–3% [1–4]. The incident rate of the present cohort was 0.25%, a relatively lower rate than reported. Although the occurrence of SSEH is rare, if patients are not treated timely and properly, the neurological sequella could be devastating. Therefore, it is important to

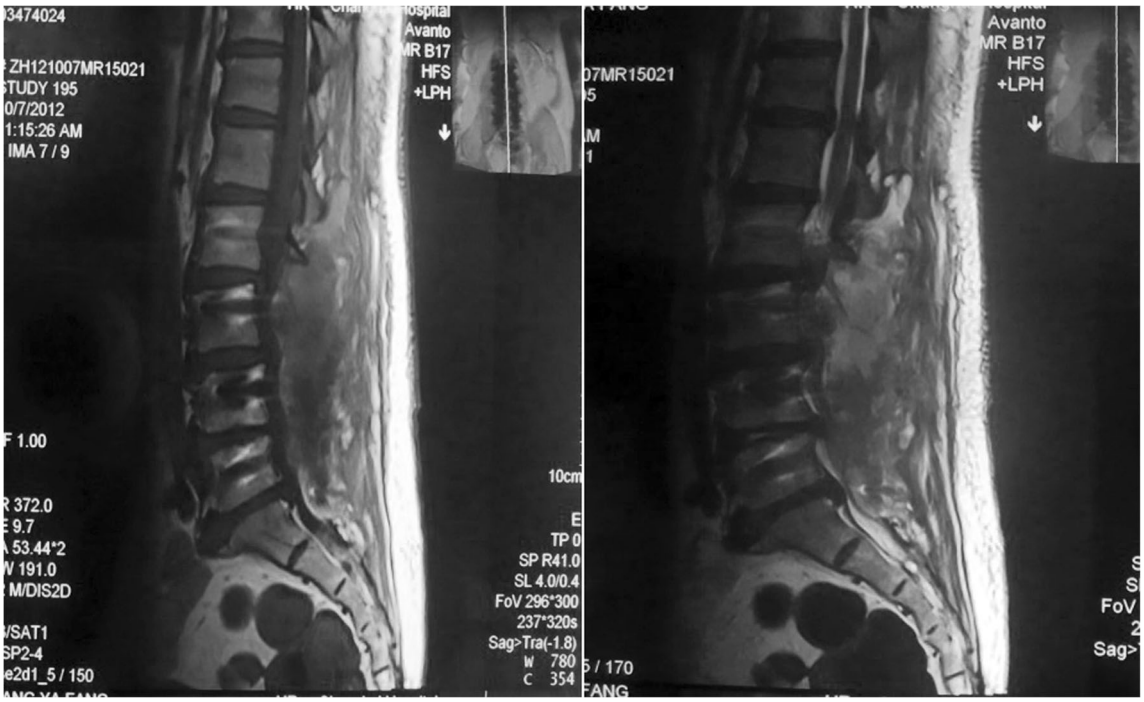

Fig. 3 A 62-year-old female who had lumbar spinal stenosis. She complained of progressive motor and sensory dysfunction in her lower limb 24 hours after the operation on L2-S1 laminectomy and fusion. MRI showed a huge haematoma and a compression on the dural sac

Table 3 The relationships of symptom duration and ASIA grading between complete and incomplete/no improvement groups

Recovery (number of cases)	SDBHE (h)	ASIA grading (number of cases)				
		Before initial operation	Immediately after initial operation	Before haematoma evacuation	Two weeks after haematoma evacuation	Latest follow-up
Complete (6)	5.58 ± 10.02	D(4), E(2)	D(4), E(2)	D(4), C(2)	D(4), E(2)	D(4), E(2)
Incomplete (3), no improvement (2)	61.50 ± 126.65	D(4), E(1)	D(4), E(1)	C(4), B(1)	B(1), D(2), C(2)	D(2), C(3)
Statistical value	$t = -1.089$	Whitney U = 13.000	Whitney U = 13.000	Whitney U = 4.000	Whitney U = 4.000	Whitney U = 3.000
P-value	0.304	0.637	0.637	0.024	0.028	0.019

SDBHE symptom duration before haematoma evacuation

have preventive measures, proper diagnosis and treatments as early as possible.

Causes of SSHE development

Clotting disorder

Case number 6 had small volume platelets and a history of chronic lymphocytic leukemia, indicating a higher risk of clotting dysfunction. Others had no predisposing factors for blood clotting disorder.

Six patients were administered with LMWH post-operatively for thromboprophylaxis, and two of them developed SSEH after the drain was removed (3–4 days after initial operation). The development of haematoma may be attributed to the use of LMWH. Although, it was reported that the well-controlled use of anticoagulant and drainage were not associated with the increased risk of post-operative spinal epidural haematoma, the accurate control of anticoagulant effect may be difficult to achieve due to individual differences that may affect bioavailability and pharmacodynamics of drugs [1, 9, 11]. In addition, patients might have lower concentration of coagulation factors and platelets due to massive liquid infusion/transfusion during operation. The change in internal body environment (e.g. lowering of body temperature and acidosis) will also affect the normal coagulation process.

There is no clear consensus on thromboprophylaxis after spinal surgery [12]. Guidelines published by the Seventh American College of Chest Physicians (ACCP) Conference recommended that only patients with risk factors need thromboprophylaxis management. The risk factors include: age ≥ 60 years, BMI ≥30 kg/m^2, genetic thrombophilia, history of VTE, anterior or combined procedure, thoracic/lumbar/sacral procedure. Among the six patients who received LMWH in this study, only two patients had the above risk factors: one was ≥60 years old and the other one underwent a combined anterior and posterior procedure. The reduced use of LMWH may help to lower the likelihood of SSEH development. It is worth noting that mechanical prophylaxis or early ambulation were proposed for thromboprophylaxis management [13, 14], which could also be taken into consideration. A report showed that the use of mechanical prophylaxis, pneumatic compression stocking, could reduce the incidence of deep venous thrombosis and pulmonary embolism in spinal surgery [15]. Indeed the National Institute for Care and Excellence (NICE) guideline recommends mechanical prophylaxis for patients with spinal injury. The guidance outlines certain risk factors of bleeding, and if such criteria are met, LMWH should be used.

Fluctuations of blood pressure

Coughing, sneezing or experience of severe pain during wake-up from general anaesthesia may result in fluctuations of blood pressure, causing re-bleeding [16]. Patients with high blood pressure, atherosclerosis, diabetes mellitus or hypoproteinemia are more likely to have re-bleeding after surgery. Extra caution is required when moving, turning over, or extubating such patients.

Incomplete hemostasis during initial surgery

Case number 6 was found to have active bleeding at the muscular layer during haematoma evacuation. During the initial surgery, the injured vessels had stopped bleeding temporarily with compression by retractor and gauze. This patient has small volume platelet, and re-bleeding was likely to occur. It is also possible that some other sites of bleeding were not noticed before suturing, or vessels were damaged during suturing [17]. It is therefore important to ensure no active bleeding before closure.

Inadequate drainage

Nine cases in this study developed SSEH before the drainage tube was removed. And seven of them were found to have haematoma of uncoagulated blood. Obstruction of drainage tubes should be the primary reason for the SSEH. When

internal bleeding occurs, blood clots formed could block the drainage tube. Some surgeons are fond of placing a block of gelatin sponge on the dural and placing the tube on the sponge. This practice may lead to an inadequate drainage, as the debris from the gelatin sponge may block the tube. In addition, folding or compression of the tube, for example, via clots formed around the tube, could also lead to inadequate drainage. To mitigate the risk, some surgeons suggested placing two tubes on both sides of the wound, so that there is at least one functional drainage tube when the other one is compressed or obstructed.

The material and internal diameter of the tube are important factors which influence the effect of drainage. The tube that has a large internal diameter and is not easily compressed is recommended. If the tube was mostly obstructed by clot, a drainage tube with a coating of anticoagulants may help.

The outflow suction of the drains is created by connecting the tube to a vacuum device, like a deformable grenade-shaped container. It is important to maintain the negative pressure inside the device; otherwise, a positive pressure could be formed along with the continuous internal bleeding.

Although the use of drains is controversial, with the potential for infection [18, 19], no obvious evidence was found to support such association in the present study. Indeed a prospective randomization trial showed no significant difference in the rates of infection in patients with or without a drain placed after complicated spinal surgery [20]. It is clear, however, that protocols should be optimized to minimize chance of wound contamination, e.g. limiting duration of drains [19].

Diagnosis and treatment of SSEH

It is important to diagnose SSEH in an early stage. SSEH should be considered if the following happened [16, 21, 22]: severe pain of the wound with blood oozing or swelling, unexplainable sensor and/or motor dysfunction after open spinal operation (e.g. deteriorating or new neurologic signs or symptoms) or pain in the innervated area, progressive deterioration of neurologic dysfunction.

To confirm the diagnosis of SSEH, the following examinations could be performed [21, 23–26]: re-examination of haematology, blood chemistry, and coagulation tests; MRI scan to determine the location and volume of the haematoma, and whether the dural sac or spinal cords were compressed. To avoid prolonged compression of the spinal cord, confirmation with MRI scan should be performed as soon as possible if the likelihood of SSEH is high [6, 26]. Some studies, however, suggested that the use of post-operative MRI have a high false-positive rate for diagnosis of SSEH [4, 27]. Therefore, in addition to imaging, it is important for the surgeons to carefully monitor the physical signs and patients' symptoms.

Once the SSEH is confirmed, check if there is any blockage in the drainage tube; take out some stitches to allow the release of pressure from haematoma ooze; patients with no improvement after the above measures, or patients with severe symptoms or progressive deterioration will need re-operation to clear the haematoma and stop the internal bleeding.

Nursing personnel also plays an important role in early detection of SSEH. The nurse's prompt recognition and reporting of neurological symptoms of SSEH has been shown to help achieve a positive clinical outcome [28]. It is therefore important to have post-operative nursing personnel aware of the risk factors, clinical presentation and the need for rapid treatment.

Factors that influence the neurologic recovery

We found larger differences in symptom duration before haematoma evacuation between complete and incomplete/no improvement recovery groups. Although the differences were not statistically significant, the finding suggested that the earlier the haematoma was evacuated, the better neuro-function recovery was obtained. Patients with lower grade of damaged neuro-function before haematoma evacuation recovered better after treatment ($P<0.05$), suggesting it is the major factor associated with prognosis, while the duration of haematoma compression is relatively less important. This is in accordance with other reports that recovery of neurologic injury is related to the severity of the initial neurologic injury [29]. As such, it was once a controversy as to whether emergency operation was needed for traumatic spinal cord injury with vertebral fracture. However, nowadays early decompression is most recommended [30–32]. It is believed that patients with both shorter symptom duration and less severity of neurologic injury would recover better [4, 8], since continuous bleeding in the wound occurring after the onset of SSEH may lead to increasing pressure and further neurologic injury.

The present study is limited by its retrospective nature and small case number. Since development of SSEH after spinal surgery is very rare and catastrophic, it may not be possible to conduct a formal prospective case-control clinical study. We reviewed a relatively large data set from two medical centres over several years, but we could not find a large cohort size for evaluation, as the occurrence of SSEH is very rare.

In conclusion, post-operative bleeding in the wound and inadequate drainage are the key factors related to the formation of spinal epidural haematoma. It is important to pay attention to every step of the operation to prevent occurrence of SSEH. Since the sequelae of SSEH is devastating, it should be diagnosed as early as possible, and confirmatory tests should be done when progressive neurological deterioration occurs in the innervated area. Severity of the neurologic state before haematoma evacuation is the major factor associated with recovery. Therefore, once SSEH is diagnosed, the nerve compression should be relieved at once to prevent progression of neurologic injury.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest. There was no funding source.

Ethical approval This study was approved by The Institutional Review Board of the Ethics Committee of Renmin Hospital, Hubei University of Medicine.

Informed consent No informed consent was required because data were analyzed anonymously.

References

1. Awad JN, Kebaish KM, Donigan J, Cohen DB, Kostuik JP (2005) Analysis of the risk factors for the development of post-operative spinal epidural haematoma. J Bone Joint Surg Br 87(9):1248–1252. doi:10.1302/0301-620X.87B9.16518
2. Gerlach R, Raabe A, Beck J et al (2004) Postoperative nadroparin administration for prophylaxis of thromboembolic events is not associated with an increased risk of hemorrhage after spinal surgery. Eur Spine J 13:9–13
3. Aono H, Ohwada T, Hosono N, Tobimatsu H, Ariga K, Fuji T, Iwasaki M (2011) Incidence of postoperative symptomatic epidural hematoma in spinal decompression surgery. J Neurosurg Spine 15(2):202–205. doi:10.3171/2011.3.SPINE10716
4. Amiri AR, Fouyas IP, Cro S, Casey AT (2013) Postoperative spinal epidural hematoma (SEH): incidence, risk factors, onset, and management. Spine J 13(2):134–140. doi:10.1016/j.spinee.2012.10.028
5. Modi HN, Lee DY, Lee SH (2011) Postoperative spinal epidural hematoma after microscopic lumbar decompression: a prospective magnetic resonance imaging study in 89 patients. J Spinal Disord Tech 24(3):146–150. doi:10.1097/BSD.0b013e3181e1958e
6. Sokolowski MJ, Garvey TA, Perl J 2nd, Sokolowski MS, Akesen B, Mehbod AA, Mullaney KJ, Dykes DC, Transfeldt EE (2008) Postoperative lumbar epidural hematoma: does size really matter? Spine (Phila Pa 1976) 33(1):114–119. doi:10.1097/BRS.0b013e31815e3a26
7. Mirzai H, Eminoglu M, Orguc S (2006) Are drains useful for lumbar disc surgery? A prospective, randomized clinical study. J Spinal Disord Tech 19(3):171–177. doi:10.1097/01.bsd.0000190560.20872.a7
8. Lawton MT, Porter RW, Heiserman JE, Jacobowitz R, Sonntag VK, Dickman CA (1995) Surgical management of spinal epidural hematoma: relationship between surgical timing and neurological outcome. J Neurosurg 83(1):1–7. doi:10.3171/jns.1995.83.1.0001
9. Kou J, Fischgrund J, Biddinger A, Herkowitz H (2002) Risk factors for spinal epidural hematoma after spinal surgery. Spine (Phila Pa 1976) 27(15):1670–1673
10. Sokolowski MJ, Garvey TA, Perl J 2nd, Sokolowski MS, Cho W, Mehbod AA, Dykes DC, Transfeldt EE (2008) Prospective study of postoperative lumbar epidural hematoma: incidence and risk factors. Spine (Phila Pa 1976) 33(1):108–113. doi:10.1097/BRS.0b013e31815e39af
11. Hemker HC, Al Dieri R, Beguin S (2005) Laboratory monitoring of low-molecular-weight heparin therapy—part II. Monitoring LMWH therapy? For the moment a non-question. J Thromb Haemost 3(3):571–573. doi:10.1111/j.1538-7836.2005.01206.x
12. Bryson DJ, Uzoigwe CE, Braybrooke J (2012) Thromboprophylaxis in spinal surgery: a survey. J Orthop Surg Res 7:14. doi:10.1186/1749-799X-7-14
13. Takahashi H, Yokoyama Y, Iida Y, Terashima F, Hasegawa K, Saito T, Suguro T, Wada A (2012) Incidence of venous thromboembolism after spine surgery. J Orthop Sci 17(2):114–117. doi:10.1007/s00776-011-0188-2
14. Glotzbecker MP, Bono CM, Wood KB, Harris MB (2010) Postoperative spinal epidural hematoma: a systematic review. Spine (Phila Pa 1976) 35(10):E413–E420. doi:10.1097/BRS.0b013e3181d9bb77
15. Epstein NE (2006) Efficacy of pneumatic compression stocking prophylaxis in the prevention of deep venous thrombosis and pulmonary embolism following 139 lumbar laminectomies with instrumented fusions. J Spinal Disord Tech 19(1):28–31. doi:10.1097/01.bsd.0000173454.71657.02
16. Lee DY, Lee SH (2010) Cervicothoracic spinal epidural hematoma after anterior cervical spinal surgery. J Korean Neurosurg Soc 48(6):541–543. doi:10.3340/jkns.2010.48.6.541
17. Choi JH, Kim JS, Lee SH (2013) Cervical spinal epidural hematoma following cervical posterior laminoforaminotomy. J Korean Neurosurg Soc 53(2):125–128. doi:10.3340/jkns.2013.53.2.125
18. Liu Y, Li Y, Miao J (2016) Wound drains in posterior spinal surgery: a meta-analysis. J Orthop Surg Res 11:16. doi:10.1186/s13018-016-0351-8
19. Rao SB, Vasquez G, Harrop J, Maltenfort M, Stein N, Kaliyadan G, Klibert F, Epstein R, Sharan A, Vaccaro A, Flomenberg P (2011) Risk factors for surgical site infections following spinal fusion procedures: a case-control study. Clin Infect Dis 53(7):686–692. doi:10.1093/cid/cir506
20. Brown MD, Brookfield KF (2004) A randomized study of closed wound suction drainage for extensive lumbar spine surgery. Spine (Phila Pa 1976) 29(10):1066–1068
21. Yu HP, Fan SW, Yang HL, Tang TS, Zhou F, Zhao X (2007) Early diagnosis and treatment of acute or subacute spinal epidural hematoma. Chin Med J 120(15):1303–1308
22. Firat AK, Firat MM, Akmangit I, Dincer C, Gelebek V (2006) Acute epidural hematoma involving entire thoracic and lumbar spine. Eur J Radiol Extra 59(1):7–10
23. Leonardi MA, Zanetti M, Saupe N, Min K (2010) Early postoperative MRI in detecting hematoma and dural compression after lumbar spinal decompression: prospective study of asymptomatic patients in comparison to patients requiring surgical revision. Eur Spine J 19(12):2216–2222. doi:10.1007/s00586-010-1483-x
24. Morse K, Weight M, Molinari R (2007) Extensive postoperative epidural hematoma after full anticoagulation: case report and review of the literature. J Spinal Cord Med 30(3):282–287
25. Carragee EJ, Golish SR, Scuderi GJ (2011) A case of late epidural hematoma in a patient on clopidogrel therapy postoperatively: when is it safe to resume antiplatelet agents? Spine J 11(1):e1–e4. doi:10.1016/j.spinee.2010.10.013
26. Braun P, Kazmi K, Nogués-Meléndez P, Mas-Estellés F, Aparici-Robles F (2007) MRI findings in spinal subdural and epidural hematomas. Eur J Radiol 64:119–125
27. Uribe J, Moza K, Jimenez O, Green B, Levi AD (2003) Delayed postoperative spinal epidural hematomas. Spine J 3(2):125–129
28. Daniels AH, Schiebert SS, Palumbo MA (2015) Symptomatic spinal epidural hematoma after lumbar spine surgery: the importance of diagnostic skills. AORN J 101(1):85–90; **quiz 91-83**. doi:10.1016/j.aorn.2014.03.016
29. Vander Have KL, Caird MS, Gross S, Farley FA, Graziano GA, Stauff M, Segal LS (2009) Burst fractures of the thoracic and lumbar spine in children and adolescents. J Pediatr Orthop 29(7):713–719. doi:10.1097/BPO.0b013e3181b76a44
30. Sacks GD, Panchmatia JR, Marino M, Hill C, Rogers SO Jr (2011) The effect of operative timing on functional outcome after isolated spinal trauma. J Trauma 71(6):1668–1672. doi:10.1097/TA.0b013e31823246a5

31. Furlan JC, Noonan V, Cadotte DW, Fehlings MG (2011) Timing of decompressive surgery of spinal cord after traumatic spinal cord injury: an evidence-based examination of pre-clinical and clinical studies. J Neurotrauma 28(8):1371–1399. doi:10.1089/neu.2009.1147

32. Bourassa-Moreau E, Mac-Thiong JM, Ehrmann Feldman D, Thompson C, Parent S (2013) Complications in acute phase hospitalization of traumatic spinal cord injury: does surgical timing matter? J Trauma Acute Care Surg 74(3):849–854. doi:10.1097/TA.0b013e31827e1381