

Effects of perioperative use of two doses of magnesium sulfate infusion on intraoperative blood loss in patients undergoing lumbar spinal fusion surgery



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Abstract

Objective: In general, spinal fusion surgery causes heavy bleeding. The purpose of this study was to evaluate the use of two different doses of magnesium sulfate to control the bleeding in lumbar fusion surgery.

Methods: This study was carried out as a randomized double-blinded clinical trial in 2020 in Al-Zahra hospital in Isfahan. The participants were 60 patients selected using inclusion and exclusion criteria and were randomly allocated into three groups. In the first group, 50 mg/kg and in the second group, 40 mg/kg magnesium sulfate was infused. The third group received normal saline. From the beginning of anesthesia, heart rate, diastolic and systolic blood pressure, respiratory rate and blood oxygen saturation percentage were monitored and logged every 30 minutes during the operation and recovery. The volume of bleeding during the operation was calculated by counting the number of gauzes used and the amount of suctioned blood during the operation. Other required information such as the duration of operation, duration of anesthesia, time of intubation and the time period of hospitalization and recovery were determined and recorded in all patients. We used independent t-test and repeated measure ANOVA tests to compare data between different time lines and also different groups. *P* value < 0.05 was considered as significance threshold. The collected data were analyzed by using SPSS software version 23.

Results: The group receiving 50 mg/kg magnesium sulfate had a significantly lower systolic blood pressure compared to other groups within 15, 30 and 45 minutes after the injections (*P*=0.04 for all). The pulse rate was significantly lower in the 50 mg/kg magnesium sulfate group compared to other groups within 15, 30 and 45 minutes after the injections (*P*<0.05 for all). Patients that received 50 mg/kg magnesium sulfate had a lower duration of surgery (*P*=0.007), lower duration of anesthesia (*P*=0.007), lower bleeding volume (*P*<0.001), lower fluid intake (*P*=0.01) and also lower transfused blood (*P*=0.01). The surgeons also had a significantly higher satisfaction with these patients (*P*=0.001).

Conclusion: Injection of 50 mg/kg magnesium sulfate had a correlation with reduced blood pressure as well as bleeding volume compared to 40 mg/kg magnesium sulfate.

Keywords: Spinal fusion, Blood loss, Controlled hypotension, Magnesium sulfate

Introduction

In general, spinal fusion surgery causes heavy bleeding that in some cases requires transfusion of blood (1). In addition, bleeding can cause complications but this is not limited to major surgeries like deformity, but also seen in limited fusion surgery (2,3). Controlling and alleviating bleeding is necessary to keep hemodynamic stability of patients and create a field without blood with good visibility. This is important mostly in spinal surgery, in which proximity and sensitivity of nerves are key limitations (4). When a convenient condition is provided, a surgeon can perform the operation in a shorter period of time which in turn decreases the volume of bleeding (5).

Reducing bleeding also decreases the risk of

complications like transmission of viral and bacterial infections, acute lung damage, hypothermia, hemolytic/non-hemolytic reactions, coagulation disorders, etc. by reducing the necessity of blood products (6). Moreover, there has been successful use of controlled hypotension in orthopedic surgery. This method is extensively used in spinal surgery and many previous research works have indicated its effectiveness in spinal surgery (7). Lowering blood pressure is one key way to alleviate bleeding in surgery, which is also named controlled hypotension. To implement this method in the process of anesthesia of spinal surgeries, blood flow is taken away from an artery, which reduces bleeding during surgery and decreases the need for blood transfusions (8).



Various medications have been utilized for blood pressure control such as nicardipine (alpha receptor agonists), beta-adrenergic antagonists (propranolol, esmolol and labetalol), and vasodilators such as nitroprusside, dexmedetomidine, and clonidine. Hypotension has several disadvantages, including tachyphylaxis and reflex tachycardia (9,10). Thus, it is imperative to utilize compounds with predictable effects of dose-response. One of these compounds is magnesium sulfate. Magnesium sulfate is a non-competitive NMDA receptor antagonist (N-methyl-D-aspartate) with analgesic effects, which is required for acetylcholine release by presynaptic terminals (11). It also acts similarly to calcium channel blockers and prevents calcium from entering the cells. According to the research, magnesium sulfate causes hypotension by dilating blood vessels. Its vasodilatory effects are due to a higher production of prostacyclins and an inhibition of angiotensin-converting enzyme (12). Therefore, it seems that using this drug may help provide low blood pressure during various surgeries.

Evidence shows that using magnesium sulfate reduces the need for analgesia after surgery (13). Using magnesium sulfate also lowers the need for using propofol, remifentanyl and atracurium during surgery. Magnesium sulfate is commonly used with two dosages of 50 mg/kg and 40 mg/kg. Different studies have claimed significant effectiveness of both dosages but so far, very few studies have compared these two dosages in inducing controlled hypotension in patients undergoing spinal fusion surgery (14,15).

In recent years, different studies have examined the effect of various drugs to control bleeding during surgery, one of which is magnesium sulfate. Some of these studies have reported that magnesium sulfate can attenuate bleeding during surgery (16,17). Since previous studies have not investigated the outcome of using different doses of magnesium sulfate on bleeding during surgery, the present study is an attempt to examine the effect of using two different doses of magnesium sulfate during lumbar fusion surgery.

Methods

This randomized double-blinded clinical trial was carried out in Al-Zahra hospital affiliated with the Isfahan University of Medical Science in 2020 based on consort guidelines. The study was performed on patients on the waiting list for posterior spinal fusion surgery under general anesthesia. The participants were assured of the confidentiality of their data and they were informed that the measures and methods employed in hemorrhagic surgery are designed to save lives via preserving the vital organs functions. The study was conducted by obtaining the code of ethics from Isfahan University of Medical Sciences (Code: IR.MUI.MED.REC. 1399.690). The code of clinical trial is I IRCT20200825048515N15. The

purpose of the study was to lower bleeding during surgery and prevent complications caused by bleeding, as well as the need for blood transfusion.

The inclusion criteria encompassed patients between 20-60 years of age, patients on the waiting list for posterior spinal fusion surgery in level 1 and 2 based on the classification of the American Society of Anesthesiologists (ASA) and with consent to participate in the study. Exclusion criteria included severe cardiovascular diseases and existence of blood pressure higher than 185/100 mm Hg, previous allergies to magnesium sulfate, history of hepatic failure, renal failure or cardiovascular issues, opioid addiction and usage of calcium channel blockers or nonsteroidal anti-inflammatory drugs before surgery. In addition, changing the technique of operation and anesthesia as well as the occurrence of unwanted hemodynamic complications due to surgical technique were other exclusion criteria.

After approving the plan and obtaining permission from the Medical Ethics Committee of Isfahan University of Medical Sciences, 60 patients were selected by non-probabilistic easy sampling method and after obtaining their consent to participate in the study and obtain written consent, randomly using Random. According to the time of admission and random list patients were manually allocated to three groups of 20 people. In this regard, the sample size reached the required number in each group. Concerning the blinding method, the drug was prepared by one of the anesthesiologists in the operating room who was not informed about the study design. In addition, coded syringes were provided for injection of patients. The data collector, patients and the statistical analyst were blind to the dose of magnesium sulfate. Following data analysis, the codes were reopened and the groups were compared.

In total, 60 patients were selected according to the inclusion and exclusion criteria and randomly allocated to three groups. First, vital indicators like blood pressure, blood oxygen saturation, and heart rate were recorded and measured. Demographical information such as sex, age, type of operation, weight, and the underlying diseases were collected using a form.

All patients had general anesthesia after pre-oxygenation and premedication was performed with 0.03-0.05 mg/kg midazolam and 2 µg/kg of fentanyl and 100 mg lidocaine. For induction of anesthesia 2 mg/kg propofol and 0.5 mg/kg cisatracurium were used. The participants received 0.1 mg/kg morphine during surgery. Also, if there was no contraindication, 1 g of tranexamic acid was infused within 30 minutes. From the beginning, propofol was infused at a rate of 100 µg/kg/min for the maintenance of anesthesia in patients.

After positioning the patient and ensuring the patient's constant hemodynamic status, in group one, 50 mg/kg and in group two, 40 mg/kg magnesium sulfate was infused

within ten minutes before the operation. The third group received the same volumes of normal saline. All patients also received an infusion of magnesium sulfate with a dosage of 15 mg/kg during the surgical procedure.

From the beginning of anesthesia, heart rate, diastolic and systolic blood pressure, respiratory rate and blood oxygen saturation percentage (SPO₂) were monitored and logged every 30 minutes during the operation and recovery. The incidence of any hemodynamic disorders including hypotension (systolic blood pressure < 70 mm Hg), hypertension (systolic blood pressure > 140 mm Hg), tachycardia (heart rate > 100 b/min) and bradycardia (heart rate < 60 b/min) during operation and recovery were monitored and recorded. In case of hypotension, 10 mg of ephedrine and in case of bradycardia, 0.5 mg of atropine were injected. The volume of bleeding during the operation was calculated by counting the number of gauzes used and the amount of suctioned blood during the operation. Other required information such as operating time (from the time of surgical incision to the time of the last suture), time period of anesthesia (from the start of injection to discontinuation of anesthesia), time of extubation (from the time of cessation of anesthesia to the exit of the tube chip) and the time period of hospitalization and recovery were determined and recorded in all patients. After the operation, the patients were discharged from the recovery according to the modified Aldrete criteria (18). If morphine was needed, the dose and frequency of injections were recorded.

To remove the bias, the operations were carried out by one neurosurgeon. Surgeon satisfaction at the end of the

operation was measured using the 5-point Likert scale (19). The above criterion is a 5-part scale that divides satisfaction from 1 to 5, in which a score of (5) meant very satisfied, (4) was satisfied, (3) was partially dissatisfied (neither satisfied or dissatisfied), (2) meant dissatisfied and (1) was very dissatisfied.

The collected data were analyzed by using SPSS software version 23. Data analysis was conducted by repeated measure tests, independent *t* test and, ANOVA to make comparisons between groups and time lines (*P* value < 0.05).

Results

In the present study, 60 patients took part in the study and were randomly allocated into three groups each with 20 patients. During the study, 1 patient in the 40 mg/kg magnesium sulfate group and 1 patient in the placebo group were excluded due to changes in the surgical procedure. The data collected from 58 participants were analyzed. Figure 1 illustrates the CONSORT flow diagram of the participants.

Analysis of demographic data between the three groups indicated that there were not any significant differences between the three groups regarding age (*P*=0.22), gender (*P*=0.47), weight (*P*=0.44), BMI (*P*=0.17), ASA classification (*P*=0.63) and level of surgeries (*P*=0.23) (Table 1).

Based on our results, the systolic blood pressure in the group receiving 50 mg/kg magnesium sulfate was significantly lower compared to other groups. In addition, systolic blood pressure was lower in patients that received

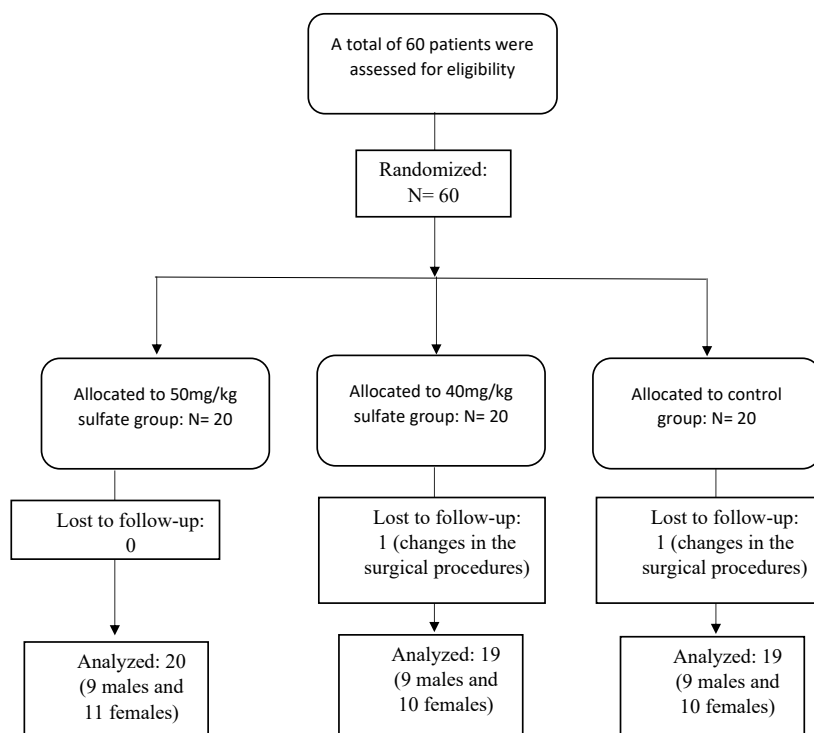


Figure 1. CONSORT flow diagram

Table 1. Analysis of demographic data between the three groups

Variable		50 mg/kg sulfate	40 mg/kg sulfate	Control	P value
Age (years) (mean±SD)		41.32±12.54	43.68±11.27	42.90±10.62	0.22*
Weight (kg) (mean±SD)		71.27±9.87	73.21±9.41	72.69±8.32	0.44*
Height (m) (mean±SD)		172.36±12.69	171.54±13.72	172.28±12.58	0.31*
BMI (kg/m ²) (mean±SD)		23.97±1.28	24.64±1.60	24.33±1.82	0.17*
ASA, No. (%)	1	18 (90)	16 (84.2)	17 (89.5)	0.63**
	2	2 (10)	3 (15.8)	2 (10.5)	
Level of surgery, No. (%)	1	3 (15)	2 (10.5)	4 (20.1)	0.23**
	2	17 (75)	17 (89.5)	15 (79.9)	
Gender, No. (%)	Female	11 (55)	10 (52.6)	10 (52.6)	0.47**
	Male	9 (45)	9 (47.4)	9 (47.4)	
Comorbidities, No. (%)	Yes	2 (10)	1 (5.3)	2 (10.5)	0.23**
	No	18 (90)	18 (94.7)	17 (89.5)	

*One-way ANOVA test, **Independent t-test. $P < 0.05$ is statistically significant.

Table 2. Systolic, diastolic blood pressure and MAP between groups

Group		T _{pre}	T ₀	T ₁₅	T ₃₀	T ₄₅	T ₆₀	T _{Recovery}	P1	P2	P3
SBP 50	Mean	138.75	120.85	113.40	100.74	98.10	96.49	96.98	0.001		
	SD	19.60	16.19	12.94	18.01	14.31	9.36	13.71			
SBP 40	Mean	141.64	121.77	117.16	105.69	104.38	102.63	98.78	0.001	0.32	0.64
	SD	16.96	10.01	14.12	12.54	9.51	9.72	10.81			
SBP Control	Mean	140.26	127.60	120.21	112.45	112.07	114.89	113.81	0.001		
	SD	15.86	16.32	16.57	12.30	10.58	10.28	11.78			
P4		0.40	0.12	0.14	0.14	0.14	0.63	0.37			
DBP 50	Mean	93.50	81.04	72.70	67.98	64.43	63.43	62.81	0.001		
	SD	16.11	14.84	11.88	11.07	13.13	8.29	11.73			
DBP 40	Mean	94.87	80.94	74.26	70.47	67.57	65.74	63.80	0.001	0.08	0.14
	SD	13.68	10.94	12.92	9.64	9.06	7.95	9.89			
DBP Control	Mean	93.25	80.27	76.39	72.08	69.82	65.44	63.74	0.001		
	SD	14.25	12.56	12.77	10.27	9.65	8.92	8.21			
P4		0.63	0.95	0.51	0.44	0.15	0.40	0.63			
MAP 50	Mean	108.01	92.54	84.94	79.36	78.07	78.63	80.67	0.001		
	SD	14.93	9.40	11.81	9.70	9.53	8.95	7.74			
MAP 40	Mean	104.87	87.98	83.87	77.34	75.45	75.02	78.34	0.001	0.37	0.28
	SD	16.95	17.97	12.39	13.215	11.04	7.90	10.15			
MAP Control	Mean	105.89	88.56	83.47	77.21	76.30	75.27	77.93	0.001		
	SD	14.26	15.44	11.22	12.83	11.97	9.33	9.17			
P4		0.30	0.09	0.64	0.36	0.06	0.10	0.12			

SBP, systolic blood pressure; DBP, diastolic blood pressure

P value 1 (Time), P value 2 (interaction), P value 3 (intervention) at a significant level of repeated measure test, P value 4 at the 5% level is statistically significant.

40 mg/kg magnesium sulfate compared to the control group within 15, 30 and 45 minutes after the injections but was not statistically significant ($P=0.14$ for all). There were not any significant changes in diastolic blood pressure and MAP between groups ($P > 0.05$) (Table 2).

We also compared pulse rate, respiratory rate and SPO₂ between groups in which the findings indicated that the pulse rate was significantly lower in the 50 mg/kg magnesium sulfate group compared to other groups.

The patients that received 40 mg/kg magnesium sulfate also had lower heart rates compared to the control group within 15, 30 and 45 minutes after the injections ($P < 0.05$ for all). There were not any significant differences between the three groups regarding SPO₂ and respiratory rate (Table 3).

Further evaluations showed that patients that received 50 mg/kg magnesium sulfate had a shorter duration of surgery ($P=0.007$), lower duration of anesthesia

Table 3. Pulse rate, respiratory rate and SPO2 between groups

Group		T _{pre}	T ₀	T ₁₅	T ₃₀	T ₄₅	T ₆₀	T _{Recovery}	P value1	P value2	P value3
HR 50	Mean	85.01	80.07	71.56	62.909	61.68	59.00	60.27	0.001		
	SD	15.47	13.91	17.05	11.91	12.93	10.79	11.60			
HR 40	Mean	84.10	79.96	75.49	68.47	65.38	64.85	61.21	0.001	0.157	0.241
	SD	13.11	14.58	12.65	12.75	13.27	11.13	12.67			
HR Control	Mean	83.78	80.22	78.25	72.33	69.57	66.47	62.39	0.001		
	SD	12.59	13.76	12.42	12.20	13.11	10.92	11.28			
P4		0.15	0.68	0.02	0.01	0.03	0.07	0.15			
SPO2 50	Mean	97.60	98.54	98.81	99.01	98.76	98.76	98.61	0.001		
	SD	2.90	1.54	1.09	1.17	1.10	1.10	1.16			
SPO2 40	Mean	97.89	98.70	98.85	99.21	98.89	98.83	98.58	0.001	0.074	0.26
	SD	2.38	1.34	1.00	1.06	0.97	1.01	1.13			
SPO2 Control	Mean	98.88	98.75	98.82	99.02	99.04	98.90	98.87	0.001		
	SD	2.33	2.44	1.20	1.62	0.99	1.08	1.02			
P4		0.56	0.55	0.85	0.35	0.52	0.72	0.88			

HR, heart rate

P value 1 (Time), P value 2 (interaction), P value 3 (intervention) at a significant level of repeated measure test, P value 4 at the 5% level of ANOVA test.

Table 4. Different variables between three groups

Variable	50 mg/kg sulfate	40 mg/kg sulfate	Control	P value
Duration of surgery (h) (mean±SD)	1.67±0.67	1.83±0.58	2.06±0.66	0.017**
Duration of anesthesia (h) (mean±SD)	2.61±0.60	2.88±0.75	2.89±0.22	0.007**
Duration of Extubation (min) (mean±SD)	38.30±12.13	39.11±12.23	40.58±11.39	0.37**
Recovery duration (h) (mean±SD)	1.63±0.43	1.77±0.35	1.63±0.39	0.22**
Bleeding volume (mL) (mean±SD)	361.78±194.11	548.58±213.10	559.36±215.77	<0.001**
Fluid intake (L) (mean±SD)	1.82±1.60	2.63±1.52	2.82±1.75	0.01**
Transfused blood (L) (mean±SD)	0.38±0.43	0.62±0.44	0.77±0.39	0.01**
Urinary output (mL) (mean±SD)	472.39±35.69	468.75±27.22	465.21±38.41	0.79**
Remifentanil (mg) (mean±SD)	6.31±2.07	6.12±1.47	6.18±1.57	0.81**
Surgeon satisfaction (mean±SD)	4.93±0.28	3.85±0.30	3.40±0.35	0.001***

Independent t test, * Chi-square test. $P < 0.05$ is statistically significant.

($P = 0.007$), lower bleeding volume ($P < 0.001$), lower fluid intake ($P = 0.01$) and also lower transfused blood ($P = 0.01$). The surgeon satisfaction was also significantly higher in these patients ($P = 0.001$) (Table 4).

Discussion

In the present study we evaluated and compared the effects of two different dosages of magnesium sulfate in reducing bleeding in patients under spinal fusion surgery. Our data showed that the use of 50 mg/kg magnesium sulfate could control hypotension more efficiently. Based on our data, patients that received 50 mg/kg magnesium sulfate had lower systolic blood pressure and lower heart rate during the surgeries.

Furthermore, these patients had a lower duration of surgery, lower duration of anesthesia, lower bleeding volume, and lower fluid intake and also lower transfused blood. The satisfaction of the surgeon was significantly higher in these patients due to a clearer surgical site.

Former studies have also evaluated and compared

different agents in inducing controlled hypotension during major surgical operations. In 2017, a study was conducted by Srivastava and colleagues evaluating the effects of dexmedetomidine and magnesium sulfate on postoperative and hemodynamics recovery and propofol consumption in spinal surgery. In this clinical trial, 90 patients were randomly allocated to one of the groups receiving 50 mg/kg magnesium sulfate before surgeries. Findings indicated that the injection of 50 mg/kg magnesium sulfate could better control hypotension and also reduce the requirements of anesthetic agents. They also claimed that patients receiving magnesium sulfate had lower bleeding and lower fluid intake (19).

Another study by Ghodratty and colleagues compared the effectiveness of 50 mg/kg magnesium sulfate to remifentanil 0.15 µg/kg in controlled hypotension during spinal surgeries. They evaluated data of 39 patients and reported that magnesium sulfate and remifentanil had an identical hypotensive effect and comparable bleeding volume without any significant adverse effects.

Significantly reduced heart rate and systolic blood pressure were also reported in this study, along with higher surgeon satisfaction in this group (20). Our findings were also consistent with the findings supporting the effectiveness of 50 mg/kg magnesium sulfate in reducing bleeding during spinal surgeries.

Hwang and colleagues also evaluated the effectiveness of 50 mg/kg magnesium sulfate in 40 patients undergoing major orthopedic surgeries in 2010. They showed that the injection of magnesium sulfate reduced bleeding as well as the requirement for fluid intake and blood transfusion (21). In another study by Martin and colleagues in 2018, 60 patients undergoing spinal fusion surgeries were evaluated. In this study, 40 mg/kg magnesium sulfate was used that led to high analgesic effects and controlled hypotension in patients, but they also reported that remifentanyl had better effects compared to magnesium sulfate (22).

Our findings were consistent with these studies. We showed that patients receiving 50 mg/kg magnesium sulfate had lower heart rate and systolic blood pressure which led to reduced bleeding during spinal fusion surgeries.

Furthermore, the important point of our study was that we evaluated and compared two different dosages of magnesium sulfate in patients, while most of the previous studies have used only 50 mg/kg magnesium sulfate. There have also been some previous studies on various surgical operations. These studies have shown significantly lower bleeding volume during middle ear surgery (23) open rhinoplasty (24) and endoscopic sinus surgery (16,25).

Most of these studies used 50 mg/kg magnesium sulfate, but some studies used 40 mg/kg dosage (26,27). So far, no previous study has compared these two different dosages in patients undergoing spinal fusion. Our study showed that magnesium sulfate injection with a dosage of 50 mg/kg significantly reduced bleeding compared to 40 mg/kg.

This study has its own limitations. First, our sample did not include many patients. Second, we did not evaluate confounding factors in the groups. We recommend that 50 mg/kg magnesium sulfate should be used in major spinal surgeries to reduce the bleeding volume.

Conclusion

Our study showed that the injection of 50 mg/kg magnesium sulfate was more effective in reducing blood pressure and bleeding volume compared to 40 mg/kg magnesium sulfate. These findings are consistent with other studies; however no previous comparisons have been made between the two dosages. Anesthesiologists need to pay particular attention to the potential use of 50 mg/kg magnesium sulfate in inducing controlled hypotension.

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Authors' Contribution

BN & ZR: Conceptualization, data collection, investigation, writing the original draft, reviewing and editing. BN, MN & MM: Conceptualization, methodology, project administration, supervision, writing the original draft, reviewing and editing. AM and BN: Conceptualization, methodology, writing, reviewing and editing.

Competing Interests

None.

Ethical Approval

The Research committee of Isfahan University of Medical Sciences and the Ethics committee approved the study design (Ethics code: IR.MUI.MED.REC.1399.690, Iranian Registry of Clinical Trials (IRCT) code: IRCT20200825048515N15). All patients signed an informed written consent.

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References

1. Tarpada SP, Morris MT, Burton DA. Spinal fusion surgery: a historical perspective. *J Orthop.* 2017;14(1):134-6. doi: [10.1016/j.jor.2016.10.029](https://doi.org/10.1016/j.jor.2016.10.029).
2. Nagabhushan RM, Shetty AP, Dumpa SR, Subramanian B, Kanna RM, Shanmuganathan R. Effectiveness and safety of batroxobin, tranexamic acid and a combination in reduction of blood loss in lumbar spinal fusion surgery. *Spine (Phila Pa 1976).* 2018;43(5):E267-E73. doi: [10.1097/brs.0000000000002315](https://doi.org/10.1097/brs.0000000000002315).
3. Huang YH, Ou CY. Significant blood loss in lumbar fusion surgery for degenerative spine. *World Neurosurg.* 2015;84(3):780-5. doi: [10.1016/j.wneu.2015.05.007](https://doi.org/10.1016/j.wneu.2015.05.007).
4. Li G, Sun TW, Luo G, Zhang C. Efficacy of antifibrinolytic agents on surgical bleeding and transfusion requirements in spine surgery: a meta-analysis. *Eur Spine J.* 2017;26(1):140-54. doi: [10.1007/s00586-016-4792-x](https://doi.org/10.1007/s00586-016-4792-x).
5. Bosch P, Kenkre TS, Londino JA, Cassara A, Yang C, Waters JH. Coagulation profile of patients with adolescent idiopathic scoliosis undergoing posterior spinal fusion. *J Bone Joint Surg Am.* 2016;98(20):e88. doi: [10.2106/jbjs.16.00114](https://doi.org/10.2106/jbjs.16.00114).
6. Ren Z, Li S, Sheng L, Zhuang Q, Li Z, Xu D, et al. Topical use of tranexamic acid can effectively decrease hidden blood loss during posterior lumbar spinal fusion surgery: a retrospective study. *Medicine (Baltimore).* 2017;96(42):e8233. doi: [10.1097/md.0000000000008233](https://doi.org/10.1097/md.0000000000008233).
7. Kako H, Gable A, Martin D, Beebe A, Thung A, Samora W, et al. A prospective, open-label trial of clevidipine for controlled hypotension during posterior spinal fusion. *J Pediatr Pharmacol Ther.* 2015;20(1):54-60. doi: [10.5863/1551-6776-20.1.54](https://doi.org/10.5863/1551-6776-20.1.54).
8. Upadhyay SP, Samant U, Tellicherry SS, Mallik S, Saikia PP, Mallick PN. Controlled hypotension in modern anaesthesia: a review and update. *Int J Biol Pharm Res.* 2015;6(7):532-42.
9. Lang B, Zhang L, Lin Y, Zhang W, Li FS, Chen S. Comparison of effects and safety in providing controlled hypotension during surgery between dexmedetomidine and magnesium sulphate: a meta-analysis of randomized controlled trials. *PLoS One.* 2020;15(1):e0227410. doi: [10.1371/journal.pone.0227410](https://doi.org/10.1371/journal.pone.0227410).
10. Ebrahimi Dehkordy M, Tavanaei R, Younesi E, Khorasanizade S, Azizi Farsani H, Oraee-Yazdani S. Effects of perioperative

- magnesium sulfate infusion on intraoperative blood loss and postoperative analgesia in patients undergoing posterior lumbar spinal fusion surgery: a randomized controlled trial. *Clin Neurol Neurosurg*. 2020;196:105983. doi: [10.1016/j.clineuro.2020.105983](https://doi.org/10.1016/j.clineuro.2020.105983).
11. Elyamany HE, Abd Elmoaty AEM, Elshaboury AM. Magnesium sulfate resistance of geopolymer mortar. *Constr Build Mater*. 2018;184:111-27. doi: [10.1016/j.conbuildmat.2018.06.212](https://doi.org/10.1016/j.conbuildmat.2018.06.212).
 12. Sousa AM, Rosado GM, de Sá Neto J, Guimarães GM, Ashmawi HA. Magnesium sulfate improves postoperative analgesia in laparoscopic gynecologic surgeries: a double-blind randomized controlled trial. *J Clin Anesth*. 2016;34:379-84. doi: [10.1016/j.jclinane.2016.05.006](https://doi.org/10.1016/j.jclinane.2016.05.006).
 13. Irazuzta JE, Paredes F, Pavlicich V, Domínguez SL. High-dose magnesium sulfate infusion for severe asthma in the emergency department: efficacy study. *Pediatr Crit Care Med*. 2016;17(2):e29-33. doi: [10.1097/pcc.0000000000000581](https://doi.org/10.1097/pcc.0000000000000581).
 14. Taheri A, Haryalchi K, Mansour Ghanaie M, Habibi Arejan N. Effect of low-dose (single-dose) magnesium sulfate on postoperative analgesia in hysterectomy patients receiving balanced general anesthesia. *Anesthesiol Res Pract*. 2015;2015:306145. doi: [10.1155/2015/306145](https://doi.org/10.1155/2015/306145).
 15. Bayram A, Ülgeç A, Güneş I, Ketenci I, Çapar A, Esmoğlu A, et al. [Comparison between magnesium sulfate and dexmedetomidine in controlled hypotension during functional endoscopic sinus surgery]. *Rev Bras Anesthesiol*. 2015;65(1):61-7. doi: [10.1016/j.bjan.2014.04.003](https://doi.org/10.1016/j.bjan.2014.04.003). [Portuguese].
 16. Rokhtabnak F, Djalali Motlagh S, Ghodrati M, Pournajafian A, Maleki Delarestaghi M, Tehrani Banihashemi A, et al. Controlled hypotension during rhinoplasty: a comparison of dexmedetomidine with magnesium sulfate. *Anesth Pain Med*. 2017;7(6):e64032. doi: [10.5812/aapm.64032](https://doi.org/10.5812/aapm.64032).
 17. White PF, Song D. New criteria for fast-tracking after outpatient anesthesia: a comparison with the modified Aldrete's scoring system. *Anesth Analg*. 1999;88(5):1069-72. doi: [10.1097/0000539-199905000-00018](https://doi.org/10.1097/0000539-199905000-00018).
 18. Lobo Prabhu K, Cleghorn MC, Elnahas A, Tse A, Maeda A, Quereshy FA, et al. Is quality important to our patients? The relationship between surgical outcomes and patient satisfaction. *BMJ Qual Saf*. 2018;27(1):48-52. doi: [10.1136/bmjqs-2017-007071](https://doi.org/10.1136/bmjqs-2017-007071).
 19. Srivastava VK, Mishra A, Agrawal S, Kumar S, Sharma S, Kumar R. Comparative evaluation of dexmedetomidine and magnesium sulphate on propofol consumption, haemodynamics and postoperative recovery in spine surgery: a prospective, randomized, placebo controlled, double-blind study. *Adv Pharm Bull*. 2016;6(1):75-81. doi: [10.15171/apb.2016.012](https://doi.org/10.15171/apb.2016.012).
 20. Ghodrati MR, Homae MM, Farazmehr K, Nikzad-Jamnani AR, Soleymani-Dodaran M, Pournajafian AR, et al. Comparative induction of controlled circulation by magnesium and remifentanyl in spine surgery. *World J Orthop*. 2014;5(1):51-6. doi: [10.5312/wjo.v5.i1.51](https://doi.org/10.5312/wjo.v5.i1.51).
 21. Hwang JY, Na HS, Jeon YT, Ro YJ, Kim CS, Do SH. I.V. infusion of magnesium sulphate during spinal anaesthesia improves postoperative analgesia. *Br J Anaesth*. 2010;104(1):89-93. doi: [10.1093/bja/aep334](https://doi.org/10.1093/bja/aep334).
 22. Martin DP, Samora WP 3rd, Beebe AC, Klamar J, Gill L, Bhalla T, et al. Analgesic effects of methadone and magnesium following posterior spinal fusion for idiopathic scoliosis in adolescents: a randomized controlled trial. *J Anesth*. 2018;32(5):702-8. doi: [10.1007/s00540-018-2541-5](https://doi.org/10.1007/s00540-018-2541-5).
 23. Ryu JH, Sohn IS, Do SH. Controlled hypotension for middle ear surgery: a comparison between remifentanyl and magnesium sulphate. *Br J Anaesth*. 2009;103(4):490-5. doi: [10.1093/bja/aep229](https://doi.org/10.1093/bja/aep229).
 24. Kosucu M, Tugcugil E, Arslan E, Omur S, Livaoglu M. Effects of perioperative magnesium sulfate with controlled hypotension on intraoperative bleeding and postoperative ecchymosis and edema in open rhinoplasty. *Am J Otolaryngol*. 2020;41(6):102722. doi: [10.1016/j.amjoto.2020.102722](https://doi.org/10.1016/j.amjoto.2020.102722).
 25. Modir H, Modir A, Rezaei O, Mohammadbeigi A. Comparing remifentanyl, magnesium sulfate, and dexmedetomidine for intraoperative hypotension and bleeding and postoperative recovery in endoscopic sinus surgery and tympanomastoidectomy. *Med Gas Res*. 2018;8(2):42-7. doi: [10.4103/2045-9912.235124](https://doi.org/10.4103/2045-9912.235124).
 26. Jangra K, Malhotra SK, Gupta A, Arora S. Comparison of quality of the surgical field after controlled hypotension using esmolol and magnesium sulfate during endoscopic sinus surgery. *J Anaesthesiol Clin Pharmacol*. 2016;32(3):325-8. doi: [10.4103/0970-9185.173400](https://doi.org/10.4103/0970-9185.173400).
 27. Forget P, Cata J. Stable anesthesia with alternative to opioids: are ketamine and magnesium helpful in stabilizing hemodynamics during surgery? A systematic review and meta-analyses of randomized controlled trials. *Best Pract Res Clin Anaesthesiol*. 2017;31(4):523-31. doi: [10.1016/j.bpa.2017.07.001](https://doi.org/10.1016/j.bpa.2017.07.001).