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Clinical Studies

Hemodynamically significant cardiac arrhythmias during general anesthesia for spine surgery: A case series and literature review

Marie-Jacqueline Reisener[a,*], Jennifer Shue[a], Alexander P Hughes[a], Andrew A Sama[a], Ronald G Emerson[c], Carrie Guheen[b], James D Beckman[b], Ellen M Soffin[b]

[a] Department of Orthopedic Surgery, Spine Service, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, Unites States of America
[b] Department of Anesthesiology, Critical Care & Pain Management, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, Unites States of America
[c] Department of Neurology, Hospital for Special Surgery, 5325 East 71st Street, New York, NY 10021, Unites States of America

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ABSTRACT

Background context: Hemodynamically significant bradycardia and cardiac arrest (CA) are rare under general anesthesia (GA) for spine surgery. Although patient risks are well defined, emerging data implicate surgical, anesthetic and neurologic factors which should be considered in the immediate management and decision to continue or terminate surgery.
Purpose: To characterize causes and contributors to significant arrhythmias during spine surgery. We also provide an updated literature review to inform spine care teams and aid in the management of intraoperative bradycardia and CA.
Study design: Case series and literature review
Patient sample: Six patients who underwent spine surgery from 03/2016 to 01/2020 at a single institution and developed unexpected hemodynamically significant arrhythmia
Outcome measures: Our primary outcome was to identify potential risk factors of interest for significant arrhythmia during spine surgery.
Methods: Medical records of patients who underwent spine surgery from 03/2016 to 01/2020 at a single institution and developed unexpected hemodynamically significant arrhythmia during spine surgery were identified from a departmental Quality Assurance Database. We evaluated the presence/absence of patient, surgical, anesthetic and neurologic risk factors and estimated the most likely etiology of the event, immediate and subsequent management, whether surgery was postponed or continued and outcomes.
Results: We found a temporal relationship of bradyarrhythmia and CA after somatosensory evoked potential (SSEP) stimulation in 4/6 cases and pharmacy/polypharmacy in 2/6. Surgery was completed in 4/6 patients, and terminated in 2/6 (subsequently completed in both). We found no adverse outcomes in any patients. Our literature review predominately identified case reports for guidance to support decision making. New literaure suggests peripheral nerve blocks and opioid-sparing anesthetic agents should also be considered.
Conclusions: Significant bradycardia and CA during spine surgery does not always require termination of the surgical procedure. Decision making should be undertaken in each case individually, with an updated awareness of potential causes. The study also suggests the need for large prospective studies to adequately assess incidence, risk factors and outcomes.

Background

Hemodynamically significant bradycardia and cardiac arrest are rare under general anesthesia for spine surgery [1–3]. Depending on the most likely etiology, surgery may be terminated to allow investigation, or continued after resolution of the event. Unexpected intraoperative arrhythmia may signal underlying coronary artery disease, valvulopathy, or conduction abnormality, and necessitate termination of surgery for diagnosis and intervention. Alternatively, arrhythmia may represent recognized side effects of sedative, hypnotic and analgesic agents used as part of a balanced anesthetic. These agents may be adjusted, and the surgery can proceed without further perioperative investigation.

Unfortunately, the etiology of intraoperative arrhythmia is likely to be unclear and multifactorial. Further, continuing or terminating surgery requires consensus of the intraoperative care team, in the absence of robust evidence to guide decision making. Indeed, we could

* Corresponding author.
E-mail address: reisenerm@hss.edu (M.-J. Reisener).

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identify no prospective studies reporting the incidence of significant intraoperative arrhythmias, immediate management strategies, and subsequent outcomes.

Given these gaps, we retrospectively reviewed a series of 6 patients to explore potential contributory factors to unexpected transient intraoperative bradycardia or asystole during spine surgery. We also reviewed the immediate management, subsequent decision making, and patient outcomes. This case series suggests the need for larger, prospective studies to adequately estimate the incidence, causes and consequences of significant arrhythmias during spine surgery. These data are needed to aid risk stratification and improve decision making for spine care teams.

Methods

This is a retrospective case series of 6 patients who underwent spine surgery by four surgeons at an orthopedic specialty hospital in New York City, NY. Cases were identified by searching the Department of Anesthesiology Quality Assurance database for reported instances of bradycardia or asystole of any duration during spine surgery between 03/2016 and 01/2020 at a single institution. Data were extracted by manual search of the electronic medical record. We defined the potential risk factors of interest for arrhythmia according to: patient factors [(history of cardiac, cardiovascular or neurological conditions, medications, age, ASA classification and body mass index (BMI)], surgical factors (diagnosis, type of surgery, time of day, time from incision to event, phase of surgery, any intraoperative neurophysiological monitoring (IONM) at the time of the event; either somatosensory evoked potentials, SSEPs, or motor evoked potentials, MEPs) and anesthetic factors (agents used, duration of nil per mouth (NPO) status and patient position). We also characterized details of the arrhythmia (bradycardia and/or asystole, and duration), subsequent management (any pharmacologic intervention, decision to proceed with or terminate surgery, any postoperative investigations) and the likely etiology. Results are presented descriptively.

Case reports

Summary details for the 6 patients are reported in Table 1. Patients ranged in age from 22 to 73 years. Four patients were male and 2 were female. Both female patients were overweight (Case 4: BMI 32.1 kg/m^2; Case 5: BMI 31.3 kg/m^2). Five patients were classified as ASA 1 or 2 and one patient as ASA 3 (Case 5). Five patients had no cardiovascular risk factors. One patient (Case 5) had a history of paroxysmal atrial fibrillation and hypertension, reported as well controlled on atenolol, amlodipine and flecanide. All 6 patients underwent routine preanesthetic medical evaluation and risk assessment. Four patients had normal preoperative electrocardiograph (ECG). One patient (Case 2) met voltage criteria for left ventricular hypertrophy (LVH). One patient (Case 3) had an ECG significant for sinus bradycardia, LVH and nonspecific T-wave abnormalities; a pre-operative echocardiogram showed no abnormalities. A standard anesthesia technique was followed for each case, as per our institutional protocol [4].

Case 1: A 26-year old man underwent L5/S1 microdisectomy, indicated for herniated nucleus pulposus (HNP).

Event: asystole, lasting 45 s.

Conditions: Pre-incision, with the patient in the prone position. Anesthetics included inhaled isoflurane, propofol and ketamine infusions. IOMN technician performed tibial SSEPs immediately prior to the event.

Management: CPR. IONM technician alerted, and SSEPs stopped, followed by ROSC.

Decision making: The surgery was completed successfully and IONM was suspended for the duration of the procedure. No further arrhythmias noted.

Attribution: SSEP stimulation.

Case 2: A 22-year old male underwent lateral lumbar interbody fusion (LLIF) with posterior instrumentation at L4-L5 indicated for spondylolisthesis.

Event: transient bradycardia (to 10–15 bpm lasting 10 s) followed by asystole (lasting 10–15 s).

Conditions: Pre-incision, with the patient in the left lateral position, during surgical time out. Anesthetics included inhaled isoflurane, propofol, ketamine and dexmedetomidine infusions. IONM technician performed tibial and ulnar SSEPs immediately prior to the event.

Management: CPR. IONM technician alerted, and SSEPs stopped, followed by ROSC.

Decision making; The surgery was completed successfully and IONM was suspended for the duration of the procedures. No further arrhythmias noted. Given pre-operative findings on the ECG, a postoperative echocardiogram was performed and the patient was reviewed by cardiology. Finding were notable for LVH. The patient was referred for neurological review as an outpatient and diagnosed with postural orthostatic tachycardia syndrome (POTS). *Attribution*: SSEP stimulation, exacerbated by hypovolemia secondary to prolonged NPO status with underlying POTS.

Case 3: A 57-year old man underwent interbody fusion and posterior instrumentation at L4-S1 indicated for degenerative lumbar scoliosis with residual spinal stenosis.

Event: bradycardia to 11 bpm with hypotension (MAPs 40 s) lasting 25 s.

Conditions: During surgical exposure, with the patient in prone position. Anesthetics included inhaled isoflurane, propofol, ketamine and dexmedetomidine infusions, with opioid analgesics within the prior hour (hydromorphone, 2 mg, iv). IOMN technician performed tibial and ulnar SSEPs immediately prior to the event.

Management: Iv fluids were administered with multiple doses of ephedrine (10 mg x2) and glycopyrrolate (0.4 mg x1) with restoration of baseline heart rate and MAP. Dexmedetomidine infusion was stopped. The patient was admitted to the ICU for overnight telemetry.

Decision making: The surgery was completed without further episodes of bradycardia. A postoperative echocardiogram, ECG and monitoring were uneventful.

Attribution: Dexmedetomidine infusion, in a patient with underlying sinus bradycardia.

Case 4: A 72-year old female underwent a LLIF with posterior instrumentation at L4-L5 indicated for degenerative disk disease.

Event: Multiple transient episodes of second-degree heart block, Mobitz Type II followed by complete heart block and asystole, lasting 45 s.

Conditions: During surgical exposure, with the patient in prone position. Anesthetics included inhaled isoflurane, propofol, ketamine and dexmedetomidine infusions. Methadone (10 mg, iv) was administered within the previous hour. IOMN technician performed tibial SSEPs immediately prior to the event.

Management: CPR, followed by ROSC, supine repositioning.

Decision making: The procedure was terminated, and the patient was transferred to the ICU for monitoring and investigation. Evaluations for cardiac, anaphylactic, and thromboembolic etiologies were unremarkable. The patient underwent the planned surgery three days later without arrhythmia or complication. Methadone and dexmedetomidine were not administered.

Attribution: Methadone/dexmedetomidine-induced heart block.

Case 5: A 73-year old woman underwent a LLIF at L2-L3 with extension posterior fusion from L3-Pelvis, indicated for spinal stenosis.

Event: Asystole lasting 20 s. Preceded by 3 episodes of transient bradycardia, poorly responsive to ephedrine and glycopyrrolate.

Conditions: The bradycardic episodes occurred in the supine position while the IONM technician was titrating stimulus parameters to obtain baseline SSEPs. Anesthetic agents included inhaled isoflurane, propofol and ketamine infusions. Opioids were administered in the previous 30 min (fentanyl 100 μg iv). Asystole occurred prior to incision, during X-ray imaging with the patient in lateral position. The IONM technician performed tibial SSEPs immediately prior to the event.

Management: Supine repositioning; iv fluids and epinephrine were administered. The IONM technician was alerted and SSEP monitoring

Table 1
Overview of patients' demographics and contributory factors which lead to unexpected intraoperative bradycardia or asystole during spine surgery.

Variables	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Age	26	22	57	72	73	61
Sex	Male	Male	Male	Female	Female	Male
Race	White	White	White	White	White	White
Hemoglobin (g/dL)	16	15.3	14.9	13.6	10.4 (chronic)	14.5
Cardiovascular risk factors	None	None	Sinus bradycardia noted on pre-operative ECG	None	Paroxysmal Arrhythmia Hypertension	None
Other relevant comorbidities	None	None	None	Chronic Hepatitis C	Bronchiectasis with mild pulmonary hypertension	Obstructive sleep apnea syndrome
Medication related to co-morbidities	None	None	Acetaminophen Enoxaparin Hydromorphone Methocarbamol	Acetaminophen Aspirin Cyclobenzaprine Oxycodone Zolpidem	Atenolol Flecanide Amlodipine Triamterene Clonazepam Paroxetine	None
Hemodynamic relevant medication at the day of surgery	None	None	None	None	None	None
ASA	1	1	2	2	3	2
BMI	27.8	24.5	28.6	32.1	31.3	22
Indication	Lumbar disk herniation	Degenerative spondylolisthesis	Lumbar scoliosis Spinal stenosis	Degenerative disk disease Spinal stenosis Lumbar scoliosis	Spinal stenosis	Degeneration of cervical intervertebral disk C4–6 Myelopathy
Intervention	Microscopic discectomy right L5/S1	LLIF L4/5	OLIF L4-S1, LLIF L3–5	LLIF L4/5, PLIF L4/5	LLIF L2/3 Extension Fusion L2-Pelvis (prior fusion L3-Pelvis)	ACDF C4–6
Time of day of surgery	Morning	Morning	Noon	Morning	Afternoon	Morning
Time to event from anesthetic Induction end (min)	8	44	102	87	18	36
Time to event from incision (min)	NA	NA	48	33	NA	NA
Phase of surgery	Drying of skin preparation	Time out	During exposure	During exposure	While positioning from Supine to lateral left	During exposure
Patient position	Prone	Supine	Lateral left	Prone	Lateral left decubitus	Supine
Use of IOMN (SSEP)	Yes	Yes	Yes	Yes	Yes	Yes
Time to event from IOMN stimulation (min)	1	1	11	1	0	15
IOMN Note	Tibial stimulation	Tibial and ulnar stimulation	Tibial and ulnar stimulation	Tibial stimulation	Tibial stimulation	Tibial and ulnar stimulation
Inhaled anesthetics	Isoflurane	Isoflurane	Isoflurane	Isoflurane	Sevoflurane	Isoflurane
Iv anesthetics	Propofol Midazolam	Propofol Midazolam Ketamine	Propofol Midazolam Ketamine	Propofol Midazolam Ketamine	Propofol Midazolam	Propofol Midazolam
Opioids	Fentanyl Hydromorphone	Fentanyl	Fentanyl Methadone	Fentanyl Methadone	Fentanyl	Fentanyl
Other anesthetic agents	Cefazolin Vecuronium Dexamethasone	Cefazolin Vecuronium Dexamethasone	Cefazolin Famotidine Vecuronium Dexamethasone Dexmedetomidine	Cefazolin Famotidine Vecuronium Dexamethasone Ondansetron Lidocaine Tranexamic Acid Dexmedetomidine	Vecuronium Lidocaine	Vecuronium Succinylcholine
Use of peripheral nerve block	No	Yes	Yes	No	No	No
Time peripheral nerve block to event (min)	NA	36	92	NA	NA	NA
Duration of NPO status (h)	8.23	9.03	13.21	10.16	13.37	9.31
Iv fluid administered (ml)	500	1500	2000	1000	2500	1200
Estimated blood loss (ml)	20	50	600	100	200	No

(*continued on next page*)

Table 1 (*continued*)

Variables	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Course of event	Continued	Continued	Continued	Aborted	Continued	Aborted
Reason	Recovered	Recovered	Recovered	Cardiac arrest	Recovered	Severe refractory hypotension
Duration event (sec)	<45	15	NA	45	<60	360
Cardiac rhythm	Asystole	Asystole	Bradycardia	Asystole	Asystole	Asystole followed by bradycardia and hypotension
Management	CPR. IONM technician alerted, and SSEPs stopped, followed by ROSC.	CPR. IONM technician alerted, and SSEPs stopped, followed by ROSC. Fluid	Iv fluids with multiple doses of ephedrine (10 mg x2) and glycopyrrolate (0.4 mg x1) with restoration of baseline heart rate and MAP. Dexmedetomidine infusion was stopped. Admitted to the ICU. Ephedrine	CPR, followed by ROSC, supine repositioning, PACU, cardiology consult	Supine repositioning; iv fluids and epinephrine. IONM technician alerted, and SSEPs stopped, followed by ROSC. Return to supine, returned	iv fluids, glycopyrrolate and ephedrine were administered. The patient's HR recovered to baseline, but the MAP was persistently low (52–60).
Postoperative cardiology investigation & evaluation	NA	Postoperative ECG: no LVH by voltage; heart murmur; outpatient cardiac MRI recommended	ECG without findings	ECG: Sinus rhythm, left axis deviation, RVCD TTE: moderate diastolic dysfunction	Bedside TTE: grossly normal RV and LV, dilated RA and LA, neutral volume status	Bedside TTE: grossly normal RV and LV; hyperdynamic appearance c/w hypovolemia; troponins: negative x3
Possible Cause	Vaso-vagal due to SSEP stimulation	Vaso-vagal due to SSEP stimulation	Dexmedetomidine infusion (underlying Sinus bradycardia)	Methadone/ Dexmedetomidine induced heart block	Vaso-vagal due to SSEP stimulation	Vaso-vagal due to SSEP stimulation

LLIF Lateral Lumbar Interbody Fusion; *OLIF* Oblique Lateral Interbody Fusion; *PLIF* Posterior Lumbar interbody Fusion; *ACDF* Anterior Cervical Discectomy and Fusion; *IOMN* Intraoperative Neurophysiological Monitoring; *SSEP* Somatosensory Evoked Potential; *NPO* Nil Per Os; *CPR* Cardiopulmonary resuscitation; *ROSC* Return Of Spontaneous circulation; *MAP* Mean Arterial Pressure; *ICU* Intensive Care Unit; *PACU* Post Anesthesia Care Unit; *HR* Heart Rate; *ECG* Electrocardiogram; *TTE* Transthoracic Echocardiogram; *RVCD* right ventricular conduction delay.

was terminated, followed by ROSC. A bedside transthoracic echocardiogram (TTE) was unremarkable with neutral volume status.

Decision making: The surgery was completed successfully and IONM was suspended for the duration of the procedures. No further arrhythmias noted.

Attribution: SSEP stimulation.

Case 6: A 61-year old male underwent anterior cervical decompression and fusion (ACDF) at C4-C6 for intervertebral disk degeneration.

Event: Asystole lasting 2 s, followed by bradycardia (15–20 bpm) lasting 80 s.

Conditions: During exposure with the patient in supine position. Anesthetics included inhaled isoflurane, propofol and ketamine infusions. The IONM technician performed tibial and ulnar SSEPs immediately prior to the event.

Management: iv fluids, glycopyrrolate and ephedrine were administered. The patient's HR recovered to baseline, but the MAP was persistently low (52–60). A bedside TTE was consistent with hypovolemia.

Decision making: The surgery was terminated, and the patient was transferred to the ICU for monitoring and further evaluation. Cardiology review and investigations were unremarkable. The planned surgery was completed the following day without arrhythmia or complications.

Attribution: SSEP stimulation, exacerbated by hypovolemia secondary to prolonged NPO status.

Discussion

In this retrospective case series, we found no adverse outcomes following hemodynamically significant arrhythmias in 6 patients undergoing spine surgery. Additionally, we attributed the most likely etiology of arrhythmia to SSEP monitoring (in 4/6 cases), or to pharmacy (in 2/6 cases). Each of these represent immediately reversible or modifiable causes of arrhythmia. Thus, it may not always be necessary to terminate spine surgery for investigation of these unexpected intraoperative events. These cases also highlight the importance of recognizing unique risks in spine surgery patients, and how emerging anesthetic, neurologic and surgical techniques may interact and contribute to the development of arrhythmias.

Risk factors for cardiac arrest during spine surgery have been well defined, including lumbar fusion, age over 65 years, obesity, cardiovascular disease, ethnicity and ASA status [1,2,8]. Bradycardia and asystole have been described under general anesthesia in combined surgical cohorts: Proposed mechanisms include unopposed parasympathetic activation, enhanced vasovagal response to decreased venous return and psychiatric stressors [5].

In contrast, few studies report significant bradycardia or transient asystole during spine surgery in otherwise healthy patients. Where described, the etiology of arrhythmia typically reflects venous thromboembolic events, preexisting cardiac abnormalities, anaphylactic shock or hypovolemia [6–9]. The absence of structural heart disease or other defined risk factors associated with arrhythmias in our case series suggest that other mechanisms should be considered.

Previous case reports suggested bradycardia during spine surgery is caused via afferent parasympathetic stimulation during dural traction or electrocautery in the lumbosacral region [10–15]. A lumbar-cardiac reflex has been proposed, in which parasympathetic stimulation leads to increased vagal tone, and consequent bradycardia and hypotension [16,17]. Typically, these reflex-mediated arrhythmias are terminated when direct or indirect manipulation of the spinal dura is discontinued [17]. In contrast, based on timing and phase of surgery, we did not find any arrhythmias attributable to a lumbar-cardiac reflex.

In our case series the only consistent contributor in all six patients was the SSEP stimulation immediately preceding the episode of bradycardia/asystole (Table 1). We therefore hypothesize SSEP stimulation may trigger a vasovagal reaction, similar to the proposed mechanism for dural traction-induced arrhythmia. Indeed, case reports describe bradycardia or/and asystole which normalize with cessation of MEPs or SSEPs [18,19], MEPs have also been implicated in the conversion from hemiblock to complete heart block in a case report [20], similar to our observation in Case 4. The mechanism by which SSEP stimulation causes arrhythmia may be via afferents from peripheral nerves which trigger a vagally mediated response which in turn depresses the sinoatrial node. It is unclear why a subset of patients experiences cardiac arrhythmia during IOMN stimulation, however an underlying predisposition or combination of factors is likely. This is highlighted by our analyses of Cases 2 and 6, in which hypovolemia was suspected as contributory. Alternatively, anatomic differences, such as cervical stenosis may render some patients more susceptible to the effects of IONM stimulation than others [21].

Patient positioning during spine surgery should also be considered in relation to unexpected arrhythmia. Prone positioning is associated with several physiologic changes, including decreased cardiac output, inferior vena cava compression, reduced venous return, and redistribution of pulmonary blood flow [6,22]. Compression of the lower extremity veins additionally raises the risk of intraoperative venous thromboembolism as a cause of arrhythmia [7]. In combination with intraoperative blood loss and hypovolemia, these position-related factors elevate the risk of cardiac arrhythmias with hemodynamic instability [5,23]. Although our analysis included just 6 cases, we did not find any consistent relationship between positioning, large blood loss and the development of arrhythmias.

The benefits of contemporary anesthetic and analgesic techniques must also be weighed against the risk for bradycardia and asystole. Dexmedetomidine is a highly selective α_2 adreno-receptor agonist with sedative, anxiolytic, sympatholytic, and analgesic effects [24,25]. Given these advantages, dexmedetomidine is increasingly included in anesthetic regimens and enhanced recovery pathways for spine surgery [4]. However, a predictable side effect of dexmedetomidine is hemodynamically significant bradycardia, with potential to progress to asystole, as we observed in Case 3. This risk may be further elevated when dexmedetomidine is added to agents which prolong the QT interval. A major emphasis of pain management in spine surgery cohorts is to provide opioid-sparing, long lasting analgesia, and to prevent the conversion of acute to chronic pain. Methadone has recently been demonstrated to be of significant value in this regard [26]. However, methadone prolongs the QT interval, and has been associated with major cardiac arrhythmias and torsade de points when administered during spine surgery [27]. Consistent with these effects, we speculate that in Case 4, methadone and dexmedetomidine acted synergistically to exacerbate an underlying predisposition to bradycardia and increased vagal tone, culminating in asystole.

In two of our patients, a transversus abdominis plane (TAP) block was performed pre-operatively as an analgesic adjunct. Peripheral nerve blocks (PNBs) are increasingly applied to spine surgery as a method to provide opioid-sparing analgesia [28,29]. Although PNBs are relatively simple and safe to perform [30,31], local anesthetic toxicity syndrome classically manifests with sudden cardiac arrhythmias and hypotension, followed by cardiovascular collapse [32].

Our study suffers from the inherent limitations of a retrospective review. We chose a Quality Assurance Database to identify cases, which relies on voluntary reporting for inclusion. This likely underestimated the true incidence of arrhythmias in our spine surgery population. Data was extracted from the medical record, which assumes accurate entry, although intraoperative hemodynamic data is automatically imported into the records. Finally, our case series is small and derived from a specialty orthopedic surgery hospital, limiting generalizability.

Conclusion

Here we report 6 cases of significant bradycardia and/or asystole during spine surgery. Although multiple factors have been implicated, the cases highlight SSEP stimulation as a common etiology of arrhythmia. Prospective research is required to understand the temporal relationship and interactions between IONM modalities and arrhythmias. Allied to this, studies exploring risk mitigating strategies for IONM should be performed. For example, test stimulation before incision may help identify at-risk patients, as was suggested by Case 4 [19]. As anesthetic options evolve, and combinations of agents are used together to achieve analgesic goals, prospective trials will be required to understand the risks and benefits unique to spine surgery. Finally, our study suggests the true incidence of hemodynamically significant arrhythmias may be higher than has been previously reported. This question can only be answered by well-designed prospective study.

In the meantime, the decision to continue or terminate surgery should be decided based on patient condition and circumstances of each event. Surgeons and anesthesiologists should be aware of and prepared to treat significant cardiac arrhythmias during spine surgery even in otherwise healthy patients without known risk factors.

Declaration of Competing interest

The authors have no conflict of interest directly relevant to this work.

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Ethics Approval

This retrospective chart review study involving human participants was conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Hospital for Special Surgery IRB approved this study (HSS-IRB #2020–0091, PI, EM Soffin).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2020.100010.

References

[1] Fineberg SJ, Ahmadinia K, Patel AA, Oglesby M, Singh K. Incidence and mortality of cardiac events in lumbar spine surgery. Spine (Phila Pa 1976) 2013;38:1422–9 https://doi.org/. doi:10.1097/BRS.0b013e3182986d71.

[2] Bovonratwet P, Bohl DD, Malpani R, Haynes MS, Rubio DR, Ondeck NT, et al. Cardiac complications related to spine surgery: timing, risk factors, and clinical effect. J Am Acad Orthop Surg 2019;27:256–63 https://doi.org/. doi:10.5435/JAAOS-D-17-00650.

[3] Quinn TD, Brovman EY, Aglio LS, Urman RD. Factors associated with an increased risk of perioperative cardiac arrest in emergent and elective craniotomy and spine surgery. Clin Neurol Neurosurg 2017;161:6–13 https://doi.org/. doi:10.1016/j.clineuro.2017.07.014.

[4] Soffin EM, Vaishnav AS, Wetmore DS, Barber L, Hill P, Gang CH, et al. Design and implementation of an enhanced recovery after surgery (ERAS) program for minimally invasive lumbar decompression spine surgery: initial experience. Spine (Phila Pa 1976) 2019 https://doi.org/. doi:10.1097/BRS.0000000000002905.

[5] Kinsella SM, Tuckey JP. Perioperative bradycardia and asystole: relationship to vasovagal syncope and the Bezold-Jarisch reflex. Br J Anaesth 2001 https://doi.org/. doi:10.1093/bja/86.6.859.

[6] Chowdhury T, Petropolis A, Cappellani RB. Cardiac emergencies in neurosurgical patients. Biomed Res Int 2015 https://doi.org/. doi:10.1155/2015/751320.

[7] Brown J, Rogers J, Soar J. Cardiac arrest during surgery and ventilation in the prone position: a case report and systematic review. Resuscitation 2001 https://doi.org/. doi:10.1016/S0300-9572(01)00362-8.

[8] Albin MS, Ritter RR, Pruett CE, Kalff K. Venous air embolism during lumbar laminectomy in the prone position: report of three cases. Anesth Analg 1991 https://doi.org/. doi:10.1213/00000539-199109000-00021.

[9] Prabhakar H, Bithal PK, Dash M, Chaturvedi A. Rupture of aorta and inferior vena cava during lumbar disc surgery. Acta Neurochir (Wien) 2005 https://doi.org/. doi:10.1007/s00701-004-0405-2.
[10] Deschamps A. Lumbo-sacral spine surgery and severe bradycardia [2]. Can J Anesth 2004 https://doi.org/. doi:10.1007/BF03019113.
[11] Mandal NG. More on lumbo-sacral spine surgery and bradycardia [2]. Can J Anesth 2004 https://doi.org/. doi:10.1007/BF03018898.
[12] Chauhan V, Tiwari A, Rath GP, Banik S. Asystole during lumbar discectomy: a case report. J Clin Anesth 2016;31:265–6 https://doi.org/. doi:10.1016/j.jclinane.2016.01.014.
[13] Weimer JM, Marinov M, Avitsian R. Dural traction a possible cause of hemodynamic changes during single-level transforaminal lumbar interbody fusion. World Neurosurg 2017 https://doi.org/. doi:10.1016/j.wneu.2016.09.102.
[14] Chowdhury T, Narayanasamy S, Dube SK, Rath GP. Acute hemodynamic disturbances during lumbar spine surgery. J Neurosurg Anesthesiol 2012 https://doi.org/. doi:10.1097/ANA.0b013e31823ac2d6.
[15] Chowdhury T, Sapra H, Dubey S. Severe hypotension in transforaminal lumbar interbody fusion surgery: is it vasovagal or? Asian J Neurosurg 2017 https://doi.org/. doi:10.4103/1793-5482.144173.
[16] McCorry LK. Physiology of the autonomic nervous system. Am J Pharm Educ 2007 https://doi.org/. doi:10.5688/aj710478.
[17] Chowdhury T, Schaller B. The negative chronotropic effect during lumbar spine surgery: a systemic review and aggregation of an emerging model of spinal cardiac reflex. Med (United States) 2017:96 https://doi.org/. doi:10.1097/MD.0000000000005436.
[18] Ponder BL, Conner TF, Floyd DT, Tao C, Enyia OK. Acute bradycardia as a result of intraoperative transcranial electric motor evoked potential stimulation: a case report. Am J Electroneurodiagnostic Technol 2003 https://doi.org/. doi:10.1080/1086508x.2003.11079424.
[19] Morano JM, Tung A. Bradycardic arrest during somatosensory-evoked potential monitoring. A A Pract 2019 https://doi.org/. doi:10.1213/xaa.0000000000001123.
[20] Bicket MC, Ritzl EK, Tamargo RJ, Mintz CD. Conversion of hemiblock to complete heart block by intraoperative motor-evoked potential monitoring. A A Case Reports 2014 https://doi.org/. doi:10.1213/xaa.0000000000000095.
[21] Khanna K, Theologis AA, Tay B. Autonomic dysreflexia caused by cervical stenosis. Spinal Cord Ser Cases 2017 https://doi.org/. doi:10.1038/s41394-017-0018-7.
[22] Edgcombe H, Carter K, Yarrow S. Anaesthesia in the prone position. Br J Anaesth 2008 https://doi.org/. doi:10.1093/bja/aem380.
[23] McNulty SE, Weiss J, Azad SS, Schaefer DM, Osterholm JL, Seltzer JL. The effect of the prone position on venous pressure and blood loss during lumbar laminectomy. J Clin Anesth 1992 https://doi.org/. doi:10.1016/0952-8180(92)90070-H.
[24] Weerink MAS, Struys MMRF, Hannivoort LN, Barends CRM, Absalom AR, Colin P. Clinical Pharmacokinetics and Pharmacodynamics of Dexmedetomidine. Clin Pharmacokinet 2017;56:893–913 https://doi.org/. doi:10.1007/s40262-017-0507-7.
[25] Naik BI, Nemergut EC, Kazemi A, Fernández L, Cederholm SK, McMurry TL, et al. The effect of dexmedetomidine on postoperative opioid consumption and pain after major spine surgery. Anesth Analg 2016 https://doi.org/. doi:10.1213/ANE.0000000000001226.
[26] Murphy GS, Avram MJ, Greenberg SB, Shear TD, Deshur MA, Dickerson D, et al. Postoperative pain and analgesic requirements in the first year after intraoperative methadone for complex spine and cardiac surgery. Anesthesiology 2020 https://doi.org/. doi:10.1097/ALN.0000000000003025.
[27] Dunn LK, Yerra S, Fang S, Hanak MF, Leibowitz MK, Alpert SB, et al. Safety profile of intraoperative methadone for analgesia after major spine surgery: an observational study of 1478 patients. J Opioid Manag 2018 https://doi.org/. doi:10.5055/jom.2018.0435.
[28] Soffin EM, Freeman C, Hughes AP, Wetmore DS, Memtsoudis SG, Girardi FP, et al. Effects of a multimodal analgesic pathway with transversus abdominis plane block for lumbar spine fusion: a prospective feasibility trial. Eur Spine J 2019 https://doi.org/. doi:10.1007/s00586-019-06081-3.
[29] Chin KJ, Lewis S. Opioid-free analgesia for posterior spinal fusion surgery using erector spinae plane (ESP) blocks in a multimodal *Anesthetic Regimen*. Spine (Phila Pa 1976) 2019 https://doi.org/. doi:10.1097/BRS.0000000000002855.
[30] Singh S, Choudhary NK, Lalin D, Verma VK. Bilateral ultrasound-guided erector spinae plane block for postoperative analgesia in lumbar spine surgery: a randomized control trial. J Neurosurg Anesthesiol 2019 https://doi.org/. doi:10.1097/ANA.0000000000000603.
[31] Brogi E, Giunta F, Kazan R, Cyr S, Hemmerling TM. Transversus abdominal plane block for postoperative analgesia: a systematic review and meta-analysis of randomized-controlled trials. Can J Anesth 2016 https://doi.org/. doi:10.1007/s12630-016-0679-x.
[32] Bourne E, Wright C, Royse C. A review of local anesthetic cardiotoxicity and treatment with lipid emulsion. Local Reg Anesth 2010;3:11–19 https://doi.org/. doi:10.2147/lra.s8814.