

ORIGINAL ARTICLE



The influence of epidural volume extension on spinal block with hyperbaric bupivacaine for elective knee arthroplasty

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Abstract

Background: Epidural volume extension (EVE) via a combined spinal–epidural is the enhancement of a small-dose intrathecal block by an epidural injection of physiological saline solution. The aim of this study was to investigate the sensory and motor block characteristics of spinal anesthesia after EVE. Eighty patients enrolled in this prospective, randomized, double-blind study. Group I ($n=40$) received 10 mg hyperbaric bupivacaine and group II ($n=40$) first received 10 mg hyperbaric bupivacaine intrathecally and subsequently 10 mL saline via epidural catheter.

Results: In the first 30 min after combined spinal–epidural anesthesia, the maximum sensory block level was significantly higher in group II than in group I. The Bromage score was significantly higher in group II than in group I at 3–6 and 9 min of the intraoperative period. EVE increased the mean S_{max} significantly in group 2 than group 1 ($p<0.05$). T_{max} was statistically similar between group 1 and group 2 ($p>0.05$). EVE significantly altered $Time_{10}$ and T_{adeq} in group 2 ($p<0.05$).

Conclusions: EVE with saline (10 mL) offer early onset of sensory and motor block and a high level of sensory block. And also delay supplemental epidural dose requirement intraoperatively.

Keywords: Total knee arthroplasty, Combined spinal–epidural anesthesia, Epidural volume extension

Background

Since the early 1970s, total knee arthroplasty (TKA) was a major advancement in the treatment of patients with chronic refractory joint pain and it continues to progress (Turnbull et al., 2017). TKA is a serious surgery and the majority of patients who undergo TKA are elderly and have co-morbidities (Okasha et al., 2014; Elmoftly & Buvanendran, 2017; Maung & Nazemzadeh, 2018). Early ambulation, short hospital stay, and minimizing the perioperative complications improve the outcomes (Elmoftly & Buvanendran, 2017). Anesthetic options for TKA are general anesthesia, neuraxial anesthesia (spinal, epidural, combined spinal–epidural), or a combination of both,

peripheral nerve block, neuraxial anesthesia with peripheral nerve block (Elmoftly & Buvanendran, 2017; Maung & Nazemzadeh, 2018; Johnson et al., 2016). Neuraxial anesthesia is preferred to general anesthesia in TKA cases (Magar et al., 2017; Güler et al., 2015; Kehlet & Aasvang, 2015). The most common preferred neuraxial anesthesia for TKA is spinal anesthesia. It is simple to apply and provides an intense and reliable block, but it has a risk of severe hypotension and a limited duration of action (Magar et al., 2017). On the other hand, even though epidural anesthesia alone provides more gradual onset of hypotension that can be controlled and the ability to titrate the duration of anesthesia; the muscle relaxation and motor block are less intense than spinal anesthesia (Buvanendran et al., 2006). Combined spinal–epidural anesthesia (CSEA) provides rapid onset and reliable block by spinal anesthesia perioperatively and maintains postoperative analgesia through the epidural

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catheter in the postoperative period (Okasha et al., 2014; Magar et al., 2017; Heesen et al., 2017; Kaur et al., 2012; Yun et al., 2014; Kucukguclu et al., 2008). Also, epidural catheter helps to achieve target block at inadequate block levels (Magar et al., 2017; Yun et al., 2014; Kucukguclu et al., 2008). The advantage of the EVE technique is that a small dose of intrathecal local anesthetic may provide an adequate level of anesthesia while allowing faster motor recovery of lower limbs (Kaur et al., 2012; Ong & Sashidharan, 2007). But the mechanism of EVE has not been clearly understood (15). Several hypotheses have been proposed to explain this mechanism (Blumgart et al., 1992; Zaphiratos et al., 2016).

1. Leakage of extradural local anesthetic into the subarachnoid space via the hole created by the subarachnoid puncture (Blumgart et al., 1992).
2. The fluid in the epidural space causes compression of the dural sac, resulting in a cephalad shift of local anesthetic within the cerebral spinal fluid (Blumgart et al., 1992; Zaphiratos et al., 2016).

The aim of this study is to investigate does the sensory was higher and motor block onset and resolution are faster with lower dose spinal anesthesia combined with epidural volume extension applied by saline.

Methods

This prospective, randomized, double-blind study was conducted after approval from Institutional Ethical and Scientific Committee and written informed consent from the patients. Eighty patients of American Society of Anesthesiologists (ASA) status I–III, aged ≥ 18 years, body-weight between 50 and 100 kg, and height between 150 and 180 cm undergoing knee arthroplasty using CSEA were included to the study. Patients with a history of spinal disease, coagulation abnormality, sensitivity to local anesthetic, contraindications to CSEA, and those not consenting were excluded from the study.

Cases were randomly allocated to two groups by computer-generated “randomizer.org” program. Group I ($n=40$) received 10 mg hyperbaric bupivacaine (Buvasin 0.5% Spinal heavy, bupivacain HCl, Vem^R) and group II ($n=40$) first received 10 mg hyperbaric bupivacaine (Buvasin 0.5% Spinal heavy, bupivacain HCl, Vem^R) intrathecally and subsequently 10 mL saline via epidural catheter. On arrival to the operating theater, an intravenous (IV) line was inserted and 10 mL/kg of saline solution was infused over 10–15 min. Standard monitoring including non-invasive arterial pressure (NIAP), three-lead electrocardiogram, and pulse-oximetry (SpO₂) were applied. CSE block was performed by a separate technique for CSEA.

In the sitting position, the epidural space was identified with a 18-G, 9-cm Tuohy epidural needle using a loss of resistance to saline (<0.5 mL saline) technique at L3–L4 level. The epidural catheter was threaded 3 cm into the epidural space. After epidural catheter placement, it was confirmed with negative aspiration of blood and cerebrospinal fluid and 60 mg 2 % lidocaine HCl (Aritmal %2, Osel^R) injected from epidural catheter as a test dose. While the patient was still in sitting position, 25-G Quincke (Egemen^R) needle confirmed dural puncture at L4–L5 level and 10 mg hyperbaric bupivacaine 0.5% was injected into the intrathecal space at a rate of 0.5–1 mL/s. Depending on group randomization, group II received 10 mL normal saline for EVE via the epidural catheter over 10–15 seconds after patients were repositioned to the supine position for surgery. Oxygen 4 L/min was administered through a simple face mask. A blinded researcher assessed sensory dermatome level (by a nontraumatic pinprick test), motor blockade, blood pressure, and heart rate every 3 min for 30 min after placing the patient to the supine position for surgery after neuroaxial anesthesia and in the postanesthesia care unit.

The outcome of block for surgery was defined as one of the following:

1. Adequate block: Sensory block of at least T10 and Bromage score 2–3 within 20 min of intrathecal injection.
2. Inadequate block: Either sensory block lower than T10 or Bromage score 0–1 even after 20 min of intrathecal injection

After the maximum sensory block (S_{max}) was achieved, the level of analgesia was tested every 15 min until the block started receding. In cases with adequate block, the following additional block characteristics were noted:

1. Maximum sensory level (S_{max}): Level with no further increase for three consecutive readings.
2. Time to achieve S_{max} (T_{max}): Time from intrathecal injection to the time when the maximum level of sensory blockade was first recorded.
3. Time to regression of sensory level T_{10} ($Time_{10}$): Time to regression of sensory level T_{10} after intrathecal injection.
4. Time to achieve adequate blockade (T_{adeq}): Time from intrathecal injection to the time when an adequate block was established.

In case of an inadequate block, epidural injection of 0.5% plain bupivacaine in aliquots of 3 mL was given to facilitate surgery. Sensory level of the block was assessed using an absolute loss of sensation to pinprick with 25-gauge needle,

and the level was recorded as the highest dermatome with no sensation to pinprick.

Motor block was assessed by Bromage score (0 = able to move hip, knee, and ankle; 1 = unable to move hip, able to move knee and ankle; 2 = unable to move hip and knee, able to move ankle; 3 = unable to move hip, knee, and ankle).

Hypotension was defined as systolic BP < 100mmHg or a reduction of more than 20% from baseline. Hypotension was treated with ephedrine boluses of 5mg (Okasha et al., 2014; Kucukguclu et al., 2008). Bradycardia was defined as a heart rate <55/min or a reduction of more than 25% from baseline. Bradycardia was treated by intravenous boluses atropine (0.5mg) (Okasha et al., 2014; Jain et al., 2012). Shivering was treated by IV Tramadol 25 mg. Patients were observed for intraoperative nausea and vomiting.

Statistical analyses were performed using the SPSS version 23.00 for windows. Data are presented as mean±SD, number of patients, or median (range) where appropriate. Independent samples *t* test was used to compare parametric data, and Mann-Whitney *U* test was used to compare nonparametric data. Categorical variables were assessed by Pearson’s chi-square or Fisher’s exact result chi-square test. Statistical powers were also calculated for intergroup comparisons. The size of the sample was based on the results of previous studies investigating the effect of EVE on the spread of anesthesia to detect a clinically significant difference in the extension of the maximal segmental spread of sensory block of two dermatomes, with an α risk at 0.05 and β risk at 0.20. The power analysis revealed that 40 patients would be required in every two groups.

Results

The two groups were statistically similar with respect to sex, age, weight, height, and BMI ($p>0.05$) (Table 1). Median maximum sensory block level was significantly higher in group II than in group I in the first 30 min after neuroaxial anesthesia. The median Bromage score was significantly higher in group II than in group I at 3th–6th and 9th minutes after neuroaxial anesthesia (Table 2).

Table 1 Patient characteristics

		Group 1 (n=40)	Group 2 (n=40)	<i>p</i>
Gender	Male	7	10	0.412
	Female	33	30	
Age (year)		67±9	69±7	0.317
Weight (kg)		83±11	83±10	0.957
Height (cm)		158±8	160±8	0.304
BMI		33±5	33±5	0.272

Data are mean±SD or number, BMI body mass index (kg/m²)

For patients developing S_{max} , T_{max} , $Time_{10}$ and T_{adeq} were compared between the groups (Table 3). Epidural volume extension increased the mean S_{max} significantly in Group II than group I ($p<0.05$). T_{max} was statistically similar between Group I and Group II. Epidural volume extension significantly altered $Time_{10}$ and T_{adeq} in Group II.

Systolic blood pressure was dropped in both groups after intrathecal injection but this was not statistically significant between the groups. The number of patients who developed hypotension in the first 30 min after neuroaxial anesthesia were similar in the two groups (Table 4).

The number of patients requiring ephedrine, atropine, and epidural supplementation intraoperatively and also total ephedrine dose administered perioperatively and duration of surgery were similar between the groups ($p>0.05$). The first epidural dose requirement was later in group II than group I intraoperatively. This difference was statistically significant ($p<0.05$). Intraoperative nausea and vomiting occurred in 6 patients in group I and at 5 patients in group II. Recovery in terms of sensory and motor block was similar in two groups ($p>0.05$).

Discussion

The main finding of our study is that EVE with saline increases sensory block in the intraoperative period increases Bromage score at 3th–6th and 9th minutes of the intraoperative period. Patients had early onset of sensory and motor block and high level of sensory block. And also delayed supplemental epidural dose requirement intraoperatively.

Techniques for CSEA are (1) needle-through-needle (the most widely used CSE technique), (2) separate needle, and (3) double-barrelled needles (Ong & Sashidharan, 2007). The CSE technique has undergone several modifications to increase its safety and efficacy (Kucukguclu et al., 2008). One of the developments on this modification is epidural volume extension (EVE) (Ong & Sashidharan, 2007). The EVE technique is a modification of CSEA in which a small dose of intrathecal local anesthetic and/or opioids are used to produce a limited block, that can be extended with epidurally administered saline or local anesthetic within the 5 min after spinal anesthesia (Okasha et al., 2014; Yun et al., 2014; Kucukguclu et al., 2008; Ong & Sashidharan, 2007; Blumgart et al., 1992; Zaphiratos et al., 2016; Jain et al., 2012; Bhandari et al., 2018; Salman et al., 2013; Tyagi et al., 2008; Tyagi et al., 2014). EVE with local anesthetic from the epidural catheter provides more intensive motor block and longer sensory block (Salman et al., 2013). However, the dose of the local anesthetic and the volume of saline for administration into the epidural space remains unclear (Sitkin et al., 2015).

Table 2 Sensory and motor block (Bromage score) profile after intrathecal injection

	Group 1 (n=40)	Group 2 (n=40)	p
Sensory block dermatome level			
3 min	T10 (T6–T12)	T9 (T6–T12)*	0.000
6 min	T9 (T5–T12)	T7 (T4–T12)*	0.000
9 min	T8 (T4–T10)	T6 (T4–T10)*	0.000
12 min	T8 (T4–T10)	T6 (T4–T10)*	0.000
15 min	T8 (T4–T10)	T6 (T4–T10)*	0.000
18 min	T8 (T4–T10)	T6 (T4–T8)*	0.000
21 min	T8 (T4–T10)	T6 (T4–T8)*	0.000
24 min	T8 (T4–T10)	T6 (T4–T8)*	0.000
27 min	T8 (T4–T10)	T6 (T4–T8)*	0.000
30 min	T8 (T4–T10)	T6 (T4–T8)*	0.000
Bromage score			
3 min	1 (0–2)	1 (0–2)*	0.007
6 min	2 (1–3)	2 (1–3)*	0.004
9 min	3 (1–3)	3 (2–3)*	0.018
12 min	3 (2–3)	3 (2–3)	1
15 min	3 (3–3)	3 (3–3)	1
18 min	3 (3–3)	3 (3–3)	1
21 min	3 (3–3)	3 (3–3)	1
24 min	3 (3–3)	3 (3–3)	1
27 min	3 (3–3)	3 (3–3)	1
30 min	3 (3–3)	3 (3–3)	1

Data are presented as median (range) *p<0.05

Okasha et al. (Okasha et al., 2014) reported that spinal anesthesia (low dose hyperbaric bupivacaine (10 mg) and 25 µg fentanyl) with EVE (10 mL saline, 5 min after performing the block) is associated with early onset of motor block, high level of sensory block, shorter time of two-segment regression while maintaining hemodynamic stability.

Salman et al. (Salman et al., 2013) compared combined spinal–epidural anesthesia (0.5% levobupivacaine followed by 5 mL saline or 5 mL 0.5% levobupivacaine for EVE, 5 min after performing the block) to spinal anesthesia (0.5 % levobupivacaine according to the patient height) in 138 patients posted for elective cesarean section. They

evaluated the patients in terms of sensory and motor profiles. They observed that motor and sensory blocks had faster onset, lasted longer, and was a higher level in EVE groups. These effects were more pronounced in the EVE group in which EVE was applied by local anesthetic.

Stienstra et al. (Stienstra et al., 1999) reported an increase in maximal sensory block level with both epidural bupivacaine 0.5% and saline 0.9%, by using volumes of 5 mL and 10 mL. Also, Blumgart and colleagues (Blumgart et al., 1992) reported similar results with Stienstra et al results applying either bupivacaine 0.5% (10 mL) or saline (10 mL) for EVE. They explained the increase in sensory block level as an epidural volume effect. Takiguchi and colleagues (Takiguchi et al., 1997) demonstrated clinical and myelographic extension of the sensory block with 10 mL saline 0.9% applied for EVE.

Bhandari et al. (Bhandari et al., 2018) compared CSEA with and without EVE in hip surgery. They reported that CSEA with EVE is associated with early onset of sensory and motor block, high level of sensory block, longer time of two-segment regression while maintaining hemodynamic stability due to the decreased dose of intrathecal local anesthetic.

Table 3 Block characteristics in patients with adequate blockade

	Group 1 (n=40)	Group 2 (n=40)	p
S _{max}	T8 (T4–T10)	T6 (T4–T8)*	0.000
T _{max} (min)	9 (6–15)	9 (6–18)	0.229
Time ₁₀ (min)	75 (60–120)	90 (60–135)*	0.002
T _{adeq} (min)	6 (3–12)	3 (3–9)*	0.000

Data are presented as median (range) *p<0.05

Table 4 The number of patients who experienced hypotension in each time interval

	Group 1 (n=40)	Group 2 (n=40)	p
3 min	11	6	0.172
6 min	12	13	0.809
9 min	20	16	0.369
12 min	19	13	0.171
15 min	17	17	1
18 min	22	15	0.116
21 min	19	16	0.499
24 min	16	12	0.348
27 min	12	13	0.809
30 min	19	13	0.171

Data are presented as the number of patients * $p < 0.05$

Magar et al. (Magar et al., 2017) reported that both spinal and sequential CSEA provide good quality sensory and motor block for lower limb surgery but sequential CSEA provides significantly more stable hemodynamics with feasibility to prolong block. They prefer sequential CSEA in high-risk patients for major limb surgeries.

CSEA has advantages of both spinal and epidural anesthesia. Furthermore, if the anesthetic level with spinal anesthesia is insufficient for the operation, epidural anesthesia can produce additional anesthesia (Yamazaki et al., 2000). On the other hand, sequential CSEA has advantages over CSEA. It involves intentional subarachnoid blockade with a low dose of local anesthetic and titration of the epidural top-up dose according to surgical needs to restrict acute high sympathetic blockade (Magar et al., 2017). Epidural top-up dose can be done by saline or local anesthetic. The effect of EVE with saline in the enhancement of spinal block includes volume effect (time-dependent effect) in which theca is compressed by injected saline solution and extends the block height by mechanical volume effect (Bhandari et al., 2018). Insufficient level of analgesia can be slightly raised without the need for increasing total local anesthetics or using repeated spinal anesthesia (Yamazaki et al., 2000).

In TKA, we targeted hemodynamic stability and Bromage 3 motor block during the operation and early mobilization after the operation. To achieve these advantages, we preferred separate needle techniques from different levels. Our study showed early onset of sensory and motor block, high level of sensory block, a longer time for regression to T_{10} sensory block level with EVE. But we can not report perioperative hemodynamic stability and early motor recovery as stated in previous studies. Most of our patients had developed hypotension and required ephedrine. The possible explanation for these are (1) we preferred separate needle techniques

and (2) we applied EVE immediately after intrathecal injection in the supine position. Contrary to our study reports, Higuchi et al., Kaur et al., Kucukguclu et al., and Yamazaki et al. have reported that EVE failed to increase the level of sensory block.

A magnetic resonance imaging study done by Higuchi et al (Higuchi et al., 2005) reported that 5, 10, and 15 mL saline, given into the epidural space, did not result in an increase in maximal sensory block level.

Kaur et al. (Kaur et al., 2012) demonstrated a benefit in using EVE with 10 mL normal saline as a part of CSEA provides a more rapid motor recovery of the lower limbs after elective cesarean section. But their study failed to demonstrate the cephalad spread of the sensory block. They explained this failure by that all neuroaxial blocks were done in the sitting position.

Kucukguclu et al. (Kucukguclu et al., 2008) observed that there was no effect of EVE on the profile of spinal anesthesia with the CSE technique for cesarean section using hyperbaric and plain bupivacaine.

Yamazaki and colleagues (Yamazaki et al., 2000) studied the role of intrathecal drug baricity in affecting cephalad augmentation of spinal block after EVE. They reported that there was no difference between the augmenting effect in isobaric and hyperbaric spinal anesthesia. They performed EVE 20 min after the intrathecal injection. So they reported that EVE is a time-dependent phenomenon, so it may not be effective.

The limitation of the present study was (1) The volume of lidocaine test dose used after the epidural catheter was secured. It may affect the local anesthetic spread in the dural sac. (2) We applied EVE not only with saline but also with epidural lidocaine that was used as a test dose.

Conclusions

EVE with saline (10 mL) offer early onset of sensory and motor block and a high level of sensory block. And also delay supplemental epidural dose requirement intraoperatively.

Abbreviations

EVE: Epidural volume extension; TKA: Total knee arthroplasty; CSEA: Combined spinal–epidural anesthesia; ECG: Electrocardiogram; HR: Heart rate; S_{max} : Maximum sensory level; T_{max} : Time to achieve S_{max} ; $Time_{10}$: Time to regression of sensory level T_{10} ; T_{adeq} : Time to achieve adequate blockade

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Authors' contributions

FY and EO reviewed the available literature, prepared the study design, reviewed and edited the final manuscript, and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations**Ethics approval and consent to participate**

Ethical committee approval (University of Health Sciences Izmir Bozyaka Training and Research Hospital Ethical Committee) was approved for this study. (Date 21.06.2016 No: 4)

The patients were informed about the study, and written informed consent was obtained.

Consent for publication

Written permission/consent of the patients for the purpose of publication in an educational medical journal was obtained from the patients.

Competing interests

The authors declare that they have no competing interests.

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References

- Bhandari RS, Bhatia R, Agrawal S (2018) Epidural volume extension with saline in combined spinal–epidural anesthesia for hip surgeries using low dose of intrathecal hyperbaric bupivacaine. *Anesth Essays Res* 12(1):145–148. https://doi.org/10.4103/aer.AER_189_17
- Blumgart CH, Ryall D, Dennison B, Thompson-Hill LM (1992) Mechanism of extension of spinal anaesthesia by extradural injection of local anaesthetic. *Br J Anaesth* 69(5):457–460. <https://doi.org/10.1093/bja/69.5.457>
- Buvanendran A, Tuman KJ, McCoy DD, Matusic B, Chelly JE (2006) Anesthetic techniques for minimally invasive total knee arthroplasty. *J Knee Surg* 19(2): 133–136. <https://doi.org/10.1055/s-0030-1248095>
- Elmofly DH, Buvanendran A (2017) Regional anesthesia in total joint arthroplasty. What Is the Evidence? *J Arthroplasty* 32(9):74–76. <https://doi.org/10.1016/j.arth.2017.05.017>
- Güler G, Atıcı Ş, Kurt E, Karaca S, Yılmazlar A (2015) Current approaches in hip and knee arthroplasty anaesthesia. *Turk Anaesthesiol Intens Care Soc* 43(3): 188–195. <https://doi.org/10.5152/TJAR.2015.26096>
- Heesen M, Weibel S, Klimek M, Rossaint R, Arends LR, Kranke P (2017) Effects of epidural volume extension by saline injection on the efficacy and safety of intrathecal local anaesthetics: systematic review with meta-analysis, meta-regression and trial sequential analysis. *Assoc Anaesth Great Britain Ireland* 72(11):1398–1411. <https://doi.org/10.1111/anae.14033>
- Higuchi H, Adachi Y, Kazama T (2005) Effects of epidural saline injection on cerebrospinal fluid volume and velocity waveform: a magnetic resonance imaging study. *Anesthesiology* 102(2):285–292. <https://doi.org/10.1097/0000542-200502000-00008>
- Jain G, Singh DK, Bansal P, Ahmed B, Dhama SS (2012) Comparison of low doses of intrathecal bupivacaine in combined spinal epidural anaesthesia with epidural volume extension for caesarean delivery. *Anesth Essays Res* 6(1):47–52. <https://doi.org/10.4103/0259-1162.103373>
- Johnson RL, Kopp SL, Burkle CM, Duncan CM, Jacob AK, Erwin PJ, Murad MH, Mantilla CB (2016) Neuraxial vs general anesthesia for total hip and total knee arthroplasty: a systematic review of comparative effectiveness research. *Br J Anaesth* 116(2):163–176. <https://doi.org/10.1093/bja/aev455>
- Kaur S, Jayant R, Aggarwal S (2012) Epidural volume extension in combined spinal epidural anaesthesia for rapid motor recovery after elective caesarean section: a comparative study. *Internet J Anesthesiol* 30(4):1–7
- Kehlet H, Aasvang EK (2015) Regional or general anesthesia for fast-track hip and knee replacement - what is the evidence? *F1000 Research* 4(F1000 Faculty Rev):1449
- Kucukguclu S, Unlugenc H, Gunenc F, Kuvaki B, Gokmen N, Gunasti S, Guclu S, Yilmaz F, Isik G (2008) The influence of epidural volume extension on spinal

- block with hyperbaric or plain bupivacaine for Caesarean delivery. *Eur J Anaesthesiol* 25(4):307–313. <https://doi.org/10.1017/S0265021507002670>
- Magar JS, Bawdane KD, Patil P (2017) Comparison of efficacy and safety of unilateral spinal anesthesia with sequential combined spinal epidural anaesthesia for lower limb orthopaedic surgery. *J Clin Diagn Res* 11(7):17–20
- Maung CN, Nazemzadeh M (2018) Spinal or general anesthesia? Book Chapter Install Scott Surg Knee 83:1058–1061
- Okasha MM, Kamal S, Ramzy A (2014) Epidural volume extension with saline in combined spinal epidural anesthesia for dynamic hip screw surgeries using low dose of intrathecal hyperbaric bupivacaine. *Ain-Shams J Anesthesiol* 07(3):350–355. <https://doi.org/10.4103/1687-7934.139565>
- Ong KB, Sashidharan R (2007) Combined spinal–epidural techniques. *Contin Educ Anaesth Crit Care Pain* 7(2):38–41. <https://doi.org/10.1093/bjaceaccp/mkm003>
- Salman C, Kayacan N, Ertugrul F, Bigat Z, Karsli B (2013) Combined spinal-epidural anesthesia with epidural volume extension causes a higher level of block than single-shot spinal anesthesia. *Revista Brasileira De Anestesiologia* 63(3): 267–272. <https://doi.org/10.1590/S0034-70942013000300007>
- Sitkin SI, Ronenson AM, Savel'eva YV (2015) The new technique of spinal anesthesia with the epidural extension provides qualitative analgesia and stable hemodynamics in pregnant women with concomitant cardiac pathology. *Anesteziol Reanimatol* 60(6):58–61
- Stienstra R, Dilrosun-Alhadi BZ, Dahan A, van Kleef JW, Veering BT, Burm AG (1999) The epidural 'top-up' in combined spinal–epidural anesthesia: the effect of volume vs. dose. *Anesth Analg* 88(4):810–814. <https://doi.org/10.1213/00000539-199904000-00024>
- Takiguchi T, Okano T, Egawa H, Okubo Y, Saito K, Kitajima T (1997) The effect of epidural saline injection on analgesic level during combined spinal and epidural anesthesia assessed clinically and myelographically. *Anesth Analg* 85(5):1097–1100. <https://doi.org/10.1213/00000539-199711000-00024>
- Turnbull ZA, Sastow D, Giambone GP, Tedore T (2017) Anesthesia for the patient undergoing total knee replacement: current status and future prospects. *Local Region Anesth* 10:1–7. <https://doi.org/10.2147/LRA.S101373>
- Tyagi A, Kumar A, Sethi AK, Mohta M (2008) Epidural volume extension and intrathecal dose requirement: plain versus hyperbaric bupivacaine. *Anesth Analg* 107(1):333–338. <https://doi.org/10.1213/ane.0b013e3181734436>
- Tyagi A, Kumar S, Salhotra R, Sethi AK (2014) Minimum effective volume of normal saline for epidural volume extension. *J Anaesthesiol Clin Pharmacol* 30(2):228–232. <https://doi.org/10.4103/0970-9185.130028>
- Yamazaki Y, Mimura M, Hazam K, Namik A (2000) Reinforcement of spinal anesthesia by epidural injection of saline: a comparison of hyperbaric and isobaric tetracaine. *J Anesth* 14(2):73–76. <https://doi.org/10.1007/s005400050070>
- Yun MJ, Kwon MY, Kim DH, Lee JW (2014) Combined spinal-epidural anesthesia using a reduced-dose of spinal bupivacaine and epidural top up leads to faster motor recovery after lower extremity surgeries. *Korean J Anesthesiol* 66(1):28–33. <https://doi.org/10.4097/kjae.2014.66.1.28>
- Zaphiratou V, George RB, Macaulay B, Bolleddula P, McKeen DM (2016) Spinal – Epidural labor analgesia does not increase sensory block. *Anesth Analg* 123(3):684–689. <https://doi.org/10.1213/ANE.0000000000001281>

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