Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/mjafi

Original Article

A fluoroscopic assessment of brachial plexus block by the supraclavicular approach: Have we been overmedicating?

Rashmi Datta ^{a,*}, Jyotsna Agrawal ^b, Gagan Narula ^c, Bhavna Pahwa ^d

^a MG (Med), Delhi Area, C/o 56 APO, India

^b Associate Professor, Hamdard Institute of Medical Sciences & Research, New Delhi, India

^c Addl Director, Critical Care, Park Hospital, Gurgaon, India

^d Graded Specialist (Anaesthesia), 179 Military Hospital, C/o 99 APO, India

ARTICLE INFO

Article history:

Received 21 April 2017

Accepted 18 June 2019

Available online 2 December 2019

Keywords:

Fluoroscopic assessment

Brachial plexus block

Supraclavicular approach

ABSTRACT

Background: Ultrasonography-guided supraclavicular brachial plexus block has demonstrated safety as compared with landmark or nerve stimulation techniques. However, the minimum effective analgesic volume (MEAV) necessary for adequate blockade has not been determined. This study was undertaken to assess under fluoroscopy the postinjection spread of different drug volumes with clinical correlation. Secondary outcome measures included correlation of onset of block, block quality, and incidence of side effects.

Methods: This randomized, multiarm, cross-sectional, observational study was conducted at a single tertiary care center. A total of 549 patients were randomly allocated to 3 groups (20 ml, 30 ml, and 40 ml of drug mixture). A local anesthetic drug mixture with a radiopaque dye was administered under ultrasonographic guidance, and postinjection fluoroscopic drug spread was studied.

Results: Surgical anesthesia was achieved in 494 (89.98%) patients with 85.25%, 92.97%, and 91.71% in 20-, 30-, and 40-ml groups, respectively, being significantly low ($p = 0.0317$) in the 20-ml group. Cephalad and infraclavicular spread was higher in the 40-ml group than in other two groups ($p = 0.103$). Horner syndrome (HS) was seen in 51.18% of patients. First, ipsilateral superficial cervical plexus block was also observed in 40.22% of patients. Among patients who developed both, ~60% of patients (99/167) belonged to the 40-ml group. **Conclusions:** Optimal MEAV appears between 20 and 30 mL. Higher drug volumes are associated with more cephalad spread and side effects. Drug spread can predict block efficacy as well. It is postulated that loss of sensation in the ipsilateral neck can be used to predict development of hemidiaphragmatic paresis similar to HS.

© 2019 Director General, Armed Forces Medical Services. Published by Elsevier, a division of RELX India Pvt. Ltd. All rights reserved.

* Corresponding author.

E-mail address: drashmidatta@gmail.com (R. Datta).

<https://doi.org/10.1016/j.mjafi.2019.06.004>

0377-1237/© 2019 Director General, Armed Forces Medical Services. Published by Elsevier, a division of RELX India Pvt. Ltd. All rights reserved.

Introduction

Brachial plexus block is performed by surrounding the nerve bundles with a local anesthetic drug mixture (LADM) as much as possible. The supraclavicular approach is the most common one. Traditionally, high volumes (up to 40 mL) of a single drug or a mixture of local anesthetics with or without adjuvants have been used. The traditional blind techniques that depend on sensory paresthesia and nerve stimulation techniques have been replaced with ultrasonography-guided technique. The latter is popular because of not only easy visualization but also a proposed reduction in volumes of LADM, thereby improving safety and reducing side effects.^{1–4} However, several dose evaluation studies have been unable to conclusively demonstrate the minimum effective analgesic volume (MEAV) necessary for adequate blockade.^{4–7} The dynamics of drug spread and its clinical significance has also not been specifically studied.^{2,5,6} This study was undertaken to assess the postinjection spread of different volumes of LADM through the supraclavicular approach under fluoroscopy and determine the clinical correlation. The secondary outcome measures were the correlation of onset of the block, the block quality and incidence of side effects with spread of injectate. The aim of the study was to quantify the LADM so that side effects are minimized while achieving surgical anesthesia. It was a prospective, randomized, multiarm, cross-sectional, observational study conducted at a tertiary level hospital from June 2015 to July 2016.

Material and methods

A total of 549 patients of both sexes, aged between 18 and 65 years and weighing 30–110 kg with American Society of Anesthesiologists (ASA) Physical Status I–III, with obvious normal anatomy scheduled to undergo elective major operative surgery of the upper limb, excluding shoulder arthroscopy, were enrolled in the study. The study was approved by the hospital institute ethics committee which meets the International Committee of Medical Journal Editors (ICMJE) guidelines (31/16/Apr/BH-15 date 16 Apr 2015) and registered with the Clinical Trial Registry of India (CTRI REF/2017/04/013976).

A well-explained, written informed consent for the procedure, was obtained from all patients. Patients were assigned to three groups using three LADM volumes (20 mL, 30 mL, and 40 mL) through computer-generated random numbers. The anesthesiologist administering the drug was blinded from the one carrying out the fluoroscopy and recording the data. The LADM consisted of a 2:1 proportion of 0.5% bupivacaine and 2% lidocaine, making a working concentration of 0.2% and 0.4%, respectively, with the maximum dose not exceeding 2 mg/kg for bupivacaine and 4 mg/kg for lidocaine. Radiopaque, nonionic, water-soluble iohexol (Omnipaque; GE Healthcare, Phoenix, AZ) 1.5 mL/10 mL was added after ascertaining nonsensitivity to contrast agent. Spread of nerve bundles under the ultrasound was used as the end point of correct placement of the LADM.

Technique: All blocks were performed according to a standardized protocol with a preprocedure fasting status of 6 h. A

peripheral intravenous (IV) line was established. Standard noninvasive monitoring equipment (electrocardiogram [ECG], noninvasive blood pressure measurement, pulse oximetry) was attached to all patients.

Position: The patients were placed in a supine position with head turned to opposite side and arm pulled down gently. Mild neck extension was obtained using a small positioner placed in the interscapular area to make the field more prominent.

After skin preparation, the brachial plexus was ultrasonically identified (transducer frequency 4–15 MHz, Terason uSmart 3200T; Teratech Corporation, Burlington) as a collection of hypoechoic oval structures lateral and superior to the subclavian artery above the midpoint of the clavicle. A 50-mm, 22G insulated short-beveled stimulation needle (Stimuplex® A, B. Braun Melsungen AG, Germany) was inserted in plane with medial angulation. The injection site was confirmed using a peripheral nerve stimulator (1-Hz frequency, 0.1-ms pulse, 1-mA current) with a progressive reduction to 0.3 mA. If there were muscle contractions at 0.3-mA current, if the injection pressure was high, or if paresthesia was experienced during needle placement or injection, it was presumed to be an intraneural placement and the needle was readjusted. The LADM was given as a single aliquot, lateral to the subclavian artery.

After the block, the spread of the LADM was visualized under fluoroscopy within 5 min. A cephalic LADM spread was taken as extending above C6 vertebra, and an infraclavicular spread was taken as extending beyond 2 cm of the coracoid process in the deltopectoral groove. The time of removal of the stimulating needle was considered time 0 for evaluating the effectiveness of the block. The primary outcome was achievement of surgical analgesia not requiring supplementation within 30 min of time 0. Additional data collected included the time of onset of sensory block (assessed by loss of cold sensation) and motor block in the terminal nerves (median nerve by deltoid, biceps, triceps, finger flexors; radial nerve by finger extensors; ulnar nerve by finger abductors) as per the modified Bromage scale,⁷ proportion of blocks needing supplementation, and complications. However, these were not subjected to analysis. Patients who did not reach the sensory end point within 5 min or motor end point within 30 min were excluded from the study.

Assuming a two-tailed α error probability of 0.05 and β less than 0.20 for a power of 80%, a total sample size of 107 for each group was required to detect a 10% clinically significant difference between the block qualities. After the detection of another factor, the number was increased, and a total of 594 patients were included, out of which 549, randomly allocated to the three groups, were subjected to analysis. All data were subjected to the Kolmogorov-Smirnov test, and a p-value of <0.05 was taken as statistically significant. Data were checked for normality before statistical analysis using Shapiro-Wilk test. Data are expressed as means (standard deviation [SD]), medians (interquartile range), and proportions as appropriate. Quantitative and qualitative data were subjected to analysis. Student t-test or Mann-Whitney U-test was used to compare continuous variables, and chi-squared test was used for categorical variables. Comparison between and within groups are performed using one-way ANOVA and post-hoc analyses for continuous variables.

Results

A total of 593 consecutive patients were enrolled into the study. Forty-four patients were excluded because of various reasons (Fig. 1). Demographic data including age, gender, weight, ASA classification, and type of surgery did not show any statistically significant difference between the three groups (Table 1). The distribution of patients in different LADM volume groups is shown in Table 2 (See Figs. 2 and 3).

Surgical anesthesia was achieved in 494 (89.98%) patients, 85.25%, 92.97%, and 91.71% in 20-, 30-, and 40-mL groups, respectively, with significantly low value ($p = 0.006$) observed in the 20-mL group as compared with the other two groups. The requirement of supplementation was also higher in the 20-mL group ($p = 0.012$; Table 2).

LADM spread was limited to the perivascular region only in 16 and 7 patients in the 20- and 30-mL groups, respectively (23;4.18%). In contrast, all patients in the 40-mL group showed extension beyond the perivascular region. A total of 220 (40.07%) patients demonstrated both cephalad and infraclavicular spread with a statistically significant number (116; $p = 0.0037$) in the 40-mL group as compared with both 20- and 30-mL groups with no statistically significant difference between the latter two groups. Incidence of cephalad LADM spread was higher than infraclavicular extension (384 vs. 362) but was not statistically significant ($p = 0.0817$). Between the groups, significantly higher cephalad extension without infraclavicular spread was seen in the 20-mL group (87 vs. 47, 30; $p = 0.0059$) (Fig. 4; Supplementary Figs. 1–5).

Fifty-five patients required supplementation, thirty-eight patients were extremely anxious and were given intravenous fentanyl (in 20- μ g aliquots, maximum of 40 μ g). Three patients

posted for hand surgery had sparing of C8-T1 dermatomes and were supplemented with axillary block where 10 mL of LADM without the radiocontrast agent was injected in the medial-to-axillary artery. Fourteen patients undergoing humeral surgeries required local anesthetic infiltration at the upper end of incision extending medially to the acromion (Table 2, Fig. 5).

Incomplete or complete HS was seen in almost half of the patients (51.18%). This was more in patients who received 40 mL of LADM (72.93% in 40 mL vs. 43.24% and 37.7% in 30- and 20-mL groups, respectively; $p = 0.0161$). Incidence was higher in those who demonstrated cephalad extension alone along with perivascular spread ($p = 0.0292$). A small percentage of patients who demonstrated only an infraclavicular extension of LADM spread also developed HS (14.28% and 32.76% in 20- and 30-mL group, respectively, as compared with 34.28% in the 40-mL group; $p = 0.0284$) (Table 3, Fig. 5).

After the initial 22 cases, sensory loss in the ipsilateral C2–C4 neck dermatomes was accidentally observed. This superficial cervical plexus block (SCPB) was subsequently observed in 40.22% (212/527) of patients, out of which a significant number had cephalad extension with/without infraclavicular extension ($p = 0.0382$). Development of SCPB was also directly proportional to drug volume (60.57% in 40 mL vs. 35.95% and 24.13% in 30 mL and 20 mL; $p = 0.0176$), with 50% of the patients of cervical plexus block (CPB) belonging to the 40-mL group (Table 2, Fig. 5).

A total of 167 patients developed both HS and CPB. Out of these, almost 60% of patients (99/167) received 30 mL and 83.23% (139/167) received 40 mL of LADM. One-third of the patients (32.82%) developed neither CPB nor HS, with no significant difference within the groups (Table 3).

Fig. 1 – Cohort.

Table 1 – Patient demography and surgery details.

Variables	20 mL n = 183	30 mL n = 185	40 mL n = 181
Age (yrs) (mean $\pm$ SD; range)	37 $\pm$ 15 (18–65) p = 0.0626	36 $\pm$ 15 (18–65) p = 0.0712	37 $\pm$ 14 (18–65) p = 0.0641
Sex			
Male	139	140	137
Female	44	45	44
p-value ^a	0.152	0.169	0.159
Height and weight			
Height (cm) (mean $\pm$ SD; range)	166 $\pm$ 10 (150–185) p = 0.065	167 $\pm$ 12 (152–185) p = 0.071	165 $\pm$ 10 (150–183) p = 0.062
Weight (kg) (mean $\pm$ SD; range)	67 $\pm$ 11 (40–80) p = 0.271	65 $\pm$ 12 (40–78) p = 0.175	65 $\pm$ 11 (41–80) p = 0.276
ASA grade			
I	143	147	146
II	29	29	27
III	11	9	8
p-value ^a	0.151	0.138	0.127
Site of surgery			
Mid arm	15	14	14
Distal arm	21	20	23
Elbow	24	26	26
Proximal forearm	21	22	21
Mid forearm	54	53	51
Distal Forearm	48	50	46
p-value ^a	0.064	0.071	0.0647

SD, standard deviation.

^a Chi-squared test.**Table 2 – Block characteristics according to volume of drug injected.**

Volume of LADM	20 ml	30 ml	40 ml	p-value
N value	183	185	181	0.831
Surgical anesthesia: proportions and percentage	(156/183; 85.25%)	(172/185; 92.97%)	(166/181; 91.71%)	0.006*
Onset of sensory block (min), mean $\pm$ SD	3.2 $\pm$ 1.5	2.8 $\pm$ 1.6	3 $\pm$ 1.8	0.311
Onset of motor block (min)	10 $\pm$ 5	9 $\pm$ 8	11 $\pm$ 9	0.251
Supplementation required	27	13	15	0.012*

LADM, local anesthetic drug mixture.

Discussion

Most authors have recommended an average MEAV of 30 mL in 90% of patients when performing a brachial plexus block through the supraclavicular approach.^{1–6} In this study, 92.35% of patients who received 30 mL or more LADM achieved surgical anesthesia. However, a clinically significant number of patients in the 20-mL group (85.25%) also achieved surgical anesthesia. Between an LADM volume of 30 mL and 40 mL, there was no significant difference in the percentage of successful blocks (92.97% vs. 91.71%). It is hypothesized that additional volume may diffuse into the surrounding soft tissues or undergo vascular uptake and therefore do not contribute to anesthesia.^{7,8} Various studies have shown variable effects of different drug volumes and concentrations on the duration of analgesia. The reasons of the high success rate and longer duration of analgesia postulated in these studies were the use of larger volume (40 mL), multiple injections, and

blocks performed by well-trained operators.^{3,4,8–11} The duration of analgesia was not studied in this series.

Perivascular LADM spread was seen in all 549 patients included in the study. Cephalad and infraclavicular spread of LADM, irrespective of the volume of LADM was comparable (384 and 362 of 549 patients, respectively). All patients in the 40-mL group showed extension beyond the perivascular area. The LADM spread was not seen beyond the infraclavicular region in any case, indicating that axillary region involvement is almost never present with supraclavicular drug administration. Studies of the brachial plexus sheath by anatomic dissection, histologic preparations, x-rays after injection of contrast media, and using computed tomography dye have reported that a multicompartimented thin connective tissue sheath surrounds the plexus. Multiple septa extend inward from the sheath, creating a fascial compartment for each nerve. However, as there is interlinking of trunks, divisions, and cords at the supraclavicular level, the connective tissues containing these nerves also interconnect, a feature observed

Fig. 2 – Radiological view of perivascular spread only of LADM. LADM, local anesthetic drug mixture.

Fig. 3 – Radiological view of perivascular and cephalad spread of LADM. LADM, local anesthetic drug mixture.

when they are dissected. This is in contrast at the axillary level, where the terminal nerves do not interconnect and the connective tissues surrounding them create distinct compartments for each. Compartmentalization may occur even in the supraclavicular region because the layers of connective tissue within the tissue plane are not homogeneous, do not necessarily interconnect, and may hinder or prevent diffusion. This appears a rational explanation for why 55 of 549

patients needed supplementation despite adequate perivascular LADM spread.^{12,13}

The brachial plexus lies in a tissue plane closely surrounded by the clavicle, scapula, chest wall, and humeral head. There is minimal space for soft-tissue expansion at any one point, and therefore, flow occurs along the plane, in the path of least resistance, one of which is the line of the nerve, and in both directions from the point of injection way.¹³ Rodriguez et al.¹⁴ studied fluoroscopic distribution of LA solution in 18 patients by the landmark technique to administer interscalene, supraclavicular, and infraclavicular brachial plexus block to six patients in each group. Drug spread was seen in both supraclavicular and infraclavicular regions in all patients receiving interscalene and supraclavicular blocks, whereas the spread was restricted to below clavicle in patients receiving infraclavicular brachial plexus block.¹⁴ In this study, patients were seen with supraclavicular, infraclavicular, both or no extension which could be due to the large difference in sample size (six patients versus 549 patients).

A total of 281 out of 549 (51.18%) patients developed HS. This is in concurrence with a study by Yang et al.¹⁵ who reported a 54% incidence of HS following the supraclavicular approach by nerve stimulator technique with 30 mL of 0.5% ropivacaine. Nash et al.¹⁶ reported that the investing layer of the deep cervical fascia in the anterior triangle of the neck is nearly nonexistent. Pandit et al.¹⁷ further demonstrated that dye injected above the prevertebral layer of the deep cervical fascia penetrates through pores where the nerves pierce the fascia, ending in the deep cervical space. This suggests that while the precise anatomy has not been completely elucidated, the fat and loose connective tissues surrounding the neurovascular structures of the neck allow for spread of the LADM from the superficial to the deeper layers, causing a potentially deeper spread of a superficial injection with time.^{16–18} The deep cervical fascia contains the cervical sympathetic chain, and this may be the reason why few patients (24.85%) without any cephalad LADM spread developed HS. Moreover, the fluoroscopic images were taken immediately after LADM injection (to prevent dye dissipation), whereas HS and other effects were recorded 30 min after block administration.

A significant 48.82% did not develop HS. Among these, most were in the 20-mL group, who demonstrated only perivascular spread with/without infraclavicular extension (Table 3).

Ipsilateral SCPB was seen in almost half of the patients (198/369) who demonstrated a cephalad extension with/without infraclavicular spread of LADM. This was seen even in volumes as low as 20 mL (41/112; 36.60%). Literature is silent on the incidence of an SCPB after a supraclavicular brachial plexus block. Both superficial and deep cervical plexus blocks have been reported with interscalene blocks, with incidence ranging from 7.7 to 31%.^{19,20} The postulated reason has been stated as spilling of the LADM from the interscalene space into the prevertebral fascia.¹⁹ The concomitant blockade of the supraclavicular nerve (a superficial sensory nerve originating from the C-3-4 nerve roots of the superficial cervical plexus supplying the skin over and medial to the acromion) is an additional advantage of interscalene blocks for shoulder surgeries. But the incidence of SCPB through the supraclavicular

Fig. 4 – Spread of LADM as per the volume injected. LADM, local anesthetic drug mixture.

Fig. 5 – Incidence of complications and requirement of supplementation CPB was studied after initial 22 patients (549 – 22 = 527). CPB, cervical plexus block.

Table 3 – Drug spread in different groups and block efficacy in relation to Horner syndrome and superficial cervical plexus block.

Drug spread	PV only	PV + cephalad	PV + cephalad + infraclavicular	PV + infraclavicular	Total
	23	164	220	142	549
HS present	3	116	124	38	(281/549; 51.18%)
Surgical anesthesia achieved	3 (100%)	104 (89.65%)	118 (95.16%)	35 (92.10%)	(260/281; 92.52%)
Supp with fentanyl	2 (66.67%)	2 (1.72%)	3 (2.42%)	2 (5.26%)	9 (3.20%)
Suppl with axillary block	—	1 (0.86%)	—	—	1 (0.35%)
Suppl with local infiltration	1 (33.33%)	—	1 (0.80%)	1 (2.63%)	3 (1.07%)
SCPB present	3	72	126	11	(212/527; 40.22%)
Surgical anesthesia achieved	2 (66.67%)	61 (84.72%)	114 (90.48%)	9 (81.82%)	186/212 (87.73%)
Suppl with fentanyl	3 (100%)	2 (2.78%)	4 (3.17%)	5 (45.45%)	14 (6.60%)
Suppl with axillary block	1 (33.33%)	1 (1.39%)	—	—	2 (0.94%) *
Suppl with local infiltration	2 (66.67%)	1 (1.39%)	—	—	3 (1.41%)

PV, perivascular spread; HS, Horner syndrome; SCPB, superficial cervical plexus block; Suppl, supplemented. CPB was studied after initial 22 patients (549 – 22 = 527).

approach is too low and unpredictable (24.13%, 35.95%, and 60.57% for 20, 30, and 40 mL, respectively) to provide an alternative for shoulder surgeries. This approach may be considered in selected patients where direct administration of cervical plexus block or interscalene block is not possible because of neck pathologies.^{20,21}

Various studies have consistently demonstrated ipsilateral hemidiaphragmatic paresis in patients who develop HS after brachial plexus block.^{3,5–7,22,23} Proposed reason for this is an unintended ipsilateral phrenic nerve paresis after spread of the LADM over the anterior scalene muscle or inadvertent puncture of the thin fascia over the cervical plexus.^{24–26} In this study, the development of hemidiaphragmatic paresis was not monitored even though both HS and SCPB block were reported. However, as none of the patients had an underlying pulmonary pathology, the clinical manifestation of the paresis may not have been apparent. Loss of sensation on the ipsilateral aspect of the neck can be considered as a predictor for development of hemidiaphragmatic paresis similar to HS. Further studies are needed to confirm this association. Until then, caution is recommended in administration of brachial plexus block in patients with underlying lung pathologies. Bilateral blocks should be avoided.

Retrospective analysis of the excluded 32 patients who did not meet sensory motor end points revealed that 29 had poor perivascular LADM spread. Fluoroscopic images of three patients could not be found. The average body mass index (BMI) of these 32 patients was 28.8 ± 1.7 kg.m⁻². The subset of 55 patients who demonstrated good perivascular spread but needed supplementation had an average BMI of 33.1 ± 23.7 kg.m⁻². Mistry et al.²⁷ studied the variability of depth of the neural elements of the brachial plexus in the supraclavicular area in an Indian population. The authors observed that sonographically, the shortest distance from skin to the most superficial neural element was 0.60 ± 0.262 cm. The longest distance from skin to the most deep neural element was found to be 1.34 ± 0.385 cm. Significant correlation between these two distances with weight and BMI was observed.²⁷ Yadav et al.²⁸ elucidated the depth of the corner pocket in supraclavicular brachial plexus in healthy Indian volunteers. They reported the mean vertical distance from skin to corner pocket to be 1.7 ± 0.8 cm and the mean distance traveled by a needle entering 1 cm from the edge of foot process to the corner pocket in an in-plane approach as 3.7 ± 0.2 cm. They found a significant correlation between weights versus the two lengths and BMI versus the two lengths.²⁸ In the present study, although a 3-cm needle was used, it is possible that the LADM did not reach the deeper pockets. The higher BMI may have resulted in more fat in the supraclavicular region where the LADM may have been deposited.

Limitations: This study is limited by a relatively small sample size of 549 patients. None of the patients in this study underwent shoulder surgery. The hemidiaphragmatic movement was not studied, and therefore, a direct correlation between these findings and hemidiaphragmatic paresis cannot be established. In addition, it appears that increasing the contrast volume or concentration might delineate the structures better. Further studies using different contrast concentrations, single-point injection of drug in the brachial plexus sheath, inclusion of more proximal surgeries including

shoulder surgeries, and analysis of hemidiaphragmatic movements are needed.

Conclusion

Perivascular LADM spread is mandatory for a successful brachial plexus block. Studying the spread of LADM can be useful in predicting block efficacy and the side effects. Presence of fat in the connective tissues in the sheath may be responsible for a partial block. It is difficult to predict the extension of the LADM by any specific anatomy, but cephalad extension is more common and is associated with complications such as HS and SCPB, even with low volumes. Optimal MEAV appears between 20 and 30 mL. Development of SCPB in supraclavicular approach can provide an alternative to interscalene block in selected patients undergoing shoulder surgeries.

Conflicts of interest

The authors have none to declare.

Trial registration

Base Hospital Delhi Cantt, New Delhi, India 31/16/Apr/BH-15 date 16 Apr 2015 and Clinical Trial Registry of India (CTRI REF/2017/04/013976).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.mjafi.2019.06.004>.

REFERENCES

1. Eichenberger U, Stockli S, Marhofer P, et al. Minimum local anesthetic volume for peripheral nerve block: a new ultrasound-guided, nerve dimension based method. *Reg Anesth Pain Med.* 2009;34:242–246. 14.
2. Klaastad O, Sauter AR, Dodgson MS. Brachial plexus block with or without ultrasound guidance. *Curr Opin Anaesthesiol.* 2009 Oct;22:655–660.
3. Williams SR, Chouinard P, Arcand G, et al. Ultrasound guidance speeds execution and improves the quality of supraclavicular block. *Anesth Analg.* 2003;97:1518–1523.
4. Chan VW, Perlas A, Raw R, Odukoya O. Ultrasound-guided supraclavicular brachial plexus block. *Anesth Analg.* 2003;97:1514–1517.
5. Tsui BC, Doyle K, Chu K, Pillay J, Dillane D. Case series: ultrasound-guided supraclavicular block using a curvilinear probe in 104 day-case hand surgery patients. *Can J Anaesth.* 2009;56:46–51.
6. Duggan E, El Beheiry H, Perlas A, et al. Minimum effective volume of local anesthetic for ultrasound-guided supraclavicular brachial plexus block. *Reg Anesth Pain Med.* 2009 May-Jun;34:215–218.

7. O'Donnell BD, Iohom G. An estimation of the minimum effective anesthetic volume of 2% lidocaine in ultrasound-guided axillary brachial plexus block. *Anesthesiology*. 2009 Jul;111:25–29.
8. McNaught A, Shastri U, Carmichael N, et al. Ultrasound reduces the minimum effective local anaesthetic volume compared with peripheral nerve stimulation for interscalene block. *Br J Anaesth*. 2011 Jan;106:124–130.
9. Harper GK, Stafford MA, Hill DA. Minimum volume of local anaesthetic required to surround each of the constituent nerves of the axillary brachial plexus using ultrasound guidance: a pilot study. *Br J Anaesth*. 2010;104:633–636.
10. Gautier P, Vandepitte C, Ramquet C, DeCoopman M, Xu D, Hadzic A. The minimum effective anesthetic volume of 0.75% ropivacaine in ultrasound-guided interscalene brachial plexus block. *Anesth Analg*. 2011 Oct;113:951–955.
11. Renes SH, Rettig HC, Gielen MJ, Wilder-Smith OH, van Geffen GJ. Ultrasound-guided low-dose interscalene brachial plexus block reduces the incidence of hemidiaphragmatic paresis. *Reg Anesth Pain Med*. 2009 Sep-Oct;34:498–502.
12. Cornish PB, Greenfield LJ. Brachial plexus anatomy. *Reg Anesth*. 1997;22:106–107.
13. Cornish PB, Leaper CJ, Hahn JL. Evaluation of spread of a bolus injection administered via a brachial catheter using contrast-enhanced computerised axial tomography (CECT) scanning. *Reg Anesth Pain Med*. 2004;29:25.
14. Rodríguez J, Bárcena M, Alvarez J. Restricted infraclavicular distribution of the local anesthetic solution after infraclavicular brachial plexus block. *Reg Anesth Pain Med*. 2003 Jan-Feb;28:33–36.
15. Yang CW, Kwon HU, Cho CK, et al. A comparison of infraclavicular and supraclavicular approaches to the brachial plexus using neurostimulation. *Korean J Anesthesiol*. 2010 Mar;58:260–266.
16. Nash L, Nicholson HD, Zhang M. Does the investing layer of the deep cervical fascia exist? *Anesthesiology*. 2005;103:962–968.
17. Pandit JJ, Satya-Krishna R, Gratton P. Superficial or deep cervical plexus block for carotid endarterectomy: a systematic review of complications. *Br J Anaesth*. 2007;99:159–169.
18. Pintaric TS, Hocevar M, Jereb S, et al. A prospective, randomized comparison between combined (deep and superficial) and superficial cervical plexus block with levobupivacaine for minimally invasive parathyroidectomy. *Anesth Analg*. 2007;105:1160–1163.
19. Murphy TM. Somatic blockade of head and neck. In: Cousins MJ, &Bridenbaugh PO, eds. *Neural Blockade in Clinical Anesthesia and Management of Pain*. 3rd ed. vol. 494. Philadelphia, New York: Lippincott- Raven; 1998:509.
20. Broderick AJ, Mannion S. Brachial plexus blockade as a result of aberrant anatomy after superficial cervical plexus block. *Reg Anesth Pain Med*. 2010 Sep-Oct;35:476–477.
21. Christ S Rindfleisch F, Friederich P. Superficial cervical plexus neuropathy after single-injection interscalene brachial plexus block. *Anesth Analg*. 2009 Dec;109:2008–2011.
22. Erickson JM, Louis DS, Naughton NN. Symptomatic phrenic nerve palsy after supraclavicular block in an obese man. *Orthopedics*. 2009 May;32:368.
23. Walid T, Mondher BA, Mohamed Anis L, Mustapha F. A case of Horner's syndrome following ultrasound-guided infraclavicular brachial plexus block. *Case Rep Anesthesiol*. 2012;2012:125346.
24. Bigeleisen PE. Anatomical variations of the phrenic nerve and its clinical implication for supraclavicular block. *Br J Anaesthesia*. 2003;91:916–917.
25. Park SK, Lee SY, Kim WH, Park HS, Lim YJ, Bahk JH. Comparison of supraclavicular and infraclavicular brachial plexus block: a systemic review of randomized controlled trials. *Anesth Analg*. 2017 Feb;124:636–644.
26. Kessler J, Schafhalter-Zoppoth I, Gray AT. An ultrasound study of the phrenic nerve in the posterior cervical triangle: implications for the interscalene brachial plexus block. *Reg Anesth Pain Med*. 2008;33:545–550.
27. Mistry T, Mangal V, Sharma G, Agrawal A. Assessment of variation in depth of brachial plexus using ultrasound for supraclavicular brachial plexus block in patients undergoing elective upper limb surgery. *Indian J Anaesth*. 2016 Jun;60:393–397.
28. Yadav N, Ayub A, Garg R, Nanda S, Gupta B, Sawhney C. Sonographic assessment of predictors of depth of the corner pocket for ultrasound-guided supraclavicular brachial plexus block. *J Anaesthesiol Clin Pharmacol*. 2016;32:25–28.