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SCIENTIFIC ARTICLE

Hemidiaphragmatic paralysis after ultrasound-guided supraclavicular block: a prospective cohort study

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KEYWORDS
Regional anesthesia;
Phrenic nerve;
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Abstract
Background and objectives: The frequent onset of hemidiaphragmatic paralysis during interscalene block restricts its use in patients with respiratory insufficiency. Supraclavicular block could be a safe and effective alternative. Our primary objective was to assess the incidence of hemidiaphragmatic paralysis following ultrasound-guided supraclavicular block and compare it to that of interscalene block.
Methods: Adults warranting elective shoulder surgery under regional anesthesia (Toulouse University Hospital) were prospectively enrolled from May 2016 to May 2017 in this observational study. Twenty millilitres of 0.375% Ropivacaine were injected preferentially targeted to the ''corner pocket''. Diaphragmatic excursion was measured by ultrasonography before and 30 minutes after regional anesthesia. A reduction $\geq$25% in diaphragmatic excursion during a *sniff test* defined the hemidiaphragmatic paralysis. Dyspnoea and hypoxaemia were recorded in the recovery room. Predictive factors of hemidiaphragmatic paralysis (gender, age, weight, smoking, functional capacity) were explored. Postoperative pain was also analysed.
Results: Forty-two and 43 patients from respectively the supraclavicular block and interscalene block groups were analysed. The incidence of hemidiaphragmatic paralysis was 59.5% in the supraclavicular block group compared to 95.3% in the interscalene block group ($p < 0.0001$). Paradoxical movement of the diaphragm was more common in the interscalene block group (RR = 2, 95% CI 1.4–3; $p = 0.0001$). A similar variation in oxygen saturation was recorded between patients with and without hemidiaphragmatic paralysis ($p = 0.08$). No predictive factor of hemidiaphragmatic paralysis could be identified. Morphine consumption and the highest numerical rating scale (NRS) at 24 hours did not differ between groups.

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Conclusions: Given the frequent incidence of hemidiaphragmatic paralysis following supraclavicular block, this technique cannot be recommended for patients with an altered respiratory function.

PALAVRAS-CHAVE
Anestesia regional;
Nervo frênico;
Paralisia diafragmática

Paralisia hemidiafragmática após bloqueio supraclavicular guiado por ultrassom: um estudo coorte prospectivo

Resumo
Justificativa e objetivos: O aparecimento frequente de paralisia hemidiafragmática durante o bloqueio interescalênico restringe seu uso em pacientes com insuficiência respiratória. O bloqueio supraclavicular pode ser uma opção segura e eficaz. Nosso objetivo primário foi avaliar a incidência de paralisia hemidiafragmática após bloqueio supraclavicular guiado por ultrassom e compará-lo com o bloqueio interescalênico.
Métodos: Os adultos agendados para cirurgia eletiva do ombro sob anestesia regional (Hospital Universitário de Toulouse) foram prospectivamente incluídos neste estudo observacional, de maio de 2016 a maio de 2017. Vinte mililitros de ropivacaína a 0,375% foram injetados, preferencialmente objetivando a interseção da primeira costela e da artéria subclávia. A excursão diafragmática foi medida por ultrassonografia antes e 30 minutos após a anestesia regional. Uma redução $\geq$ 25% na excursão diafragmática durante um *sniff test* definiu a paralisia hemidiafragmática. Dispneia e hipoxemia foram registradas na sala de recuperação. Fatores preditivos de paralisia hemidiafragmática (sexo, idade, peso, tabagismo, capacidade funcional) foram explorados. A dor pós-operatória também foi avaliada.
Resultados: Quarenta e dois e 43 pacientes dos grupos bloqueio supraclavicular e bloqueio interescalênico, respectivamente, foram avaliados. A incidência de paralisia hemidiafragmática foi de 59,5% no grupo bloqueio supraclavicular em comparação com 95,3% no grupo bloqueio interescalênico ($p < 0{,}0001$). O movimento paradoxal do diafragma foi mais comum no grupo bloqueio interescalênico (RR = 2, 95% IC 1,4–3; $p = 0{,}0001$). Uma variação semelhante na saturação de oxigênio foi registrada entre os pacientes com e sem paralisia hemidiafragmática ($p = 0{,}08$). Nenhum fator preditivo de paralisia hemidiafragmática pôde ser identificado. O consumo de morfina e o maior escore na escala numérica na escala numérica (NRS) em 24 horas não diferiram entre os grupos.
Conclusões: Devido à frequente incidência de paralisia hemidiafragmática após bloqueio supraclavicular, essa técnica não pode ser recomendada para pacientes com função respiratória alterada.

Introduction

Interscalene Block (ISB) is deemed to be the reference post-surgical analgesic technique for shoulder surgery.[1] However, hemidiaphragmatic paralysis (HdP) due to phrenic nerve involvement in the interscalene region limits its use in patients with a precarious respiratory function.[2,3] As the brachial plexus and phrenic nerve diverge from each other as they move caudally, ultrasound-guided Supraclavicular Block (SCB) could be a safe, reliable and effective alternative.[4] However, the incidence of HdP following SCB (preferentially targeted to the ''corner pocket'') remains to be defined as the results previously published are contradictory.[5,6] Moreover, there is still uncertainty about the postoperative analgesic efficacy of the SCB for shoulder surgery.[4]

Ultrasonography of the diaphragmatic dome is a straightforward, reliable, non-invasive and reproducible method for assessing the activity of the diaphragm. In fact, Motion-mode can be used to assess diaphragmatic excursion (i.e., displacement) during a voluntary sniff test for which patients forcefully inhaled through the nose in a sniffing fashion.[7]

The primary objective of our study was to assess and compare the incidence of HdP by diaphragmatic ultrasonography following supraclavicular or interscalene injection of 20 mL of 0.375% ropivacaine. In this setting, we hypothesized that the incidence of HdP following a SCB is half that of an ISB.

Methods

Ethical approval for this study (Ethical Committee nº 03-0415) was provided by the Comité d'Ethique Recherche of Toulouse University Hospitals, Toulouse, France (Chairman Dr N. Nasr) on 30 April 2015 according to the declaration of Helsinki.

After collecting the written informed consent of each patient, this observational, prospective, single-centre study carried out from May 2016 to May 2017 within the operating theatre of the Orthopaedic Department at Hôpital Riquet (Purpan University Hospital of Toulouse).

Inclusion/exclusion criteria

All patients over 18 years of age requiring elective arthroscopic shoulder surgery under regional anesthesia were enrolled. The exclusion criteria comprised the existence of controlateral diaphragmatic paralysis, a history of respiratory insufficiency (Chronic Obstructive Pulmonary Disease patients with a modified Medical Research Council [mMRC] Dyspnea Scale $\geq$2), the inability to undergo diaphragmatic ultrasonography, patient refusal, the presence of major spontaneous or acquired haemostasis disorders, infection at the puncture site, pregnancy and protection of adults (legal guardian, guardianship, trusteeship).

The choice between ISB and SCB was determined by the physician in charge of the patient the day of surgery and was based on his personal convictions and preferences. The physician who evaluated the outcome criteria (notably, diaphragmatic function on ultrasound) did not know the chosen method of brachial plexus block. Each patient was conditioned according to the standard department protocol with the introduction of 500 mL intravenous Ringer Lactate solution and standard monitoring comprising a continuous electrocardioscope, non-invasive arterial pressure measurement and pulse oximetry. No premedication was administered to the patient before regional anesthesia.

Regional anesthesia protocol

Regional anesthesia was carried out using an echograph (X-Porte, Fujifilm Sonosite®, Inc., Bothell, USA) fitted with a high-frequency linear sensor (10–12 MHz). For SCB, 20 mL of 0.375% ropivacaine were injected by preferentially targeting the ''corner pocket'' (i.e., junction of the subclavian artery and first rib or pleura).[8] Once identified, 5 mL of 0.375% ropivacaine were slowly injected after aspiration, while the spread of local anesthetic was observed. Hereafter, the needle was withdrawn posterolateral to the brachial plexus and 15 mL of 0.375% ropivacaine were slowly injected.[6] For ISB, a posterior approach was used with a periplexic injection of 20 mL of 0.375% ropivacaine on contact with roots C5 and C6.[9]

The success of the regional anesthesia was determined at the 30th minute by the loss in terms of cold sensation using a compress saturated with cold alcohol.

Ultrasound-guided evaluation of diaphragmatic excursion

Before administering the regional anesthesia (basal state) and 30 min after, diaphragmatic excursion was assessed by one of the study investigators (F.F., C.M., JM.M.). Diaphragmatic ultrasonography was carried out using a cardiac probe of 3.5–5 MHz (X-Porte, Fujifilm Sonosite®, Inc., Bothell, USA) with the patient in a strictly supine position. The ultrasound probe was placed immediately below the costal margin, in the region of the anterior axillary line, and directed in the medial, cephalic and dorsal directions towards the posterior third of the hemidiaphragm. The two-dimensional mode was initially used to obtain the best approach. The Motion-mode was then used to measure inspiratory (caudal) and expiratory (cephalic) diaphragmatic movements along the selected line (Fig. 1). The liver (to the right) or spleen (to the left) served as the acoustic window. Diaphragmatic excursion (displacement, expressed in cm) was measured during a sniff test, with respiratory manoeuvres corresponding to brief, rapid, forced, nasal inhalation.[5]

The ultrasound-guided visibility of the diaphragmatic line and its excursion were noted in a semi-quantitative manner (0 = poor, 1 = mediocre, 2 = good). The best of three diaphragmatic excursion measurements was retained for each evaluation. Diaphragmatic paralysis was considered total in cases where a >75% reduction in diaphragmatic excursion was recorded or partial with a diaphragmatic excursion of 25–75%.[5] During inspiration, paradoxical movement of the diaphragm, highlighted by a cephalic movement, defined total HdP (Fig. 1).

In the case of general anesthesia, a standardised protocol was used with induction using Propofol (2–3 $mg.kg^{-1}$) and Sufentanil (10–15 mcg) and upper airways management via a laryngeal mask. General anesthesia was maintained with IV propofol administered via an electric syringe (2–8 $mg.kg^{-1}.h^{-1}$). At the end of the surgical procedure, patients were transferred to the Postanesthesia Care Unit (PACU). Oxygen saturation on room air and the presence of dyspnoea (secondary outcomes) were recorded before the patient left the PACU.

Postoperative pain and opioid consumption

Post-surgical pain was assessed according to a numeric rating scale (NRS of 0–10 where 0 = no pain and 10 = the worst pain ever). Post-surgical analgesia was maintained by the systematic administration (unless contra-indicated) of 1 g of paracetamol and 100 mg of ketoprofen. In the recovery room, an IV titration of Morphine Sulphate was administered in the case of a NRS > 3. Assessments of the highest 24 h NRS score at rest and opioid consumption (intravenous morphine equivalent doses) were recorded since PACU discharge (secondary oucomes).

Prediction of sample size

We projected the trial's sample size on the basis of an a priori power analysis and the assumption of an incidence of any (total or partial) hemidiaphragmatic paralysis following supraclavicular blockade of 40%, estimated based

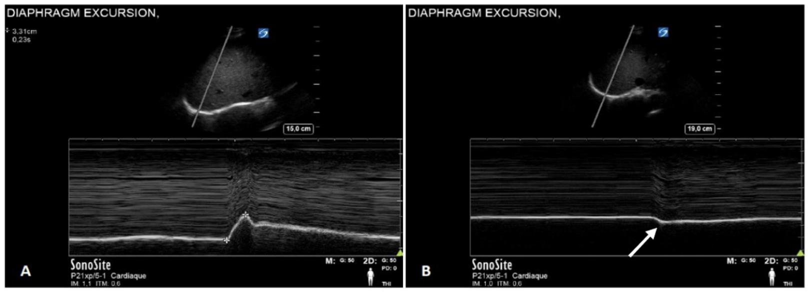

Figure 1 Diaphragmatic excursions during a *sniff test* before (A) and after (B) Intrascalene Brachial plexus block (ISB). Prior to ISB, the diaphragmatic excursion (i.e. displacement) was measured at 33.1 mm (A). Please, note the paradoxical downward movement of the diaphragm (white arrow) 30 min after ISB (B).

on a reported incidence of 44% following ultrasound-guided techniques.[5] Since the incidence of HdP following ISB was greater than 80%,[4] 29 patients per group are required to highlight a 50% reduction in HdP after SCB compared to ISB with an α risk of 0.05 and a power of 90% (2 tailed). In order to compensate for any inclusion errors and patients lost to follow up (generally estimated at 10%), 32 patients must be enrolled per group.

Statistical analysis

Data normality was checked using the Shapiro—Wilk test. Continuous variables were summarized with mean ± SD and analysed using unpaired *t*-test if symmetric distributed, otherwise summarized with median [ranges], and analysed with Mann—Whitney U-test as appropriate. Qualitative variables are expressed in number (%) and compared according to the Chi^2 test or Fischer exact test when appropriate. The extent of the association between the onset of diaphragmatic paralysis and the type of regional anesthesia (ISB or SCB) was expressed as a Relative Risk (RR) and its 95% Confidence Interval (95% CI). The explanatory variables of HdP were analysed using a generalised linear model (stepwise logistic regression).

The statistical analysis was carried out using MedCalc software (version 12.6.1, MedCalc Software bvba, Ostend, Belgium; 2013). A value of $p < 0.05$ was deemed statistically significant.

Results

Overall, 92 patients were eligible (Table 1). Seven patients (7.6%) were excluded due to the absence of diaphragmatic excursion on the ultrasound image. Eighty-five patients were finally enrolled and analysed, 42 of whom underwent SCB and 43 ISB (Fig. 2).

In terms of demographic characteristics, most of the patients had undergone shoulder surgery under the combination of regional anesthesia and general anesthesia (Table 1).

Analysis of the primary endpoint found 59.5% cases of HdP in the SCB group versus 95.3% in the ISB group ($p < 0.0001$) (Table 2). The relative risk of HdP in the ISB group compared to the SCB group was 1.6 (95% CI 1.2–2.1, $p = 0.0003$).

In the SCB group, paralysis was classed as total in 42.9% of cases and partial in 16.7% whereas in the ISB group, paralysis was total in 88.4% of cases and partial in 7% ($p < 0.0001$) (Table 2). The relative risk of total HdP in the ISB group compared to the SCB group was 1.8 (95% CI 1.3–2.6, $p = 0.0003$). A paradoxical movement of the diaphragm during the sniff test was noted in 81.4% of patients in the ISB group compared to 40.5% of patients in the SCB group (relative risk at 2 (95% CI 1.4–3; $p = 0.0001$) (Table 2). The variations in diaphragmatic excursion between the SCB and ISB groups are shown in Figure 3.

In the splenic window (i.e., left side), 25% (9/36) of patients presented poor ultrasound presentation of the diaphragm compared to 6.1% (3/49) with the hepatic window (i.e., right side) ($p < 0.0001$).

The reduction in oxygen saturation was comparable between the groups of patients with and without HdP with -2 points (95% CI -3- -1) and -1 point (95% CI -2.2–0) respectively; $p = 0.08$.

Furthermore, there was no statistical difference in terms of the incidence of dyspnoea (12.9% vs. 5.3% respectively, $p = 0.3$).

Table 1 Demographic characteristics of patients enrolled in the study.

	ISB (n = 47)	SCB (n = 45)	*p*
Age	55 (18–87)	54 (18–87)	0.85
Gender (M/F)	31/16	24/21	0.12
BMI	25 (16–39)	24 (16–34)	0.77
ASA 1, 2, 3, 4	23, 22, 2, 0	29, 13, 3, 0	0.25
Respiratory med. hist.	5	3	0.50
Smoker	13	13	0.90
MET < 4, 4–7, > 7	1, 13, 33	2, 15, 28	0.36
Left/right side	19/28	22/23	0.42
LA volume	20 (20–20)	20 (20–20)	1
GA yes/no	45/2	40/5	0.12
Duration of surgery	48 (20–115)	45 (20–165)	0.38

ISB, Inter Scalene Block; SCB, Supra Clavicular Block; M/F, Male/Female; BMI, Body Mass Index; ASA, score of the American Society of Anesthesiology; med. hist., medical history; MET, functional capacity in Metabolic Equivalent of Task; LA, Local Anesthetic; GA, General Anesthesia.
Continuous variables are expressed as median values (ranges) and were analysed using Mann—Whitney *U* test. Qualitative variables are expressed in number and compared according to the Chi^2 test or Fischer exact test when appropriate.

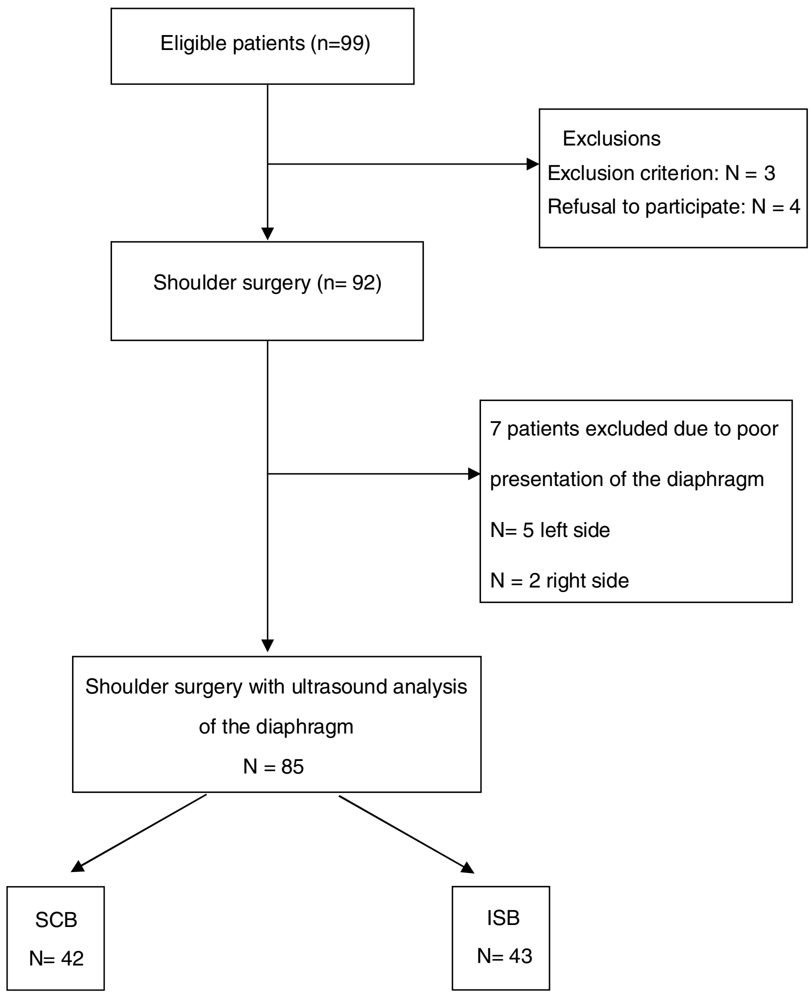

Figure 2 Flow chart. SCB, Supraclavicular Brachial plexus block; ISB, Interscalene Brachial plexus block.

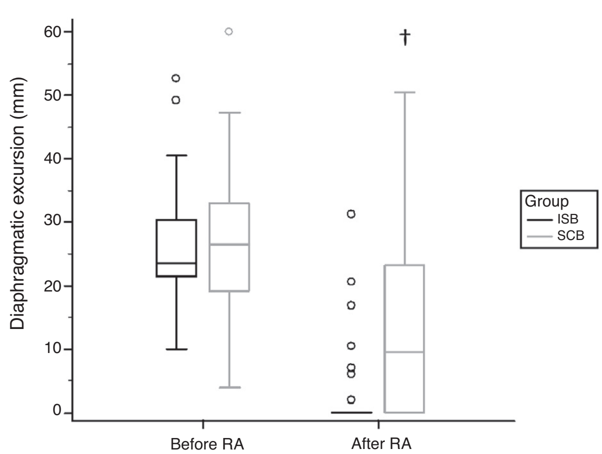

Figure 3 Variations in diaphragmatic excursion induced by regional anesthesia and compared between groups. RA, Regional Anesthesia; ISB, Interscalene Block; SCB, Supraclavicular Block. † Significant difference compared to the ISB group ($p = 0.0001$).

The ASA score, gender, Body Mass Index, age, smoking habits and basal functional capacity cannot explain the onset of HdP (p = NS).

The Body Mass Index was significantly higher in patients with post-surgical dyspnoea than in patients with no dyspnoea (30 [21–39] kg.m^{-2} vs. 24 [16–34] kg.m^{-2} respectively, $p = 0.004$). A moderate (4–7 Metabolic Equivalent of Task) or low (< 4 Metabolic Equivalent of Task) basal functional capacity was observed in 66.6% of patients with dyspnoea compared to 30% in patients without dyspnoea ($p = 0.002$).

Cumulative morphine consumption and the highest NRS at 24 hours after discharge did not differ between groups ($p = 0.15$ and $p = 0.14$, respectively, Table 3).

Discussion

We assessed the incidence of HdP during ultrasound-guided SCB achieved with 20 mL of 0.375% ropivacaine and we compared it to the one induced by ISB realized with the same dose of local anesthetic. As expected, almost all patients experienced an HdP (mostly total) after an ISB, whereas 60%

Table 2 Variation in diaphragmatic excursion during a *sniff test* before and after regional anesthesia.

	ISB (n = 43)	SCB (n = 42)	*p*
DE before RA (mm)	23.6 (10–52.7)	26.8 (11.6–60)	0.3
DE 30 min after RA (mm)	0 (0–31.3)	15.3 (0–50.5)	0.0001
Total HdP	38 (88.4%)	18 (42.9%)	0.0001
Partial HdP	3 (7%)	7 (16.7%)	0.0001
Total + Partial HdP	41 (95.3%)	25 (59.5%)	0.0001
Paradoxical movement	35 (81.4%)	17 (40.5%)	0.0001

ISB, Inter Scalene Block; SCB, Supra Clavicular Block; DE, Diaphragmatic Excursion; RA, Regional Anesthesia; HdP, Hemidiaphragmatic Paralysis.
Continuous variables are expressed as median values (ranges) and were analysed using Mann-Whitney *U* test. Qualitative variables are expressed in number (%) and compared according to the Fischer exact test.

Table 3 Intravenous morphine equivalent doses consumption and evaluation of pain after 24 h (since PACU discharge) according to the regional anesthesia.

	ISB(n = 43)	SCB(n = 42)	*p*
Cumulative IV morphine consumption after 24 hours (mg)	6.8 ± 3.5	5.7 ± 3.4	0.15
The highest 24 hour NRS score (/10)	4 (0–10)	4 (0–10)	0.14

PACU, Postanesthesia Care unit; ISB, Inter Scalene Block; SCB, Supra Clavicular Block; IV, Intravenous; NRS, Numeric Rating Scale.
Continuous variables are summarized with mean ± SD and analysed using unpaired *t*-test if symmetric distributed, otherwise summarized with median (ranges), and analysed with Mann-Whitney *U* test as appropriate.

of patients presented diminished diaphragmatic excursion following supraclavicular brachial plexus blockade.

ISB is recognized as the reference analgesia following shoulder surgery.[1] However, a near 100% loss of hemidiaphragmatic activity resulting from phrenic nerve paralysis limits the use of ISB for patients with limited pulmonary reserve because of concerns about dyspnea, atelectasis, and respiratory failure.[3,10] The onset of HdP secondary to ISB is due to cephalic propagation of the local anesthetic towards nerve roots C3–C5 and/or its anterior diffusion towards the phrenic nerve.[4] Consequently, a more caudal brachial plexus anesthesia via the supraclavicular approach should reduce the incidence of HdP (the phrenic nerve and brachial plexus diverge from each other at a rate of 3 mm per centimetre under the cricoid cartilage.[4] In 2001, Mak et al. recorded 67% cases of HdP following SCB performed in neurostimulation with 0.5 mL.kg^{-1} of 0.375% bupivacaine.[11] In our study, the use of ultrasound guidance to control local anesthetic distribution preferentially to the ''corner pocket'' did not reduce the incidence of HdP following SCB. Our result disagreed with that previously published by Renes et al. where none of the patients in the ultrasound group showed complete or partial paresis of the hemidiaphragm after a SCB with 20 mL of 0.75% ropivacaine.[6] The presence of an accessory phrenic nerve or retrograde diffusion of the local anesthetic could account for the incidence of this complication that we found following SCB.[12] Anyway, even if the incidence of HdP following SCB is reduced when compared to ISB, our available results do not support the use of high-volume, multiple-injection SCB when HdP is a clinical concern. An ultrasound-guided SCB with 20 mL of 0.375% ropivacaine is unfortunately afflicted with a relatively high 60% incidence of HdP.

Contrary to our expectations, no predictive factor could be identified for HdP. The risk of HdP is no greater in elderly patients, obese, smokers or those with a low functional capacity compared to others. Thus, the onset of HdP following SCB or ISB would depend only on the characteristics of regional anesthesia (injection site, type, volume and dose of the local anesthetic used) as well as anatomical variations of subjects. However, previously published data have shown that diaphragmatic paralysis was frequently associated with dyspnoea in patients with a Body Mass Index $\geq$30 kg.m^{-2}.[13] Indeed, we demonstrated in our study that the Body Mass Index was significantly higher in patients with post-surgical dyspnoea than in patients with no dyspnoea. In other words, the clinical respiratory implications of diaphragmatic paralysis could be more pronounced in obese patients who must be considered a high-risk population.

The quality of postoperative analgesia after SCB seems to be similar to that obtained after ISB for shoulder surgery. This similarity has recently been advocated by Ryu et al. and Auyong et al. for major outpatient arthroscopic shoulder surgery.[14,15] Indeed, from an anatomical standpoint, all of the brachial plexus (upper, mid and lower trunks) is anesthetised with SCB, successfully achieving post-surgical analgesia secondary to shoulder surgery. Therefore, SCB provide a reliable alternative to ISB for shoulder surgery insofar as postoperative analgesia can be achieved for shoulder surgery.

Our study has several limits. Firstly, the absence of double-blind randomisation is one of the major limits of our study. In addition to the ensuing loss of methodological robustness, the choice of regional anesthesia left at the discretion of attending anesthesiologists could have made our populations heterogeneous. Secondly, the measurement of ultrasound-guided diaphragmatic excursion is not a reference method for diagnosing HdP. However, the recording of trans-diaphragmatic pressure is an invasive technique warranting simultaneous measurement of gastric and oesophageal pressures. It cannot be carried out in current practice in this context. Thus, ultrasonography is a reliable, reproducible, non-invasive alternative that can be carried out directly at the patient's bedside.[7] The difficulties associated with the ultrasound presentation of diaphragmatic excursion in the splenic acoustic window could be overcome by measuring the thickness of the diaphragm in its zone of apposition to the rib cage during deep inspiration.[10,16] Lastly, a diaphragmatic excursion reduction cut-off of 25% to define HdP remains subject to controversy.[5,6,17] Further multiparametric studies (involving pulmonary function parameters like vital capacity) are required to shed more light on the clinical repercussions of hemidiaphragmatic involvement and thus to refine positive ultrasound-guided diagnosis.

Conclusion

In conclusion, the high incidence of HdP (60% of patients) and total HdP (43% of patients) following supraclavicular injection of 20 mL of 0.375% ropivacaine makes SCB a risky procedure when HdP is a clinical concern. Other data focusing on respiratory repercussions are required in order to gain a better understanding of the consequences of HdP.

Prior presentation

Preliminary data for this study were presented as a e-poster presentation at the Congress SFAR, 27—29 September 2018, Paris.

Conflicts of interest

The authors declare no conflicts of interest.

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