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Patient-controlled Interscalene Analgesia with Ropivacaine 0.2% Versus *Patient-controlled Intravenous Analgesia after Major Shoulder Surgery*

Effects on Diaphragmatic and Respiratory Function

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Background: **The authors compared the effects of patient-controlled interscalene analgesia (PCIA) with ropivacaine 0.2% and patient-controlled intravenous analgesia (PCIVA) with opioids on hemidiaphragmatic excursion and respiratory function after major shoulder surgery.**

Methods: **Thirty-five patients scheduled for elective major shoulder surgery were prospectively randomized to receive either PCIA or PCIVA. All patients received an interscalene block before surgery. In the PCIA group, a catheter was introduced between the anterior and middle scalene muscles. Six hours after the initial block, patients received for 48 h either a continuous infusion of 0.2% ropivacaine through the interscalene catheter at a rate of 5 ml/h plus a bolus dose of 3 or 4 ml with a lockout time of 20 min (PCIA group) or a continuous intravenous infusion of nicomorphine at a rate or 0.5 mg/h plus a bolus dose of 2 or 3 mg with a lockout time of 20 min (PCIVA group). Hemidiaphragmatic excursion and respiratory function were assessed with the patient in a 45° semirecumbent position the day before the operation and 20 min (in the operating room), 24 h, and 48 h after the initial block by means of ultrasonography and spirometry, respectively. Pain relief was regularly assessed, side effects were noted, and patient satisfaction was rated 6 h after the end of the study.**

Results: **Hemidiaphragmatic excursion was similar in the two groups 20 min after interscalene block. Hemidiaphragmatic excursion was increased in the PCIA group on the nonoperated side 24 and 48 h after the interscalene block ($P < 0.05$). Pulmonary function was similar in the two groups at each time. Pain was better controlled in the PCIA group at 12 and 24 h ($P < 0.05$). The incidence of nausea and vomiting were 5.5% *versus* 60% for the PCIA and PCIVA groups, respectively ($P < 0.05$). Patient satisfaction was greater in the PCIA group ($P < 0.05$).**

Conclusions: **The use of PCIA or PCIVA techniques to provide analgesia after major shoulder surgery is associated with similar effects on respiratory function. In the PCIA group, hemidiaphragmatic excursion showed a significantly greater amplitude 24 and 48 h after the initial block on the nonoperated side. The PCIA technique provided better pain control, a lower incidence of side effects, and a higher degree of patient satisfaction. (Key words: Local anesthetics; opioids; peak expiratory flow rate; vital capacity.)**

SEVERE postoperative pain, particularly within the first 48 h after surgery, is frequently observed after major shoulder surgery.[1] Adequate management of pain is important in this setting, not only to improve the patient's well-being, but also to facilitate rehabilitation. Interscalene block (IB) is a recognized effective means of providing anesthesia–analgesia in this clinical context.[2] One of the theoretic disadvantages of this technique is hemidiaphragmatic paresis[3] and the potential decrease of pulmonary function.[4] Indeed, a continuous infusion of bupivacaine 0.125% through an interscalene catheter was shown to reduce the diaphragmatic motility and ventilatory function.[5] Patient-controlled interscalene analgesia (PCIA) with bupivacaine 0.15%[6] or ropivacaine 0.2%[7] was associated with better pain control, a lower incidence of side effects, and a higher degree of patient satisfaction after major shoulder surgery compared with patient-controlled intravenous analgesia (PCIVA) with nicomorphine. However, no study has investigated and compared the effects of the two techniques on pulmonary function in this clinical context. The aim of this trial was to assess the influence of the PCIA technique with ropivacaine 0.2% on hemidiaphragmatic excursion and respiratory function and to compare PCIA with PCIVA in

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this clinical context during the first 48 h after major shoulder surgery.

Patients and Methods

After we obtained approval of our institutional ethics committee and written informed consent from patients, we prospectively enrolled 35 adults of both sexes (classified as American Society of Anesthesiologists physical status I or II; age 18–70 yr; weight 50–100 kg; height 155–190 cm) who were scheduled for elective shoulder arthroplasty or rotator cuff repair. Exclusion criteria were any contraindications to IB, including severe bronchopulmonary disease; known allergy to ropivacaine or opioids; previous analgesic treatment with opioids; and pain in the shoulder caused by other conditions. Patients were assigned, according to a computerized randomization list, to either the PCIA or PCIVA group. All patients received an IB before induction of general anesthesia. In both groups, the interscalene brachial plexus was identified using a nerve stimulator (Stimuplex-DIG; B. Braun Melsungen AG, Melsungen, Germany) connected to the proximal end of the metal inner needle (Contiplex; stimulation needle 21G; B. Braun Melsungen AG) of a plastic cannula (Contiplex; external diameter 20G; B. Braun Melsungen AG). The placement of the needle was considered successful when a muscle distal to the deltoid was stimulated with a threshold stimulation < 0.5 mA. In both groups, IB was performed with 30 ml ropivacaine 0.75%. In the PCIA group, a catheter (Contiplex; 23F with stylet) was introduced distally between the anterior and middle scalene muscles for up to 5–6 cm and fixed to the skin with adhesive tape. In this group, the initial IB was performed by administering ropivacaine through the catheter. In the PCIVA group, the IB was performed by injecting ropivacaine once the stimulation needle was adequately placed. IB was confirmed in all patients by a sensory (inability to recognize cold temperature) and motor block (inability to extend the arm, paresthesia in the tip of the first and third finger) involving the radial and median nerves within 20 min after the administration of local anesthetic.

The general anesthetic technique was standardized for all patients. They were premedicated with 0.1 mg/kg midazolam given orally 1 h before the IB. After the IB was complete, induction was performed with 1.5–2 mg/kg propofol, and anesthesia was maintained with 8–10 $mg \cdot kg^{-1} \cdot h^{-1}$ propofol. Tracheal intubation was facilitated using 0.8 mg/kg rocuronium, and 1–2 μg/kg fentanyl was given within the first 15 min after induction. All patients received an infusion of either ropivacaine through the interscalene catheter or intravenous nicomorphine in the recovery room starting 6 h after the initial IB. The PCIA group (Pain Management Provider, Abbott Laboratories, North Chicago, IL) received through the interscalene catheter a continuous infusion of 0.2% ropivacaine at a rate of 5 ml/h plus a bolus dose of 4 ml for patients weighing > 65 kg and 3 ml for those weighing < 65 kg, with a lockout time of 20 min. At the same time, the PCIVA group (Pain Management Provider, Abbott Laboratories) received a continuous intravenous infusion of nicomorphine at a rate of 0.5 mg/h plus a bolus dose of 3 mg for patients weighing > 65 kg and 2 mg for those weighing < 65 kg, with a lockout time of 20 min. The study period ended 48 h after the IB was performed. All patients received 2 g propacetamol (the predrug of acetaminophen) intravenously four times a day on a regular basis. Diaphragm excursion was assessed by ultrasonography using a Sonoline Prima ultrasonograph (Siemens Medical, Erlangen, Germany). With the patient lying supine in a 45° semirecumbent position, a 3.5-MHz convex transducer was placed posterolaterally at the midclavicular line. The precise position of the scanner was also determined by the specific anatomy of the patient, avoiding air in the pleural recesses or intestinal structures. After identifying the dome of the hemidiaphragm (right and left separately), its excursion was measured in the M mode during rest and maximal forced inspiration. For some patients, especially those with a large excursion, the hemidiaphragm could not be followed throughout the entire respiration cycle because of interference of the lung in the costophrenic angles. In such cases, the position of the transducer was slightly changed (moved to an adjacent intervertebral space or within the same intervertebral space) until the diaphragm could be followed throughout its entire excursion. The measurements were performed four times: the day before surgery and 20 min (in the operating room), 24 h, and 48 h after the IB. The position of the patient was standardized for all measurements. At each time, the distance of diaphragmatic excursion (centimeters) was measured three times, and the values were averaged. Paradoxical motion, defined as a cranial motion during inspiration and caudal motion during expiration, was noted as a negative value.

Respiratory function was assessed using a Cardiovit AT 6 recorder in its spirometry configuration (Schiller Reomed AG, Dietikon, Switzerland) with patients placed in a 45° semirecumbent position and after extensive

instruction on how to perform the test. Vital capacity (VC), forced expiratory volume in 1 s (FEV_1), and peak expiratory flow rate (PEFR) were performed four times: the day before surgery and 20 min (in the operating room), 24 h, and 48 h after the IB. Measurements for VC, FEV_1, and PEFR were made immediately after ultrasonography. Each test was performed three times, and the values were averaged and graphically documented. The prints were analyzed by a certified pneumologist blinded to the patient's group assignment. All patients had a pulse oximeter (Cardiocap; Datex, Helsinki, Finland) during the study period. A value $< 90\%$ was considered as a hypoxemic episode.

A research nurse who was not involved in the study was responsible for asking the patient about the pain score at rest, the sedation levels according to the Ramsay scale, the appearance of side effects, and his or her satisfaction. Pain was assessed with a visual analog score ranging from 0 (no pain) to 100 (most severe pain imaginable) at the beginning of the PCIA or PCIVA (6 h after the IB) and 12, 14, 36, and 48 h after the IB. The appearance of nausea, vomiting, pruritus, or other side effects was noted. The time of the first PCIA or PCIVA bolus dose was noted. Nausea and vomiting were treated with 2 mg tropisetron intravenously, and pruritus was treated with 10 or 20 mg propofol intravenously and repeated as necessary. Patient satisfaction was assessed 6 h after the end of the study period (54 h after the IB) using a visual analog score ranging from 0 (not satisfied) to 10 (entirely satisfied).

Statistical Analysis

Results are expressed as mean ± SD unless otherwise stated. Demographic data were assessed using the Mann–Whitney test. The time course of diaphragmatic excursion of the operated and nonoperated side between the PCIA and PCIVA groups was assessed with the Mann–Whitney test with Bonferroni correction for multiple comparisons. The time course of diaphragmatic excursion within the PCIA and the PCIVA groups (operated and nonoperated side) was compared by the Wilcoxon signed rank test with Bonferroni correction. Respiratory function and pain score between the PCIA and PCIVA groups were analyzed by the Mann–Whitney test with Bonferroni correction for multiple comparisons. Respiratory function within the PCIA and PCIVA groups was assessed by the Wilcoxon signed rank test with Bonferroni correction. Time of first bolus dose was compared with the Mann–Whitney test, and side effects were analyzed using the Fisher exact test. For all determinations, a P value < 0.05 was considered significant.

Table 1. Patient Characteristics

	PCIA Group	PCIVA Group
No. of patients	18	15
Age (yr)	51 ± 2	47 ± 1
Weight (kg)	79 ± 14	81 ± 15
Height (cm)	173 ± 8	170 ± 10
Sex (male/female)	12/6	11/4
Surgery type: SA/RC	4/14	3/12
Duration of surgery (min)	161 ± 31	179 ± 25

Values are expressed as mean ± SD.

PCIA = patient-controlled interscalene analgesia; PCIVA = patient-controlled intravenous analgesia; SA = shoulder arthroplasty; RC = rotator cuff repair.

Results

The two groups were similar with regard to demographic and surgical data (table 1). Two patients were excluded from the study in the PCIVA group because of intractable vomiting that necessitated a change in the pain treatment.

Baseline hemidiaphragmatic excursion on both sides was similar in the two groups. Twenty minutes after the IB, the diaphragmatic movement on the operated side was statistically significantly decreased during normal respiration as well as during forced respiration in the PCIA and PCIVA groups (figs. 1A and 1B). There was no difference in diaphragmatic excursion between the groups. On the nonoperated side, no difference was noted between the two groups during normal respiration at each time (fig. 2A). During forced respiration, a significant increase of hemidiaphragmatic excursion was observed in the PCIA group 24 and 48 h after the IB as compared with the PCIVA group ($P < 0.05$; fig. 2B). Paradoxical movements were observed in four patients 20 min after the IB (one in the PCIA group and three in the PCIVA group) and in one patient in the PCIA group 24 h after the IB. In the PCIA group, the decrease of the hemidiaphragmatic excursion was statistically significant on the operated side 20 min and 24 and 48 h after the IB during normal and forced respiration as compared with the nonoperated side. In the PCIVA group, the decrease in hemidiaphragmatic excursion observed on the operated side was only significant 20 min after the IB as compared with the nonoperated side.

Baseline VC, FEV_1, and PEFR values were similar in the two groups (table 2). There was no statistical difference between the two groups for VC, FEV_1, and PEFR at each

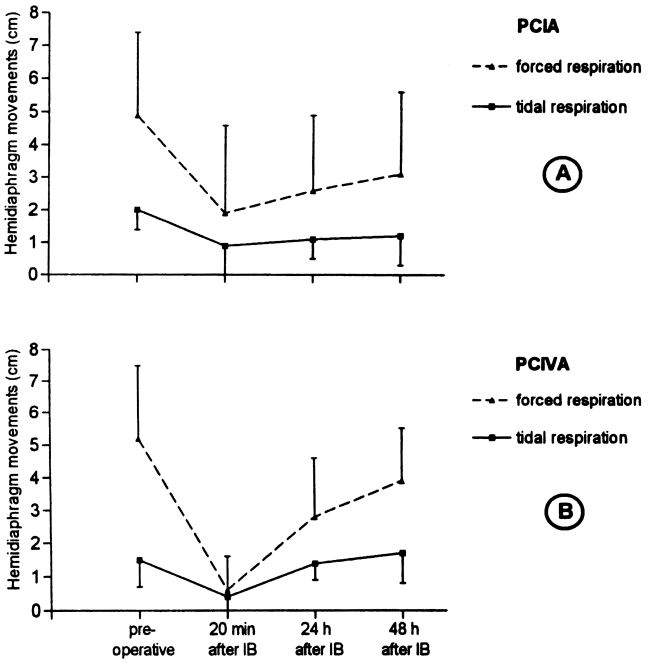

Fig. 1. Time course and extent of diaphragmatic excursion in the PCIA (*A*) and PCIVA (*B*) groups as measured by ultrasonography during normal respiration and forced respiration on the operated side. Values are expressed as mean ± SD. PCIA = patient-controlled interscalene analgesia; PCIVA = patient-controlled intravenous analgesia; IB = interscalene block.

time. In the PCIA group, the VC, FEV_1, and PEFR were statistically decreased 20 min and 24 and 48 h after the IB compared with the basal value ($P < 0.05$). In the PCIVA group, the VC, FEV_1, and PEFR (except PEFR at 48 h) were also statistically decreased 20 min and 24 and 48 h after the IB compared with the basal value ($P < 0.05$). No hypoxemic episode was detected in either group.

Pain score was similar in both groups when PCIA and PCIVA were started (6 h after the IB; table 3). Significantly better pain control was observed in the PCIA group 12 and 24 h after IB ($P < 0.05$; table 3).

Side effects observed during the study are summarized in table 4. Nausea and vomiting were observed more frequently in the PCIVA group ($P < 0.05$). No change of sedation was noted during the study in either group.

Visual analog score for overall patient satisfaction was 9.7 (range, 8–10) in the PCIA group compared with 7.5 (range, 2–10) in the PCIVA group ($P < 0.05$).

Discussion

In this study we demonstrated that the effect on diaphragmatic mobility and respiratory function are comparable between PCIA with ropivacaine 0.2% through an interscalene catheter and PCIVA with nicomorphine after major shoulder surgery in patients who received a surgical IB before anesthesia. This trial also showed an increased activity of the contralateral hemidiaphragm in the PCIA group as compared with the PCIVA group.

Hemidiaphragmatic excursion was measured by means of ultrasonography, which is considered a reproducible and precise technique in this condition,[8] permits repetitive measurements, and is noninvasive. In the PCIVA group, the mean decrease of hemidiaphragmatic excursion 20 min after IB on the operated side (side on which the IB was performed before induction of anesthesia) was 73% and 88% during normal and forced respiration, respectively. These results are comparable to those found by Al-Kaisy *et al.*[9] after administering 10 ml 0.5% bupivacaine and Pere,[5] who administered 20–28 ml 0.75% bupivacaine plus epinephrine. In the PCIA group (the IB was performed through the interscalene catheter before induction of anesthesia), the mean decrease of hemidiaphragmatic excursion was 55% and 61% during

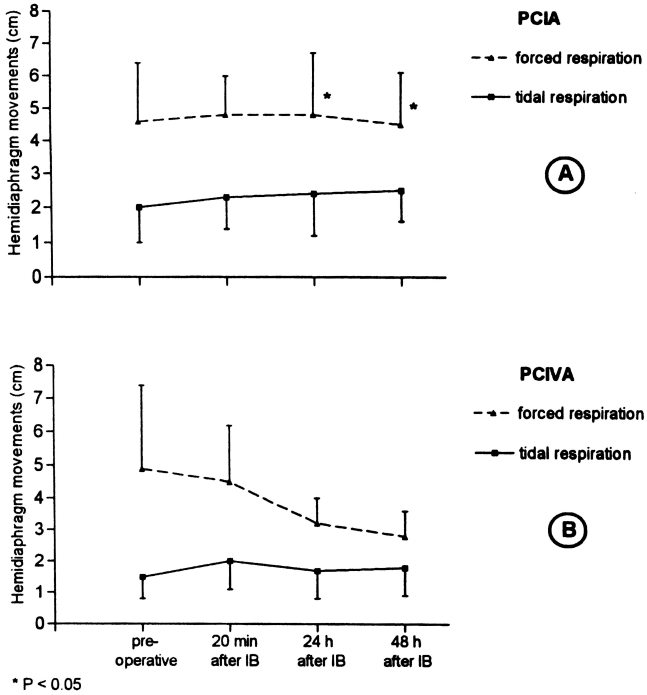

Fig. 2. Time course and extent of diaphragmatic excursion in the PCIA (*A*) and PCIVA (*B*) groups as measured by ultrasonography during normal respiration and forced respiration on the nonoperated side. Values are expressed as mean ± SD. PCIA = patient-controlled interscalene analgesia; PCIVA = patient-controlled intravenous analgesia; IB = interscalene block. *$P < 0.05$ between forced respiration 24 and 48 h after the IB in the PCIA and PCIVA groups.

Table 2. Mean Spirometry Values in the PCIA and PCIVA Groups

	PCIA Group	PCIVA Group
VC (l)		
0	3.7 ± 1.5	3.8 ± 1.7
1	2.4 ± 1.1	2.6 ± 1.4
2	2.6 ± 1.2	3.1 ± 1.6
3	2.9 ± 1.7	3.3 ± 1.6
FEV_1 (l)		
0	2.9 ± 1.0	3.0 ± 1.2
1	1.8 ± 0.9	2.1 ± 1.1
2	2.0 ± 0.9	2.4 ± 1.1
3	2.3 ± 1.2	2.6 ± 1.2
PEFR (l/min)		
0	7.0 ± 2.7	6.7 ± 2.9
1	4.6 ± 2.1	5.1 ± 2.4
2	5.1 ± 2.3	5.7 ± 2.5
3	5.6 ± 2.5	6.0 ± 2.4

Values are expressed as mean ± SD.

PCIA = patient-controlled interscalene analgesia; PCIVA = patient-controlled intravenous analgesia; VC = vital capacity; FEV_1 = forced expiratory volume in 1 s; PEFR = peak expiratory flow rate; 0 = preoperative; 1 = 20 min after interscalene block; 2 = 24 h after interscalene block; 3 = 48 h after interscalene block.

normal and forced ventilation, respectively. These results are more closely related to those observed by Knoblanche *et al.*[10] and Dhuner *et al.*[11] using supraclavicular access to the brachial plexus. Our results may be explained by a more distal position of the catheter (3–5 cm distal within the interscalene sheath) and are in accordance with those observed by Boezaart *et al.*[12] The authors found that the incidence of complete hemidiaphragmatic paralysis after IB was less when 20 ml bupivacaine 0.5% was administered through the interscalene catheter (20%) compared with a single bolus dose according to Winnie's technique with (35%) and without (85%) the use of a nerve stimulator to identify the brachial plexus. Although no significant difference was observed between the two groups in our study, there may be a type II error. It would not be surprising

Table 3. Pain Score at Rest (0–100)

Time after Interscalene Block (h)	PCIA Group	PCIVA Group
6	0 ± 0–5	0 ± 0–4.5
12	6* ± 0–15	30 ± 0–40
24	4.5* ± 0–10	20 ± 0–29
36	0 ± 0–7	14.5 ± 0–27.5
48	0 ± 0–5	0 ± 0–22.5

Results are expressed as median ± 25^{th}–75^{th} percentiles.

PCIA = patient-controlled analgesia; PCIVA = patient-controlled intravenous analgesia.

* $P < 0.05$.

Table 4. Side Effects and Patient Satisfaction in the PCIA and PCIVA Groups

	PCIA Group	PCIVA Group
Nausea/vomiting [no. (%)]	1* (5.5)	9 (60)
Pruritus [no. (%)]	1 (5.5)	3 (20)
Time of first bolus (min)	970 ± 450	744 ± 291
Patient satisfaction†	9.7*	7.5
Range	8–10	2–10

* $P < 0.05$.

† According to visual analog score of 1–10 (1 = not satisfied; 10 = entirely satisfied).

to observe a less severe inhibition of the phrenic nerve when the IB is performed through a more peripherally placed interscalene catheter.

During the analgesic period (24–48 h after the IB), no difference with regard to hemidiaphragmatic excursion was noted on the operated side between the two groups during rest and forced ventilation. A residual effect of local anesthetics in the PCIVA group seems unlikely because Pere[5] demonstrated that the function of the diaphragm was almost fully restored (> 90%) within 24 h in patients who received an IB performed with bupivacaine 0.75% with added epinephrine. Urmey *et al.*[3] nicely demonstrated that diaphragmatic motion returned to normal 3 and 4 h after injection of 34–52 ml mepivacaine 1% with added epinephrine. In this group, a sedative effect of opioid may partly explain the relative inhibition of the hemidiaphragm excursion that is particularly evident during forced respiration.[13] Although the level of sedation was regularly assessed by means of the Ramsay scale, subtle changes in sedation may not have been recognized. Pain, particularly after abdominal surgery, is known to interfere with respiratory function[14]; in the present study, pain was better controlled in the PCIA group. Although not extensively investigated, pain in the shoulder area may have a negative influence on breathing, particularly during forced respiration.

Only a few studies have investigated the consequences of a continuous infusion of local anesthetics on respiratory function, and none had a control group. Pere *et al.*[15] found no difference in the diaphragmatic amplitude in 50% of patients and a decrease of 70–90% in the other 50% 24 h after a continuous infusion of bupivacaine 0.25%. In the present study, we found a mean decrease of hemidiaphragmatic excursion of 40%. The differences observed between the two studies may be explained by the different techniques used to assess the diaphragmatic excursion (radiographs *vs.* ultrasonography), the effects of the local anesthetic (bupivacaine *vs.* ropiva-

caine), and the exact placement of the interscalene catheter, which was not described in the study by Pere *et al.*[15] In the present trial an increase of the diaphragmatic activity was observed on the nonoperated side in both groups 20 min after IB and at each time during normal respiration. The significant increase of the hemidiaphragmatic excursion noted during forced respiration 24 and 48 h after IB in the PCIA group may not only be explained by a better pain control or the absence of any sedative drug, but also by a compensatory mechanism of the contralateral hemidiaphragm.[16,17] These factors may explain the absence of differences in respiratory function between the two groups despite the residual paresis of the hemidiaphragm on the operated side in the PCIA group. Indeed, Katagiri *et al.*[16] investigated respiratory muscle compensation for unilateral hemidiaphragm paralysis in awake canines. By means of electromyogram electrodes implanted on the costal and crural diaphragm segments, after infusion of bupivacaine through a cervical phrenic nerve cuff on the contralateral side, they observed an increased shortening of all diaphragm segmental muscles and corresponding increase in electromyograph activity to compensate for contralateral diaphragm paralysis. The investigators concluded that an integrated strategy of respiratory muscle compensation for unilateral or bilateral diaphragm paralysis occurs among chest wall, abdominal, and diaphragm segmental muscles, with relative contributions of muscles adjusted according to the degree of diaphragm dysfunction. Physiologically, total or partial paralysis of the diaphragm is associated with a decrease of the pulmonary resistances and therefore an improved compliance, factors that favor the shortening of the diaphragm and increase of muscular efficacy. Indeed, it has been shown in mongrel dogs that increasing the stiffness of the respiratory system by immersion in water is associated with a significant decrease of diaphragmatic contraction effectiveness.[17]

Urmey and Gloeggler[4] found a 40% and 32% reduction of VC in patients 30 min after receiving either 45 or 20 ml mepivacaine 1.5% for interscalene brachial plexus block, respectively. Casati *et al.*[18] compared VC in three groups of patients who received 20 ml of 0.5% ropivacaine, 0.75% ropivacaine, or 2% mepivacaine. Thirty minutes after IB, the investigators found no significant difference in VC between the groups (decrease of 40%, 41%, and 39%, respectively). These results are in accordance with those found in the present study. Al-Kaisy *et al.*[9] measured a reduction of 25% and 15% after 10 ml 0.5% or 0.25% bupivacaine, respectively. The smaller reduction in VC and FEV_1 observed by the investigators may be easily explained by the smaller volume of drug administered. Despite a residual 20% reduction of hemidiaphragmatic excursion in the PCIA group, the consequences on pulmonary function are similar to those observed in the PCIVA group, the latter technique being considered as a standard control group. These observations may be partly related to the contralateral compensative mechanism of the hemidiaphragm—and other respiratory muscles—in addition to some negative respiratory drug effects in the PCIVA group (sedation and respiratory depression).

The better pain control, lower incidence of side effects, and higher degree of patient satisfaction we observed confirm the results observed in previous studies.[6,7] Compared with our previous investigations, the pain scores are slightly lower in the two groups, which may be related to the regular administration of 2 g propacetamol.

In conclusion, this study shows that the administration of ropivacaine 0.2% through an interscalene catheter after major shoulder surgery is associated with a decrease of respiratory function (spirometric values) similar to those observed with a classic PCIVA technique. Moreover, the PCIA technique permitted better pain control, a lower incidence of side effects, and a higher degree of patient satisfaction. Further studies are necessary to investigate the effects of these two analgesic methods in patients with preoperative limited pulmonary function.

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References

1. Tuominen M, Pitkanen M, Rosenberg PH: Postoperative pain relief and bupivacaine plasma levels during continuous interscalene brachial plexus block. Acta Anaesth Scand 1987; 31:276–81

2. Brown AR, Weiss R, Greenberg C, Flatow EL, Bigliani LU: Interscalene block for shoulder arthroscopy: Comparison with general anesthesia. Arthroscopy 1993; 9:295–300

3. Urmey WF, Talts KH, Sharrock NE: One hundred percent incidence of hemidiaphragmatic paresis associated with interscalene brachial plexus anesthesia as diagnosed by ultrasonography. Anesth Analg 1991; 72:498–503

4. Urmey WF, Gloeggler PJ: Pulmonary function changes during interscalene brachial plexus block: Effects of decreasing local anesthetic injection volume. Reg Anesth 1993; 18:244–9

5. Pere P: The effect of continuous interscalene brachial plexus block with 0.125% bupivacaine plus fentanyl on diaphragmatic motility and ventilatory function. Reg Anesth 1993; 19:93–7

6. Borgeat A, Schäppi B, Biasca N, Gerber C: Patient-controlled analgesia after major shoulder surgery. ANESTHESIOLOGY 1997; 87:1343–7

7. Borgeat A, Tewes E, Biasca N, Gerber C: Patient-controlled interscalene analgesia with ropivacaine after major shoulder surgery: PCIA vs PCA. Br J Anaesth 1998; 81:603–5

8. Houston JG, Morris AD, Howie CA, Reid JL, McMillan N: Technical report: Quantitative assessment of diaphragmatic movement— A reproducible method using ultrasound. Clin Radiol 1992; 46:405–7

9. Al-Kaisy AA, Chan VWS, Perlas A: Respiratory effects of low-dose bupivacaine interscalene block. Br J Anaesth 1999; 82:217–20

10. Knoblanche GE: The incidence and aetiology of phrenic nerve blockade associated with supraclavicular brachial plexus block. Anaesth Intens Care 1979; 7:346–9

11. Dhuner KG, Moberg E, Oehne L: Paresis of the phrenic nerve during brachial plexus analgesia and its importance. Acta Chir Scand 1955; 109:53–7

12. Boezaart AP, de Beer JF, du Toit C, van Rooyen K: A new technique of continuous interscalene nerve block. Can J Anesth 1999; 46:275–81

13. Sjogren P, Banning A: Pain, sedation and reaction time during long-term treatment of cancer patients with oral and epidural opioids. Pain 1989; 39:5–11

14. Hendolin H, Lahtinen J, Lansimies E, Tuppurainen T, Partanen K: The effect of thoracic epidural analgesia on respiratory function after cholecystectomy. Acta Anaesth Scand 1987; 31:645–51

15. Pere P, Pitkänen M, Rosenberg PH, Björkenheim J-M, Linden H, Salorinne Y, Tuominen M: Effect of continuous interscalene brachial plexus block on diaphragm motion and on ventilatory function. Acta Anaesth Scand 1992; 36:53–7

16. Katagiri M, Young RN, Platt RS, Kieser TM, Easton PA: Respiratory muscle compensation for unilateral or bilateral hemidiaphragm paralysis in awake canines. J Appl Physiol 1994; 77:1972–82

17. Minh V-D, Dolan GF, Linaweaver PG, Friedman PJ, Konopka RG, Brach BB: Diaphragmatic function during immersion. J Appl Physiol 1977; 43:297–301

18. Casati A, Fanelli G, Cedrati V, Berti M, Aldegheri G, Torri G: Pulmonary function changes after interscalene brachial plexus anesthesia with 0.5% and 0.75% ropivacaine: A double-blinded comparison with 2% mepivacaine. Anesth Analg 1999; 88:587–92