DARING DISCOURSE

Diaphragm-Sparing Nerve Blocks for Shoulder Surgery

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Abstract: Shoulder surgery can result in significant postoperative pain. Interscalene brachial plexus blocks (ISBs) constitute the current criterion standard for analgesia but may be contraindicated in patients with pulmonary pathology due to the inherent risk of phrenic nerve block and symptomatic hemidiaphragmatic paralysis. Although ultrasound-guided ISB with small volumes (5 mL), dilute local anesthetic (LA) concentrations, and LA injection 4 mm lateral to the brachial plexus have been shown to reduce the risk of phrenic nerve block, no single intervention can decrease its incidence below 20%. Ultrasound-guided supraclavicular blocks with LA injection posterolateral to the brachial plexus may anesthetize the shoulder without incidental diaphragmatic dysfunction, but further confirmatory trials are required. Ultrasound-guided C7 root blocks also seem to offer an attractive, diaphragm-sparing alternative to ISB. However, additional large-scale studies are needed to confirm their efficacy and to quantify the risk of periforaminal vascular breach. Combined axillary-suprascapular nerve blocks may provide adequate postoperative analgesia for minor shoulder surgery but do not compare favorably to ISB for major surgical procedures. One intriguing solution lies in the combined use of infraclavicular brachial plexus blocks and suprascapular nerve blocks. Theoretically, the infraclavicular approach targets the posterior and lateral cords, thus anesthetizing the axillary nerve (which supplies the anterior and posterior shoulder joint), as well as the subscapular and lateral pectoral nerves (both of which supply the anterior shoulder joint), whereas the suprascapular nerve block anesthetizes the posterior shoulder. Future randomized trials are required to validate the efficacy of combined infraclavicular-suprascapular blocks for shoulder surgery.

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Among orthopedic procedures, shoulder surgery results in the most intense postoperative pain. In a recent survey, patients reported higher worst dynamic pain scores after total shoulder arthroplasty, stabilization procedure, biceps tenotomy/tenodesis, rotator cuff repair, and acromioclavicular resection than following revision arthroplasty of the hip and knee.[1] In the absence of neuraxial and peripheral nerve blocks, opioid consumption after shoulder surgery has been purported to rival the one recorded for thoracotomy.[2] Interscalene brachial plexus blocks (ISBs) constitute the current criterion standard for analgesia after shoulder procedures.[2,3] Compared with parenteral opioids, ISB results in lower pain scores, improved patient satisfaction, and a shorter hospital stay.[3] The most common adverse effect after ISB remains the occurrence of ipsilateral phrenic nerve block. Urmey et al[4,5] have previously demonstrated that ISB results in a 100% incidence of hemidiaphragmatic paralysis (HDP), as well as 27% decreases in forced vital capacity (FVC) and forced expiratory volume at 1 second. Although well tolerated by healthy subjects,[6] HDP becomes a prohibitive risk for patients with pulmonary pathology, who may be unable to withstand the 30% reduction in FVC. Paradoxically, these are the very patients who would benefit most from peripheral nerve blocks, as systemic opioids will further compromise oxygenation and ventilation. In recent years, considerable efforts have been deployed to develop quadriceps-sparing nerve blocks for total knee replacement.[7] Inexplicably, diaphragm-sparing blocks for shoulder surgery have received less attention.[8] This unfortunate situation needs remedy, as HDP can be as deleterious as quadriceps paralysis. Viable diaphragm-sparing alternatives to ISB should achieve 3 separate and distinct goals: adequate surgical anesthesia (without general anesthesia), adequate postoperative analgesia, and low incidence of HDP.

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BONY AND CUTANEOUS INNERVATION OF THE SHOULDER

The shoulder joint is innervated by multiple peripheral nerves.[9,10] The anterior aspect of the joint is supplied by the subscapular and axillary nerves (both of which originate from the posterior cord) and the lateral pectoral nerve (which originates from the lateral cord).[10] The posterior shoulder joint is innervated by the suprascapular nerve, as well as small branches of the axillary nerve.[10] In addition to the shoulder joint itself, adjacent soft tissues also receive innervation from the brachial plexus, ie, the rotator cuff (suprascapular and subscapular nerves), subcoracoid bursa (subscapular nerve), subacromial bursa (lateral pectoral and suprascapular nerves), coracoclavicular ligament (lateral pectoral nerve), coracohumeral ligament (suprascapular nerve), and coracoacromial ligament (suprascapular nerve).[9,10] Of the peripheral nerves that supply the shoulder and its contiguous structures, the suprascapular nerve originates from the most proximal section of the brachial plexus (ie, superior trunk). Thus, for shoulder surgery, the operator must target the brachial plexus at the level of its trunks. This is usually accomplished with an interscalene (or supraclavicular) approach.

Cutaneous innervation of the "cape region" overlying the shoulder joint is separate from the brachial plexus and mediated by the supraclavicular nerves (which originate from the superficial cervical plexus). Therefore, for shoulder surgery to be carried out solely with peripheral nerve blocks, brachial plexus blocks must be combined with superficial (or intermediate) cervical plexus blocks in order to provide coverage for skin incision and closure. Intermediate and superficial plexus blocks are easily performed with ultrasound (US) guidance and local anesthetic (LA) infiltration along the posterior border of the sternocleidomastoid muscle, respectively.[11]

INTERSCALENE BLOCKS AND HEMIDIAPHRAGMATIC PARALYSIS

Hemidiaphragmatic paralysis after ISB results from 2 possible mechanisms: rostral LA spread toward the C3-C5 nerve roots or anterior LA migration from the interscalene groove toward the phrenic nerve (which travels along the ventral surface of the anterior scalene muscle).[12] Prior to the routine implementation of US guidance, large LA volumes (30–45 mL) were commonly used for ISB. Historically, various strategies have been employed to limit the anterior and cephalad LA spread. In the first randomized controlled trial (RCT), decreasing the LA volume from 45 to 20 mL for paresthesia-guided ISB did not alleviate the impairment in diaphragmatic excursion, FVC, or forced expiratory volume at 1 second.[13] Furthermore decreasing the ropivacaine concentration from 0.75% to 0.5% provided no benefits.[14] Subsequently, Urmey et al[15] and Bennani et al[16] proposed proximal digital compression in order to decrease the rostral migration of LA molecules: this maneuver also failed to prevent HDP. Finally, Sala-Blanch et al[17] used both a lower LA volume (20 mL) and proximal digital pressure: again, the combined interventions failed to decrease the incidence of phrenic nerve block.[17] Thus, prior to the advent of US, HDP was a recognized, but inevitable, complication following ISB.

By enabling the operator to visualize the needle, nerve, and LA spread, US has revolutionized the practice of regional anesthesia.[18] Compared with conventional neurostimulation, the addition of US conferred a 6-fold decrease in the minimal LA volume required for successful analgesia after ISB in 50% of patients (ie, MEV50).[19] Since 2011, multiple dose-finding trials using ropivacaine 0.75% or adrenalized bupivacaine 0.5% have reported successful surgical anesthesia[20] or satisfactory sensorimotor block[21,22] with US and very low volumes (5.0–7.0 mL). These encouraging results prompted many researchers to investigate the impact of US and small LA injectates on the incidence of HDP. To date, 4 RCTs (combined n = 160) have tackled the issue[23–26] (Table 1). Despite methodological differences (eg, type of LA, presence/absence of confirmatory neurostimulation, detection of HDP with US/chest radiograph), the results have been remarkably consistent: compared with conventional volumes (10–20 mL), US-guided low-volume injectates (5 mL) result in a 50% decrease in the rate of ipsilateral phrenic nerve block. The lowest reported incidence of HDP (27%) belongs to Stundner et al,[26] who used ropivacaine 0.75% and an injection target behind the C5–C6 nerve roots, between the brachial plexus and the middle scalene muscle.

Interscalene blocks are commonly performed at the C6 level (cricoid cartilage).[30] In this location, the phrenic nerve is situated a mere 0.18 cm anterior to the brachial plexus.[12] As the 2 neural structures move caudally, they diverge from each other at a rate of 3 mm for every centimeter below the cricoid cartilage.[12] This simple anatomical fact may explain an intriguing finding reported by Boezaart et al.[31] In 1999, the latter performed an ISB in 40 patients at the level of the cricoid cartilage. After locating the brachial plexus with neurostimulation, they advanced a stimulating perineural catheter beyond the needle tip in a cephalocaudal direction along the interscalene groove. Subsequently, the authors bolused the catheter with 20 mL of bupivacaine 0.5%. This “caudad” version of ISB resulted in a 20% incidence of HDP.[31]

In recent years, a new crop of studies has started to examine alternate methods to circumvent phrenic nerve block with US-guided ISB (Table 1). In 2016, Palhais et al[27] compared LA deposition between the C5–C6 roots (ie, subfascial injection) versus a target point situated 4 mm lateral to the sheath of the brachial plexus (ie, extrafascial injection). These authors reported comparable postoperative analgesia but found a significant decrease in the incidence of HDP with extrafascial LA injection (21% vs 90%; $P < 0.001$).[27] Local anesthetic dose results from the mathematical product of volume and concentration. Because volumes as low as 5 mL cannot prevent phrenic blockade, trials have started to investigate dilute LA concentrations. In 2013, Thackeray et al[28] compared US-guided ISB with adrenalized bupivacaine 0.25% and bupivacaine 0.125%. These authors reported similar postoperative opioid consumption and a lower incidence of HDP with bupivacaine 0.125% (21% vs 78%; $P = 0.008$). Similarly, Wong et al[29] compared ropivacaine 0.2% and 0.1% for US-guided ISB. Again, the more dilute concentration resulted in similar analgesia coupled with a decreased rate of HDP (35% vs 67%; $P = 0.03$).

In summary, the available literature does not support the use of concurrent digital pressure with ISB in order to prevent HDP. However, US-guided low injectate volumes (5 mL), dilute LA concentrations, and LA injection 4 mm lateral to the brachial plexus have all been shown to reduce the risk of phrenic nerve block. Unfortunately, no single intervention can decrease the rate of HDP below 20%. Although theoretically impressive, a 20% rate of phrenic blockade provides minimal benefits in clinical practice. Prevention of HDP may be philosophically akin to prevention of pregnancy. It is a binary, all-or-nothing phenomenon: any (small) risk constitutes a prohibitive risk. For instance, when confronted with patients with severe pulmonary pathology, no prudent anesthesiologist would willingly roll the dice: a 20% risk signifies that, 1 time out of 5, the operator loses the gamble, and the patient requires urgent intubation as severe dyspnea sets in.[32] Therefore, for ISB to be safely used in patients with decreased pulmonary reserve, future trials must determine if (perhaps) combining the different proven modalities (ultralow volumes *and* dilute LA concentration *and* injection away from the brachial plexus) could reliably spare the phrenic nerve while providing sufficient surgical anesthesia and postoperative analgesia for shoulder surgery.

C7 NERVE ROOT BLOCKS AND HEMIDIAPHRAGMATIC PARALYSIS

In 2009, Renes et al[33] speculated that US-guided LA injection lateral and posterior to the C7 nerve root would result in a decreased incidence of phrenic blockade compared with ISB. These authors enrolled 30 patients undergoing elective shoulder surgery under general anesthesia and randomized them to ISB or C7 nerve root block (using 10 mL of ropivacaine 0.75%). Renes et al[33] observed that, despite similar sensory success rates (93%–100%) and postoperative opioid consumption, C7 root block was associated with a lower rate of HDP (13% vs 93%; $P < 0.001$).[33] The following year, Renes et al[34] proceeded to elucidate the minimum volume of ropivacaine 0.75% required for C5-C6 sensory block after US-guided C7 root block. They reported the MEV50 to be 2.9 mL. Interestingly, in their dose-finding study (n = 20), all volumes were kept below 6 mL, and no instance of phrenic block occurred.[34]

Based on the limited evidence available, US-guided C7 nerve root blocks seem to offer an attractive, diaphragm-sparing analgesic alternative to ISB. Further confirmatory trials are required to validate their efficacy in terms of surgical anesthesia. More importantly, because of the high prevalence of blood vessels surrounding the C7 foramen,[35] large studies are needed to quantify the risk of vascular breach.

SUPRACLAVICULAR BLOCKS AND HEMIDIAPHRAGMATIC PARALYSIS

Supraclavicular blocks (SCBs) provide a reliable alternative to ISBs for shoulder surgery.[36] However, HDP remains problematic. With traditional adjuncts (ie, elicitation of paresthesia or neurostimulation), the incidence of phrenic nerve block ranges from 50% to 67%.[37–41] With US guidance, reported rates of HDP vary between 0% and 34%.[41,42] In 1 RCT, Petrar et al[42] reported a 34% incidence of HDP with a 30-mL volume and a multiple-injection technique. In contrast, Renes et al[41] avoided HDP altogether by restricting LA injection to the “corner pocket”

TABLE 1. Effects of LA Volume, Concentration, and Injection Distance on the Incidence of HDP for US-Guided Interscalene Block

Study	N	Volume (mL)	LA	Site of Injection	Concomitant NS	Incidence of HDP	Diagnosis of HDP	Comments
Riazi et al[23]	40	20 vs 5	R 0.5%	Posterior or between C5-C6 roots	Y	100% (20 mL) 45% (5 mL)	US 30 min after ISB	GA for intraoperative management No intergroup differences in postoperative pain scores, intraoperative/postoperative opioid consumption, sleep quality, and patient satisfaction
Sinha et al[24]	30	20 vs 10	R 0.5% and epi 2.5 μg/mL	Between C5-C6 roots	Y	93% (for both groups)	US 15 min after ISB	GA for intraoperative management No intergroup differences in block duration, intraoperative/postoperative opioid consumption, and PACU stay
Lee et al[25]	60	10 vs 5	R 0.75%	Behind C5-C6 roots	N	66% (10 mL) 33% (5 mL)	CXR in PACU	GA for intraoperative management No intergroup differences in time to first analgesic request, intraoperative fentanyl consumption, postoperative pain scores, postoperative tramadol consumption, and patient satisfaction
Stundner et al[26]	30	20 vs 5	R 0.75%	Posterior to C5-C6 roots, between brachial plexus and middle scalene muscle	N	53% (20 mL) 27% (5 mL)	US in PACU	GA for intraoperative management No intergroup differences in block onset, block quality, intraoperative fentanyl consumption, and postoperative pain scores
Palhais et al[27]	39	20	B 0.5% epi 5 μg/mL	Behind C5-C6 roots (intrafascial injection) vs 4 mm lateral to the brachial plexus sheath (extrafascial injection)	N	90% (subfascial) 21% (extrafascial)	US (30 min after ISB)	GA for intraoperative management No intergroup differences in intraoperative/postoperative opioid consumption, postoperative pain scores, and patient satisfaction Extrafascial group: slower sensorimotor onset, less hoarseness, fewer paresthesias, better spirometry parameters at 30 min
Thackeray et al[28]	28	20	B 0.25% epi 5 μg/mL vs B 0.125% epi 5 μg/mL	Between middle scalene muscle and brachial plexus	N	78% (B 0.25%) 21% (B0.125%)	US in PACU	GA for intraoperative management No intergroup differences in intraoperative/postoperative opioid consumption and patient satisfaction
Wong et al[29]	47	20	R 0.1% vs R 0.2%	Not defined	Y	67% (R 0.2%) 35% (R 0.1%)	US in PACU	GA for intraoperative management No intergroup differences in PACU pain scores, length of stay, and opioid consumption R 0.1%: shorter block duration and higher opioid requirement in first 72 h

B indicates bupivacaine; CXR, chest radiographic exam; Epi, epinephrine; GA, general anesthesia; HDP, hemidiaphragmatic paralysis; ISB, interscalene block; LA, local anesthetic; N, no; NS, neurostimulation; PACU, Post Anesthesia Care Unit; R, ropivacaine; US, ultrasound; Y, yes.

(ie, intersection of the first rib and subclavian artery), as well as the posterolateral aspect of the brachial plexus and limiting the LA volume to 20 mL. Unfortunately, Renes et al[41] only enrolled patients undergoing elbow, forearm, and hand surgery: thus, future RCTs should determine if surgical anesthesia and postoperative analgesia could be achieved for shoulder surgery as well.

An intriguing method to prevent phrenic blockade with SCB was proposed by Cornish[43] in 2000. With the "bent-needle" technique, the brachial plexus is initially targeted in the supraclavicular fossa; subsequently, a perineural catheter is advanced several centimeters beyond the tip of the cannula. In a series of 100 patients, Cornish et al[44] reported a 1% incidence of HDP after the initial LA bolus. The bent-needle technique seems to elegantly circumvent phrenic blockade by positioning the catheter tip (and injection point) in the infraclavicular fossa, inferomedial to the coracoid process and far from the phrenic nerve.[45]

In summary, the available literature does not support the use of high-volume, multiple-injection SCB when HDP is a clinical concern. However, the bent-needle technique and US-guided LA injection posterolateral to the brachial plexus with low volumes (20 mL) may prevent incidental phrenic nerve block. Further investigation is required to determine if surgical anesthesia/analgesia for shoulder surgery could be achieved with 20 mL.

DISTAL NERVE BLOCKS FOR SHOULDER SURGERY

Distal blocks for shoulder surgery include suprascapular nerve blocks (SSBs) and axillary nerve blocks (AXBs). Although SSBs do not provide complete coverage or surgical anesthesia of the shoulder joint, they have been used for postoperative analgesia after shoulder surgery. Expectedly, SSBs outperform sham blocks.[46,47] Furthermore, compared with subacromial or intra-articular LA injection, SSBs offer better postoperative pain control, increased range of motion, and improved patient satisfaction.[48,49] However, SSB results in inferior analgesia compared with ISB.[49] In fact, Neal et al[50] concluded that "SSB adds minimal value to a primary ISB anesthetic for nonarthroscopic shoulder surgery." In 2014, Lee et al[51] tackled the issue by combining AXB and SSB in patients undergoing arthroscopic rotator cuff repair. Compared with SSBs alone, the authors found that combined AXB-SSB resulted in lower pain scores (until 24 hours), improved patient satisfaction (until 36 hours), and less rebound pain.

The idea of combining AXB and SSB for shoulder surgery can be credited to Price.[52] In 2007, the latter described his experience in a series of 70 patients undergoing various shoulder surgical procedures under general anesthesia and receiving AXB-SSB for postoperative analgesia. Analysis of the first 40 cases revealed that 57% of subjects required no opioid supplementation in the postanesthesia care unit. Subsequently, Checcucci et al[53] reported successful surgical anesthesia with combined AXB-SSB in 20 carefully selected patients undergoing acromioplasty, bursectomy, supraspinatus tendon repair, or long-head biceps tenotomy. Despite the initial success, Checcucci et al[53] and Price[52,54] cautioned that AXB-SSB should be reserved for minor arthroscopic surgery (eg, acromioplasty) because important structures, like the rotator cuff, also receive supply from other nerves, which are not anesthetized with AXB-SSB. Nonetheless, 2 RCTs (combined n = 129) set out to compare ISB and combined AXB-SSB in patients undergoing arthroscopic shoulder surgery (mainly rotator cuff repair) under general anesthesia.[55,56] The results of both trials confirmed Checcucci and colleagues' and Price's suspicion. Compared with ISB, AXB-SSB resulted in higher intraoperative opioid requirements,[56] increased pain/opioid consumption in the postanesthesia care unit,[55,56] and decreased patient satisfaction at 6 hours.[56] However, analgesic duration was longer, and pain scores were lower at 24 hours with AXB-SSB.[55,56] Unfortunately, neither study assessed the rate of HDP.

CURRENT STATE OF KNOWLEDGE

To this day, HDP remains a vexing problem after single-injection ISB. In the last 10 years, 3 possible diaphragm-sparing strategies have been investigated with RCTs, and one can be inferred from the existing trials (ISB with low volume, dilute LA, and injection 4 mm lateral to the brachial plexus) (Table 2). Of the 3 studied modalities (combined AXB-SSB, C7 root block, and SCB with LA injection posterolateral to the brachial plexus), none has convincingly been shown to provide effective surgical anesthesia. In terms of postoperative analgesia, C7 root blocks offer the most promise, as they appear equivalent to the current analgesic criterion standard (ISB). However, the potential risk of periforminal vascular breach mandates further large-scale validation. Combined AXB-SSB may provide adequate postoperative analgesia for minor shoulder surgery but does not compare favorably to ISB for major surgical procedures. In theory, SCB (with

TABLE 2. Current State of Knowledge for Diaphragm-Sparing Nerve Blocks and Shoulder Surgery

Diaphragm-Sparing Nerve Block	Surgical Anesthesia	Postoperative Analgesia	Low Incidence of HDP	Comments
AXB-SSB	TBD	Yes (for minor shoulder surgery)	Yes	Postoperative analgesia inferior to ISB for major shoulder surgery Incidence of HDP not formally assessed but presumed to be 0% because the axillary and suprascapular nerves do not travel in the vicinity of the phrenic nerve
C7 root block	TBD	Yes	Yes (13%)	Risk of vascular breach TBD Incidence of HDP may be lower if LA volume <6 mL: TBD
SCB with 20-mL volume and LA injection posterolateral to the brachial plexus	TBD	TBD	Yes (0%)	
ISB with low volume, dilute LA and injection 4 mm away from the brachial plexus	TBD	TBD	TBD	Inferred from the existing RCTs

AXB indicates axillary nerve block; HDP, hemidiaphragmatic paralysis; ISB, interscalene block; LA, local anesthetic; RCT, randomized controlled trial; SCB, supraclavicular block; SSB, suprascapular nerve block; TBD, to be determined.

LA injection posterolateral to the brachial plexus) could achieve comparable analgesia to ISB; however, further confirmatory RCTs are required. In terms of HDP occurrence, AXB-SSB and SCB (with LA injection posterolateral to the brachial plexus) appear to sidestep the issue (HDP risk = 0%). At 13%, the incidence of phrenic block following C7 root blocks may still be prohibitively high. Therefore, future trials should determine if it could reach 0% with ultralow LA volumes (<6 mL).

A NEW SOLITION TO AN OLD PROBLEM?

In science, new solutions to old problems rarely materialize out of nowhere. In most instances, they slowly build on preexisting work and develop from preliminary observations. Thus, a careful review of the shoulder's innervation and a critical reading of the published literature suggest that there may exist yet another method to anesthetize the shoulder joint and circumvent HDP.

From an anatomical standpoint, the nerves that supply the shoulder originate from the trunks (suprascapular nerve) or cords (lateral pectoral, subscapular, and axillary nerves) of the brachial plexus. Furthermore, as the brachial plexus and phrenic nerve travel caudally, the distance between the 2 neural structures starts to increase. These simple anatomical facts would explain why, using his bent-needle technique, Cornish et al[45] achieved satisfactory coverage of the shoulder joint, even though the catheter tip was positioned in the infraclavicular fossa at the level of the cords of the brachial plexus. They would also support separate observations by Boezaart et al,[31] Cornish et al[43,44] that perineural catheters threaded caudally along the brachial plexus invariably result in lower rates of HDP.

From a clinical standpoint, previous works by Price,[52] Checcucci et al,[53] Pitombo et al,[55] and Dhir et al[56] demonstrate that nerve blocks for shoulder surgery need not be unique, all encompassing procedures. In other words, they could be elegantly partitioned into separate components. All these authors elected to combine SSB and AXB to anesthetize the posterior and anterior aspects of the shoulder, respectively. Unfortunately, their decision ignored the important contributions of the lateral pectoral and subscapular nerves. However, this oversight could be easily corrected: one need simply combine SSB with an infraclavicular brachial plexus block (ICB). The latter would target the brachial plexus at the level of the cords,[30] thus providing an efficient method to block the lateral pectoral, subscapular, and axillary nerves.

A review of the literature reveals that the combination of ICB and SSB has been previously reported. In 2003, Martinez et al[57] described the case of a patient with uncontrolled bronchial asthma who underwent repair of a traumatic humeral head fracture with combined ICB-SSB. Despite the successful outcome (ie, surgical anesthesia) and obvious implications for shoulder surgery, combined ICB-SSB was forgotten thereafter and only seems to await rediscovery. However, caution should be used, and initial enthusiasm tempered. Before advocating the routine use of combined ICB-SSB for shoulder surgery in patients with decreased pulmonary reserve, multiple RCTs need to be conducted, and several questions answered. First, combined ICB-SSB must be compared with the criterion standard (ISB) both in terms of efficacy (surgical anesthesia and postoperative analgesia) and efficiency (performance and onset times). Second, the risk of HDP associated with US-guided ICB requires further elucidation. In a previous RCT, Petrar et al[42] reported a 3% incidence of HDP with US-guided ICB. However, these authors used a 30-mL volume of ropivacaine 0.5%. For the purpose of shoulder surgery, one could speculate that a smaller LA injectate would be required, as the ICB only needs to anesthetize the lateral and posterior cords. Furthermore, the new "costoclavicular" technique for ICB may enable an even more targeted block of the lateral and posterior cords.[58] Third, studies should determine the optimal diaphragm-sparing alternative to ISB by comparing ICB-SSB, C7 nerve root block, and SCB (with LA injection posterolateral to the brachial plexus). Expectedly, these trials can take place only after the individual clinical validation of each modality. Finally, future trials should also investigate the rate of HDP for continuous ICB-SSB. While a single-injection technique could initially spare the phrenic nerve, over time, HDP may occur with continuous ICBs because of LA accumulation.

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