Risk profiles of common brachial plexus block sites: results from the net-ra registry

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ABSTRACT

Introduction Regional anesthesia is frequently used for upper limb surgeries and postoperative pain control. Different approaches to brachial plexus blocks are similarly effective but may differ in the frequency and severity of iatrogenesis. We, therefore, examined large-scale registry data to explore the risks of typical complications among different brachial plexus block sites for regional anesthesia.

Methods 26,947 qualifying adult brachial plexus blocks (2007–2022) from the Network for Safety in Regional Anesthesia and Acute Pain Therapy registry were included in a retrospective cohort analysis. Interscalene, supraclavicular, infraclavicular, and axillary approaches were compared for block failure and bloody punctures using generalized estimating equations. For continuous procedures, we analyzed the influence of the approach on catheter failure, neurological disorders, and infections.

Results The axillary plexus block had the highest risk of block failure (adjusted OR, 2.3; 95% CI 1.02 to 5.1; p=0.04), catheter failure (adjusted OR, 1.4; 95% CI 1.1 to 2.0; p=0.02), and neurological dysfunction (adjusted OR, 3.0; 95% CI 1.5 to 5.9; p=0.002). There was no statistically significant difference among block sites for bloody punctures, while infraclavicular blocks had the highest odds for catheter-related infections.

Discussion The axillary approach to the brachial plexus had the highest odds for block failure and neurological dysfunction after catheter placement, as well as a significant risk for catheter failure. However, considering that the axillary approach precludes other complications such as pneumothorax, none of the four common approaches to the brachial plexus has a fundamentally superior risk profile.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Interscalene, supraclavicular and infraclavicular, and axillary brachial plexus blocks differ in the incidence of typical complications such as failure rates, bloody punctures, post-block neurological dysfunction or catheter infections. One may conclude that these differences might be interpreted as the supposed superiority of a particular block site.

WHAT THIS STUDY ADDS

⇒ Based on large-scale multicentric registry data, representing incidences of typical block-related complications under real-world clinical conditions, no block approach had a fundamentally superior risk profile.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our comparison of the typical complications of brachial plexus block approaches informs clinical providers to select the best approach based on provider experience, patient characteristics, and surgery.

INTRODUCTION

Brachial plexus blocks are well established as effective regional anesthesia during upper limb surgery and for postoperative pain control. Four approaches are commonly used to block the brachial plexus: the interscalene, supraclavicular, infraclavicular, and the axillary site. For many surgeries, blocks can be used interchangeably. For example, the supraclavicular block is a proven alternative to the interscalene block for shoulder surgery.[1 2] Supraclavicular and infraclavicular approaches are equally effective for surgery of the distal arm, elbow, forearm, or hand.[3 4] Axillary plexus blocks as well as supraclavicular and infraclavicular blocks are suitable for upper extremity surgery of the elbow and distally.[5] For this reason, the block selected often depends on the preferences of the attending anesthesiologist and in-house standards.

The benefit of regional anesthesia for postoperative pain control is well established[6 7]; however, regional anesthesia has risks. A systematic review and meta-analysis of 25 randomized controlled clinical trials that enrolled 2012 patients found no difference in vascular punctures, transient neurological injury, symptomatic diaphragmatic paralysis, or pneumothorax between the infraclavicular, supraclavicular, or axillary approaches.[8] Randomized controlled trials represent the gold standard of scientific research, but are often not feasible for the analysis of low-incidence complications due to the large number of cases required. Multicenter registry data from routine documentation can provide the required number of cases. Though causal interference should not be drawn from retrospective analyses, real-world data reflect actual clinical practice and can provide information on the risk profile of various brachial plexus blocks.

The aim of this study was to compare the risk of typical complications for four brachial plexus block sites—interscalene, supraclavicular, infraclavicular, and axillary—by examining data from the "Network for Safety in Regional Anesthesia and Acute Pain Therapy" registry (net-ra).

Specifically, we assessed the differences in odds of block-related complications, such as bloody puncture and block failure, as well as catheter-related complications, including neurological disorders, catheter failure, and infections associated with prolonged catheter use, across the four major sites.

METHODS

Written consent for this retrospective cohort study was waived as the registry data are completely anonymous (certification of compliance with data protection laws, Saarland commissioner, March 12, 2014). Based on the submitted study protocol and statistical analysis plan, registry data were released on October 20, 2022, by the Scientific Panel of the network (www.net-ra.eu). This article adheres to the REporting of studies Conducted using Observational Routinely-collected Data guideline.[9]

The Network for Safety in Regional Anaesthesia and Acute Pain Therapy was founded in 2007 under the auspices of the German Society for Anaesthesiology and Intensive Care Medicine and the Professional Association of German Anaesthesiologists (Nürnberg, Germany). The registry collects perioperative primary data related to regional anesthesia procedures, intravenous patient-controlled analgesia, and combinations thereof.[10] The typical risks associated with the placement of a brachial plexus block, bloody puncture, block failure, pneumothorax, and local anesthetic systemic toxicity are recorded in the net-ra registry. Neurological disorders, catheter failure, signs of infection at the catheter entry site and the occurrence of Horner's syndrome or respiratory insufficiency are documented during daily postoperative rounds. As described previously, each participating hospital uses its own system for documenting regional anesthesia and its acute pain service.[11 12] Since the data of the documented treatments are routine data collected at the bedside, they are subjected to on-site quality control. Our registry provides clear definitions of how the individual items are to be collected at participating hospitals. Uploaded data are not automatically checked for completeness since not all fields are required. Data are transmitted to the registry in anonymized form.

Data extraction

The registry data set included 42,801 brachial plexus blocks from January 01, 2007, to October 20, 2022 (figure 1). Since we considered the method by which the regional anesthesia was

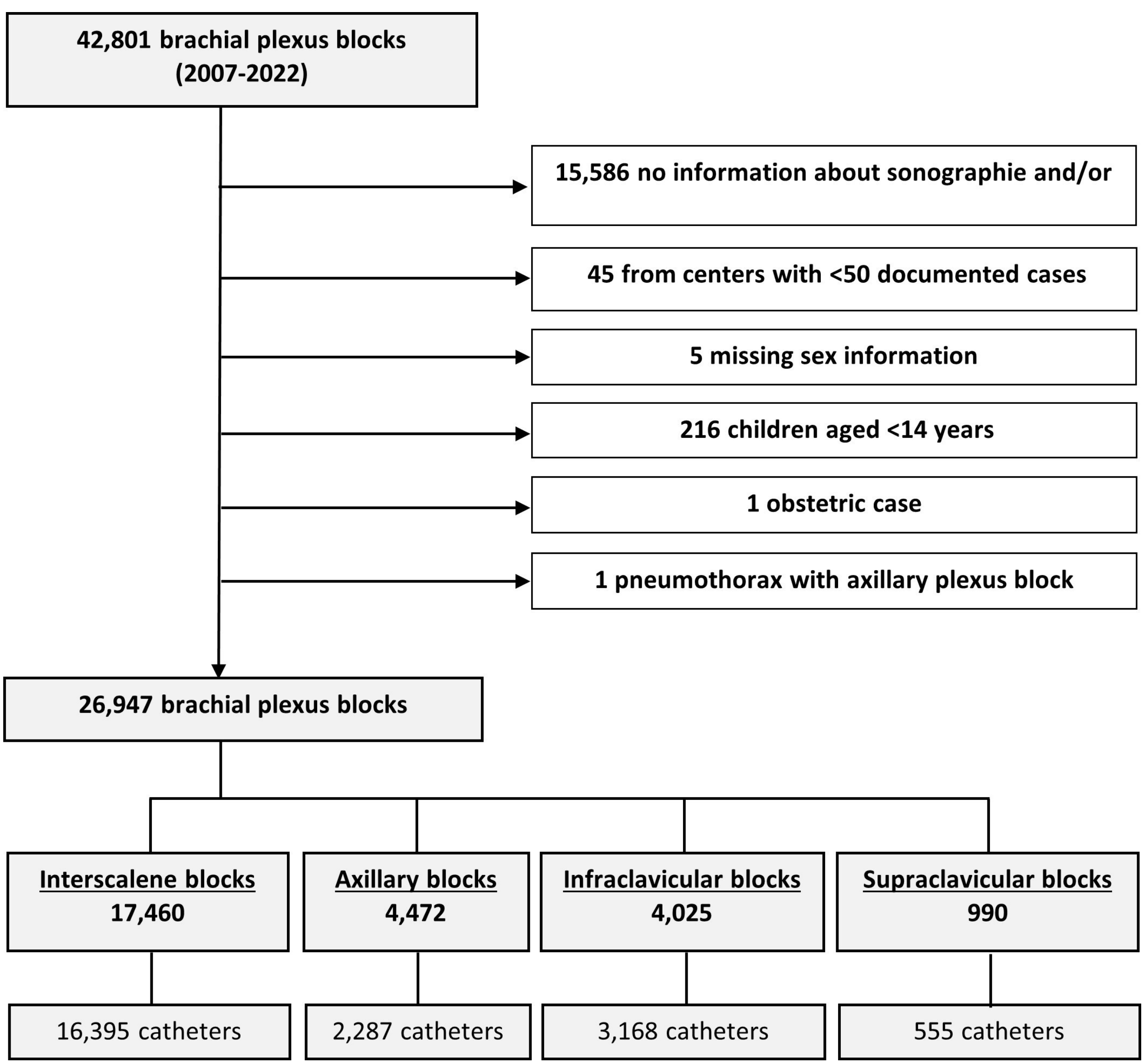

Figure 1 Flowchart of data selection.

applied (sonography and/or nerve stimulation) to be an essential factor in our analyses, we included only blocks for which this information was available (n=27,215). We limited our analysis to centers that contributed at least 50 cases during the observation period, resulting in 25 eligible centers. We excluded blocks performed for obstetric cases or those done in children (14 years or younger), as well as five cases missing information on sex. An axillary plexus block complicated by pneumothorax was also excluded as anatomically implausible.

Measurements

For the analysis of complications occurring during block placement, we considered both single shot and catheter procedures and analyzed the dichotomous occurrence (yes/no) of bloody punctures and block failures. The Network for Safety in Regional Anesthesia and Acute Pain Therapy registry defines a bloody puncture as any blood aspiration through the needle or catheter during regional anesthesia placement (online supplemental file 1). Block failure was defined as discontinuation of the procedure due to difficult anatomical conditions, lack of patient compliance, the need to switch to general anesthesia, or the need for supplemental measures (analgosedation or an additional block). For the analysis of block failure, we excluded patients who received a block under general anesthesia, as the effect of regional anesthesia could not be isolated in this case. Due to insufficient case numbers, we were unable to assess the risk for pneumothorax and local anesthetic systemic toxicity.

For the analysis of postoperative complications, we included only blocks where indwelling catheters were placed for continuous analgesia. All complications were considered dichotomously (yes/no). We defined neurological disorders as any of: patient-reported paresthesia, neuropathic pain, or hypesthesia in the area covered by the regional anesthesia—with hypesthesia considered block-related at the earliest 24 hours after placement to exclude residual effects of the initial dose of local anesthetic. Catheter failure was assumed if there was a lack of analgesia in the area targeted by regional anesthesia (due to anatomical variation or catheter malposition) or if continuous regional anesthesia had to be terminated due to unresolvable problems with the catheter (eg, dislodgement, migration, non-recoverable occlusion or damage). Infections during prolonged catheter use were defined as the occurrence of mild (presence of two of redness, swelling, and pain), moderate (mild infection plus two of elevated C-reactive protein, leukocytosis, fever, or pus at the puncture site) or severe (need for surgical intervention including incisions or revisions) signs of infection at the catheter entry site. This classification is action-based, which means that the following measures should be carried out without necessarily requiring the detection of infectious agents: removal of the catheter for mild, administration of antibiotics for moderate, and surgical sanitation for severe symptoms. As infections at the catheter entry site were previously observed to increase from postoperative day 4 onwards,[11] we considered only catheters that had been used for more than 72 hours. We limited the observation period for infections to 14 days postoperatively, as almost all regional anesthesia catheters are removed in that time frame.

The confounding factors to be considered in our multivariable models were defined a priori after a thorough literature review. We considered age, sex, American Society of Anesthesiologists (ASA) physical status greater than 2, obesity with a body mass index (BMI) greater than 30, year of procedure, guidance techniques (sonography, nerve stimulation, or dual guidance), use of catheters (vs single-shot), antithrombotic therapy, multiple skin punctures, diabetes, immunosuppression, antibiotic therapy or prophylaxis prior to regional anesthesia implementation, and pre-existing systemic infection. From this, we selected the confounders for each endpoint and the associated statistical model that are meaningful from a medical point of view, as even small, clinically insignificant group differences become statistically highly significant with very large amounts of data.

Data pre-processing

Data integrity was evaluated according to specific rules that identified and deleted incorrect data entries. Defined limits were 14–100 years for age, 150–249 cm for height, 40–249 kg for weight, and 16–85 kg/m² for BMI, corresponding to the third percentile for adolescent females and the upper limits of the registry for height and weight. Missing values for confounders were imputed using multiple imputations by chained equations[13] with five imputed data sets.

Statistical analysis

To estimate the association of the four possible block localizations of the brachial plexus on the occurrence of complications, univariable and multivariable regression models were fitted. To account for possible dependence between observations from the same hospital center (cluster effect), generalized estimating equations (GEE) with independent correlation structure were employed, providing similar point estimates as simple logistic regression, but with cluster-robust p values and CIs.

There were two reasons for using the interscalene block as a statistical reference. First, it anatomically covers the largest part of the upper extremity,[14] and second, it is the largest group. For each type of complication, a different multivariable model was used to take into account the medically relevant confounders as well as standard variables (eg, age, sex, ASA>2, BMI>30 kg/m²). Multivariable GEEs were fitted for each imputed data set and pooled according to Rubin's rule.[15]

In addition to the adjusted ORs we present adjusted percentages as the predicted risk for one example patient across different types of brachial plexus blocks derived from the fitted multivariable models. The example patient is chosen with specific characteristics to represent a "median" healthy person from our study population undergoing ultrasound-guided brachial plexus block in 2022. The predicted risk is entirely dependent on the specific covariate constellation of the patient presented and cannot be interpreted on a population level.

Analyses were performed with R V.4.3. using the following packages (among others): mice V.3.16,[13] and geepack V.1.3.9.[16]

RESULTS

Our data set comprised 26,947 brachial plexus blocks, of which almost two-thirds were interscalene blocks. Demographic and procedural data are listed in table 1. Figure 2 shows the development of the methods used for block placement during the observation period.

Axillary nerves block had the highest incidence of failure (17%), followed by supraclavicular (8%), interscalene (4%) and infraclavicular blocks (2%, table 2). Bloody punctures were infrequent and comparable across all block sites (1–2%). Neurological disorders occurred in about 1 in 10 axillary and supraclavicular blocks in the postoperative course, while the rates for interscalene (5%) and infraclavicular (2%) blocks were at most half as frequent. The affected blocks were predominantly ultrasound-guided. Intraprocedural paresthesias also occurred most frequently during ultrasound-guided procedures, but were

Table 1 Demographic and procedural data of patients with different brachial plexus block types

	Interscalene plexus n=17,460	Axillary plexus n=4,472	Infraclavicular plexus n=4,025	Supraclavicular plexus n=990	P value
Single shots, n (%)	1,065 (6)	2,185 (49)	857 (21)	435 (44)	<0.001
Catheters, n (%)	16,395 (94)	2,287 (51)	3,168 (79)	555 (56)	<0.001
Demographic data					
Male sex					
Single shots, n (%)	607 (57)	1,245 (57)	422 (49)	253 (58)	<0.001
Catheters, n (%)	8,532 (52)	1,276 (56)	2,020 (64)	305 (55)	<0.001
Median age					
Single shots, years (IQR)	56 (44–68)	56 (38–66)	56 (40–70)	60 (45–71)	<0.001
Catheters, years (IQR)	58 (49–69)	54 (39–64)	49 (35–59)	54 (42–66)	<0.001
Median BMI					
Single shots, kg×m^{-2} (IQR)	27 (24–30)	26 (23–29)	26 (23–29)	26 (23–30)	0.002
Catheters, kg×m^{-2} (IQR)	27 (24–31)	26 (23–30)	26 (24–29)	27 (24–30)	<0.001
Missing, n (%)	4,794 (28)	1,029 (23)	796 (20)	69 (7)	
ASA physical status >2					
Single shots, n (%)	239 (25)	363 (18)	129 (22)	194 (46)	<0.001
Catheters, n (%)	4,423 (31)	338 (18)	423 (17)	187 (39)	<0.001
Missing, n (%)	2,244 (13)	396 (9)	941 (23)	81 (8)	
Diabetes					
Single shots, n (%)	84 (8)	187 (9)	82 (10)	75 (17)	<0.001
Catheters, n (%)	1672 (10)	169 (7)	147 (5)	51 (9)	<0.001
Missing, n (%)	55 (0.3)	37 (1)	9 (0.2)	1 (0.1)	
Immunosuppression					
Single shots, n (%)	10 (1)	30 (1)	13 (2)	14 (3)	<0.001
Catheters, n (%)	78 (1)	22 (1)	20 (1)	12 (2)	<0.001
Preoperative infection					
Single shots, n (%)	58 (6)	7 (0.3)	8 (1)	8 (2)	<0.001
Catheters, n (%)	115 (0.7)	19 (0.8)	59 (2)	10 (2)	<0.001
Missing, n (%)	30 (0.2)	14 (0.3)	9 (0.2)	2 (0.2)	
Antibiotic prophylaxis, n (%)					
Single shots, n (%)	677 (76)	1,272 (63)	642 (84)	335 (77)	<0.001
Catheters, n (%)	10,734 (78)	1,534 (73)	2,203 (77)	368 (67)	<0.001
Missing, n (%)	2,764 (16)	358 (8)	397 (10)	7 (1)	
Antithrombotic therapy, n (%) single shots, n (%)	210 (20)	191 (9)	310 (36)	103 (24)	<0.001
Catheters, n (%)	2,664 (16)	212 (9)	278 (9)	101 (18)	<0.001
Technical data					
Use of ultrasound					
Single shots, n (%)	681 (64)	1,844 (84)	78 (9)	350 (80)	<0.001
Catheters, n (%)	9,623 (59)	1,625 (71)	767 (24)	317 (57)	<0.001
Use of nerve stimulation					
Single shots, n (%)	153 (14)	55 (3)	752 (88)	40 (9)	<0.001
Catheters, n (%)	2,661 (16)	472 (21)	788 (25)	48 (9)	<0.001
Use of dual guidance					
Single shots, n (%)	231 (22)	286 (13)	27 (3)	45 (10)	<0.001
Catheters, n (%)	4,111 (25)	190 (8)	1,613 (51)	190 (34)	<0.001
Multiple skin puncture					
Single shots, n (%)	92 (9)	278 (13)	248 (29)	46 (11)	<0.001
Catheters, n (%)	1,178 (7)	179 (8)	207 (7)	39 (7)	0.3
Missing, n (%)	11 (0.1)	2 (0)	2 (0)	1 (0.1)	
Catheter suture-fixed, n (%)	3,334 (20)	683 (30)	173 (6)	187 (34)	<0.001
Missing, n (%)	31 (0.2)	3 (0.1)	1 (0.03)	0 (0)	
Catheter tunneled, n (%)	2375 (14)	741 (32)	2,113 (67)	58 (10)	<0.001
Missing, n (%)	7 (0.04)	2 (0.09)	1 (0.03)	0 (0)	
Median year of surgery					
Single shots (IQR)	2014 (2011–2019)	2018 (2014–2020)	2012 (2010–2013)	2021 (2017–2022)	<0.001
Catheters (IQR)	2015 (2012–2018)	2016 (2014–2019)	2016 (2013–2018)	2015 (2012–2018)	<0.001

Continued

Table 1 Continued

	Interscalene plexus n=17,460	Axillary plexus n=4,472	Infraclavicular plexus n=4,025	Supraclavicular plexus n=990	P value
Specialty					
Trauma and orthopedics					
Single shots, n (%)	1,037 (97)	2,093 (96)	801 (93)	301 (69)	<0.001
Catheters, n (%)	14,429 (88)	1,632 (71)	2,403 (76)	533 (96)	<0.001
General/vascular surgery					
Single shots, n (%)	17 (2)	73 (3)	47 (6)	122 (28)	<0.001
Catheters, n (%)	29 (0.2)	20 (1)	21 (1)	7 (1)	<0.001
Other types of surgery					
Single shots, n (%)	11 (1)	19 (1)	9 (1)	12 (3)	<0.001
Catheters, n (%)	1,937 (12)	635 (28)	744 (23)	15 (3)	<0.001
Missing, n (%)	0 (0)	1 (0)	0 (0)	0 (0)	

Missing values (if any) are based on the total number of cases, unless otherwise stated; potential group differences were tested using Fisher's exact test for count data, Pearson's χ^2 test or Kruskal-Wallis rank sum test depending on the level of measurement of the observed variable.
ASA, American Society of Anesthesiologists; BMI, body mass index.

less frequent in patients who showed neurological symptoms in the postoperative course (0.1% vs 0.8 %). 86% of the cases with neurological disorders recovered until the last visit of the acute pain service. In particular, 19 (out of 22) cases of neuropathic pain, 492 (out of 548) cases of paresthesia and 551 (out of 686) cases of hypesthesia can thus be considered transient. Catheter failure was observed in 2–3% of cases, with no clinically meaningful difference between the individual block sites. The infection rate with prolonged catheter use was 4% in axillary, supraclavicular and interscalene blocks, and 7% in infraclavicular blocks. Horner‘s syndrome occurred exclusively with interscalene blocks (0.05%), and respiratory insufficiency was most frequent at this block site (0.2%).

In our adjusted model (GEE), the axillary plexus block had a significantly higher odds of failure (adjusted OR (adj.OR) 2.3; 95% CI 1.02 to 5.1; p=0.04) than the interscalene block, while the odds of block failure for supraclavicular (adj.OR 1.2; 95% CI 0.6 to 2.5; p=0.57) and infraclavicular blocks (adj.OR 0.6; 95% CI 0.2 to 2.0; p=0.42) were similar to the interscalene approach. As illustrated in figure 3, the odds for bloody punctures were comparable across all block sites (supraclavicular: adj.OR 0.7; 95% CI 0.2 to 2.4; p=0.61; infraclavicular: adj.OR 1.8; 95% CI 0.8 to 3.9; p=0.13; axillary: adj.OR 1.0; 95% CI 0.3 to 2.8; p=0.93).

The odds of postoperative neurological disorders during the postoperative course of continuous regional anesthesia was three times higher in axillary catheters than in interscalene catheters (adj.OR 3.0; 95% CI 1.5 to 5.9; p=0.002). For supraclavicular plexus catheters, the odds were more than twice as high (adj.OR 2.4; 95% CI 1.1 to 5.6; p=0.04) (figure 4). Surprisingly, the infraclavicular block more than halved the odds for neurologic complications (adj.OR 0.3; 95% CI 0.2 to 0.7; p=0.006).

Axillary catheters had 40% higher odds of failure (adj.OR 1.4; 95% CI 1.1 to 2.0; p=0.02), while infraclavicular and supraclavicular catheters had similar odds of failure compared with the interscalene region (adj.OR 1.0; 95% CI 0.7 to 1.5; p=0.95, respectively, adj.OR 1.6; 95% CI 0.6 to 4.5; p=0.4) (figure 4).

The infraclavicular catheter had the highest odds for infections with prolonged catheter use (adj.OR 1.9, 95% CI 1.4 to 2.6, p<0.001) (figure 4), while axillary (adj.OR 1.0, 95% CI 0.6 to 1.5, p=0.88) and supraclavicular catheters (adj.OR 1.1, 95% CI 0.4 to 2.9, p=0.91) had similar odds compared with interscalene catheters. Detailed results of the statistical models are presented in the online supplemental files 2 and 3.

Figure 5 shows predicted risks for a representative sample patient in a contemporary context.

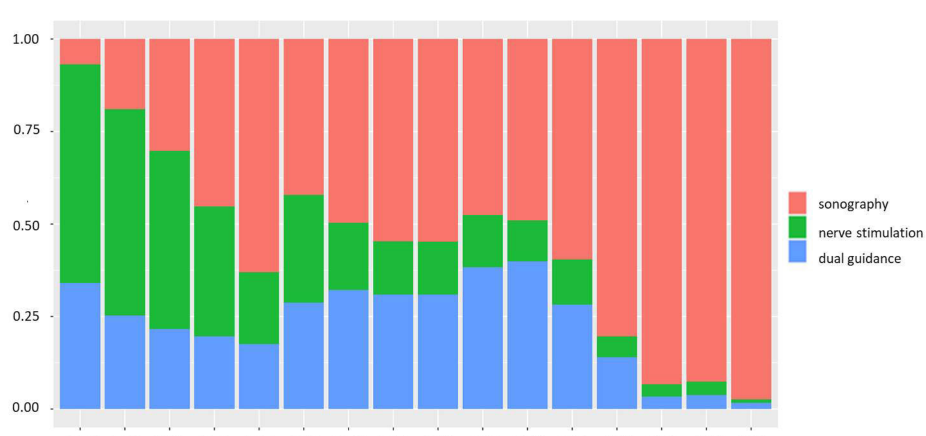

Figure 2 Development over time of the methods used for the placement of brachial plexus blocks. Methods are shown as cumulative relative frequencies.

Table 2 Number of documented complications with different types of brachial plexus blocks

Number of blocks	Interscalene plexus n=17,460	Axillary plexus n=4,472	Infraclavicular plexus n=4,025	Supraclavicular plexus n=990
Block placement*				
Block failure				
Single shot, n (%)	152 (14)	411 (19)	38 (4)	42 (10)
Catheters, n (%)	551 (3)	343 (15)	21 (1)	33 (6)
Ultrasound-guided, n (%)	674 (7)	730 (21)	15 (2)	70 (11)
Nerve stimulation, n (%)	16 (1)	15 (3)	39 (3)	4 (5)
Dual guidance, n (%)	13 (0.3)	9 (2)	5 (0.3)	1 (0.4)
Bloody puncture				
Single shot, n (%)	10 (1)	9 (0.4)	61 (7)	3 (1)
Catheters, n (%)	126 (1)	31 (1)	17 (1)	5 (1)
Ultrasound-guided, n (%)	81 (1)	29 (1)	1 (0.1)	2 (0.3)
Nerve stimulation, n (%)	15 (1)	8 (2)	73 (5)	2 (2)
Dual guidance, n (%)	40 (1)	3 (1)	4 (0.2)	4 (2)
Pneumothorax				
Single shot, n (%)	0 (0.0)	0 (0.0)	1 (0.1)	1 (0.2)
Catheters, n (%)	2 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ultrasound-guided, n (%)	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Nerve stimulation, n (%)	0 (0.0)	0 (0.0)	1 (0.1)	1 (1.1)
Dual guidance, n (%)	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Local anesthetic systemic toxicity				
Single shot, n (%)	0 (0.0)	1 (0.0)	1 (0.1)	0 (0.0)
Catheters, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Ultrasound-guided, n (%)	0 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)
Nerve stimulation, n (%)	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)
Dual guidance, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Postoperative course*				
Neurological disorders† n (%)	768 (5)	275 (12)	49 (2)	53 (10)
Hypesthesia, n (%)	454 (3)	171 (8)	29 (1)	32 (6)
Paresthesia, n (%)	370 (2)	130 (6)	22 (1)	26 (5)
Neuropathic pain, n (%)	12 (0.1)	3 (0.1)	4 (0.1)	3 (1)
Ultrasound-guided, n (%)	359 (4)	238 (15)	27 (4)	41 (13)
Nerve stimulation, n (%)	228 (9)	25 (5)	9 (1)	4 (8)
Dual guidance, n (%)	181 (4)	12 (6)	13 (1)	8 (4)
Catheter failure n (%)	326 (2)	66 (3)	62 (2)	16 (3)
Ultrasound-guided, n (%)	177 (2)	48 (3)	8 (1)	14 (4)
Nerve stimulation, n (%)	72 (3)	13 (3)	20 (3)	0 (0.0)
Dual guidance, n (%)	77 (2)	5 (3)	34 (2)	2 (1)
Horner's syndrome n (%)	8 (0.05)	0 (0.0)	0 (0.0)	0 (0.0)
Ultrasound-guided, n (%)	6 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)
Nerve stimulation, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Dual guidance, n (%)	2 (0.02)	0 (0.0)	0 (0.0)	0 (0.0)
Respiratory insufficiency n (%)	41 (0.2)	2 (0.0)	4 (0.1)	0 (0.0)
Ultrasound-guided, n (%)	8 (0.1)	2 (0.1)	0 (0.0)	0 (0.0)
Nerve stimulation, n (%)	15 (1)	0 (0.0)	1 (0.1)	0 (0.0)
Dual guidance, n (%)	18 (0.4)	0 (0.0)	3 (0.2)	0 (0.0)
Catheters used >72 hours	n=5141	n=1011	n=1466	n=*158*
Infections with prolonged catheter use‡ n (%)	188 (4)	36 (4)	102 (7)	6 (4)
Mild, n (%)	160 (3)	30 (3)	87 (6)	5 (3)
Moderate, n (%)	23 (0.4)	5 (1)	12 (1)	1 (0.6)
Severe, n (%)	5 (0.1)	1 (0.1)	3 (0.2)	0 (0.0)
Ultrasound-guided, n (%)	78 (3)	18 (3)	13 (5)	6 (6)
Nerve stimulation, n (%)	52 (5)	15 (5)	31 (8)	0 (0.0)
Dual guidance, n (%)	58 (4)	3 (3)	58 (7)	0 (0.0)

*Complications of the block placement are based on single shot blocks and catheters; complications during the postoperative course are based only on catheters.
†Neurological disorders in the area of regional anesthesia were defined as at least one of the following: hypesthesia at the earliest 24 hours after block placement, paresthesia, neuropathic pain.
‡Signs of infection of any grade (mild, moderate or severe) at the entry site of catheters used for more than 72 hours.

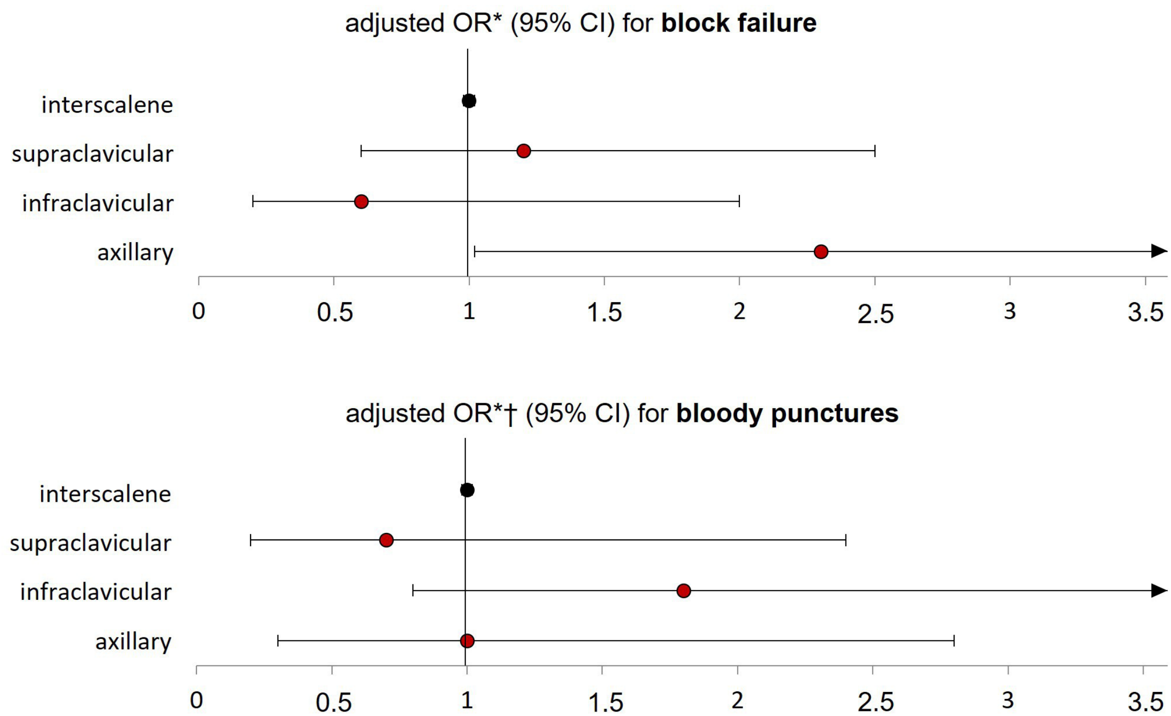

Figure 3 Associations between block type and typical complications during placement of different brachial plexus blocks. *adjusted for age, sex, American Society of Anesthesiologist Physical Status Classification Score >2, Body Mass Index >30 kg/m^2, year of procedure, method (sonography, nerve stimulation, dualguidance), use of catheters, † additionally adjusted for antithrombotic therapy and multiple skin puncture.

DISCUSSION

Our multicentric observational cohort study explores typical complications of brachial plexus nerve blocks across different sites, using a large registry data set of nearly 27,000 blocks. Additionally, we assessed postoperative complications for more than 22,000 catheter placements at the brachial plexus.

Low block failure rates are crucial for regional anesthesia, and comparison is important when different procedures are available as alternatives. Since the success of a regional anesthesia depends on many different factors, there is currently no widely accepted definition of when and under what circumstances a block is considered a failure. The complexity of block failure is reflected in a recent interesting proposal coding five possibilities of manifestation and five interventions that can be used individually or in combination to describe a block failure as accurately as possible.[17] Routine clinical data cannot provide this detailed information, so we consider the ranking of the individual blocks to be more reliable than the individual numerical values. Our study showed plausible failure rates for the infraclavicular (2%), interscalene (4%) and supraclavicular block (8%), which is consistent with previous data,[8 18] but the failure rate for the axillary block was higher than expected (17%). After adjusting for age, gender, BMI>30 kg/m², ASA physical status >2, catheter placement, year of surgery and the method of block placement, the ranking remained the same, with axillary plexus blocks having the highest odds of block failure. This appears plausible for several reasons. Axillary plexus blocks are often performed as the initial approach to regional upper limb anesthesia by novice providers, as it precludes the most severe complications. As at least four nerves must be identified separately and adequately blocked with a local anesthetic, it is also probably the most technically demanding approach. If each nerve is not targeted individually, but rather local anesthetic is sequestered in a single site or injected via a catheter after insertion, insufficient spread with subsequent block failure is likely. Failure due to tourniquet pain appears to be particularly relevant in axillary blocks when the intercostobrachial nerve or the medial brachial nerve is not reached. Our results are consistent with previous studies showing that more proximal plexus brachialis blocks are less prone to failure.[8 18 19]

Though bloody punctures are a relatively common occurrence they rarely cause serious complications. However, bleeding-related complications can result in significant patient morbidity. In a practice advisory by the Canadian Anesthesiologists‘ Society,[20] the interscalene, supraclavicular and infraclavicular block were categorized as “intermediate risk” for bleeding complications. The axillary nerve block was classified as “low-risk”. Our analysis showed a low incidence of vascular punctures (1–2%), which falls within ranges reported elsewhere (0–8.3%).[2 4 5 21] After adjusting for anti-thrombotic medication and multiple skin punctures—both proven to increase the risk of bloody punctures for peripheral blocks[22]—we found no significant difference in the ORs for vascular punctures at any of the different brachial plexus block sites. This underscores the importance of not only considering the incidence of vascular punctures but also accounting for the block’s proximity to critical structures and the potential for compression in the event of bleeding.

Pneumothoraces were infrequent—consistent with previous analyses[21 23–25]—and insufficient for inferential analysis. Only four plausible cases of pneumothoraces were documented in our registry, two at the interscalene site and one each at the infraclavicular and supraclavicular block sites. Local anesthetic systemic toxicity was similarly infrequent. The low incidence of 0.1% (n=2, one each in infraclavicular and axillary plexus approaches) in our registry is consistent with the results of Sites *et al* who searched both a local prospective registry with over 12,000 ultrasound-guided peripheral blocks,[26] and an

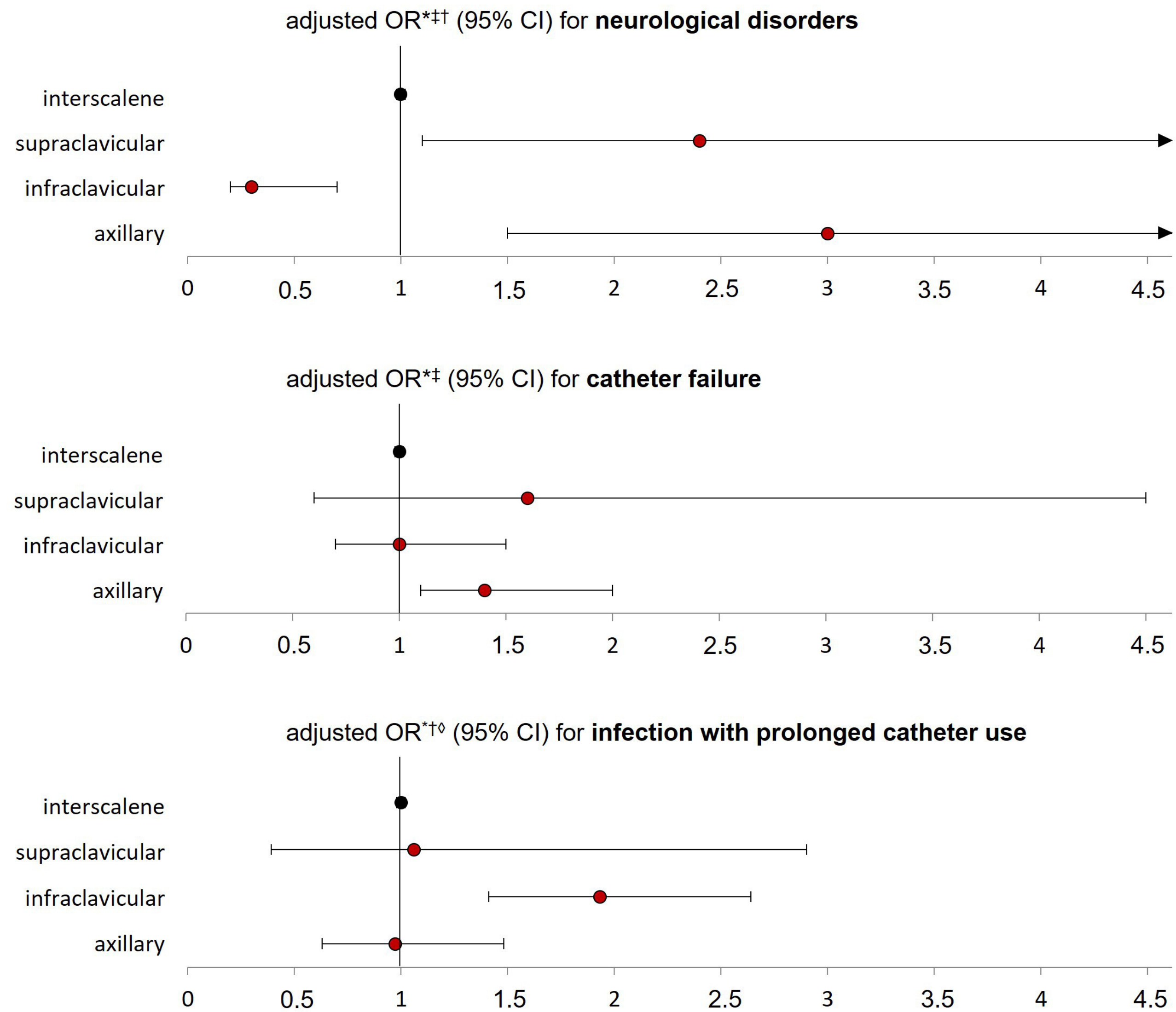

Figure 4 Association between block type and complications in the postoperative course of continuous regional anesthesia for different types of brachial plexus blocks. Neurological disorders in the area of regional anesthesia include hypesthesia at the earliest 24 hours after block placement, paresthesia and neuropathic pain. Infection was defined as an infection of any degree (mild, moderate or severe) at the entry site of catheters used for more than 72 hours. *adjusted for age, sex, American Society of Anesthesiologist Physical Status Classification Score >2, Body Mass Index >30 kg/m^2, year of procedure, † additionally adjusted for method (sonography, and/or nerve stimulation), ‡ additionally adjusted for diabetes, ◊ additionally adjusted for multiple skin puncture, immunosuppression, antibiotics prior to block implementation, pre-existing systemic infection.

international prospective multicenter registry of over 23,000 peripheral blocks.[23]

Neurological dysfunction in the context of continuous regional anesthesia is an unpleasant, frightening experience for patients which complicates the acceptability of the procedure. While permanent nerve damage is rare, the spectrum of transient neurological symptoms—which are mainly sensory in nature—ranges from hypesthesia as an expression of a prolonged or enhanced local anesthetic effect to paresthesia and neuropathic pain. Of the possible approaches to the brachial plexus, the interscalene block is most commonly associated with post-block neurological dysfunction[27]; however, shoulder surgery, per se, carries the risk of nerve injury. A comparison to incidences reported in the literature is difficult due to heterogenous outcome measures and study designs.[5 21 25] In our analysis, we defined neurological disorders as any of: (1) prolonged hypesthesia, (2) paresthesia, or (3) neuropathic pain observed during the treatment period of acute pain services for continuous procedures. Catheters in the axillary and supraclavicular region had higher odds for neurological disorders than those in the interscalene or infraclavicular region. Hypesthesia and paresthesia were most common in all blocks, while neuropathic pain only occurred occasionally. Tourniquet use, which is not recorded in the net-ra registry, may also play a role. Our results are consistent with a prospective, randomized comparison between ultrasound-guided supraclavicular, infraclavicular, and axillary brachial plexus blocks by Tran *et al*, which showed the highest incidence of paresthesias after axillary plexus block, followed by supraclavicular and infraclavicular blocks.[5] However, the heterogeneous nature of our results warrants further investigation.

Data on catheter failure rates in postoperative pain management are sparse. The Pediatric Regional Anesthesia Network registry investigators reported failure rates of 7.3% in children, which was independent of the peripheral block site and mostly caused by dislocation.[28] In our analysis, crude catheter failure rates were 2–3% across all four brachial plexus block

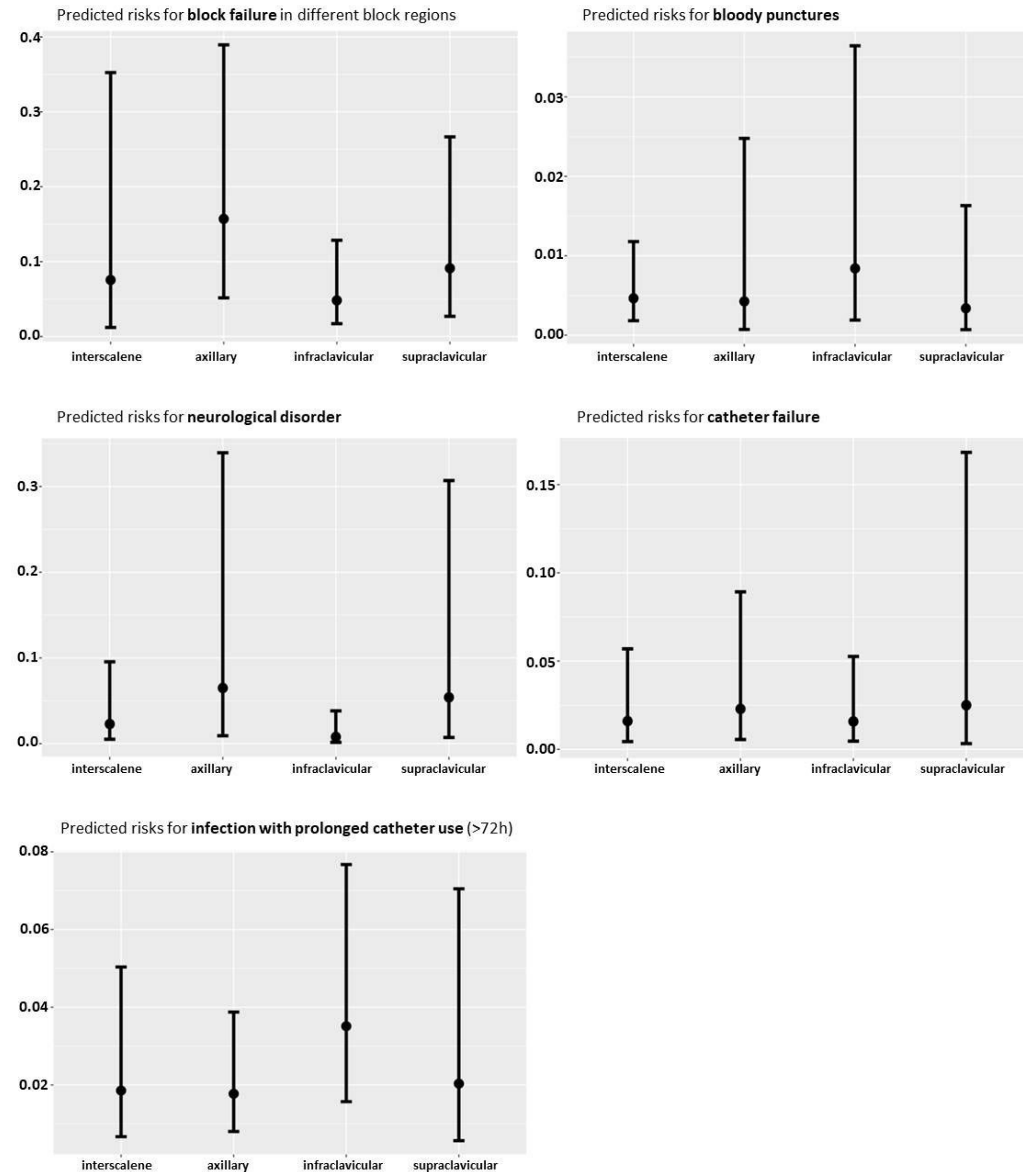

Figure 5 Predicted risks across different types of brachial plexus blocks for a sample patient representing an "median" healthy person from our study population undergoing ultrasound-guided brachial plexus block in 2022. The sample patient has the following characteristics: male sex, 56 years old, American Society of Anesthesiologists status ≤2, body mass index ≤30, catheter use, preoperative antibiotic prophylaxis, no multiple skin puncture during block implementation, no comorbidities such as diabetes, preoperative infection, immunosuppression, antithrombotic therapy.

sites; however, only the axillary plexus block had 40% higher odds of catheter failure. This seems plausible, as five individual nerves must be blocked at this level to achieve complete analgesia of the forearm. Local anesthetic infused via catheter may not be sufficient to reach all these nerves, unlike more proximal, compact sites of the plexus. Another cause may be the proximity to the shoulder joint, which could favor dislocations with its wide range of motion. Unfortunately, we cannot deduce from the registry data whether the catheter failure is due to anatomical conditions, catheter misplacement, dislodgement, migration, non-recoverable occlusion or damage.

Catheter-related infections typically appear at the puncture site and can be detected early. Although serious complications are rare, signs of infection at the catheter entry site often lead to the premature termination of continuous regional analgesia, highlighting the need to compare infection risks to optimize the duration of catheter use based on patient benefit. Most previous studies on catheter-related infections originate from the Network for Safety in Regional Anesthesia and Acute Pain Therapy.[11 12 29–32] Several factors, such as diabetes and obesity, have been shown to influence the risk of infection, which complicates a comparison of reported incidences. As the risk of infection significantly increases from the fourth day onwards,[11] only catheters indwelling for longer than 72 hours were considered. After adjustment for all available and clinically meaningful variables, we found no difference in the odds of catheter-related infections between interscalene, supraclavicular, or axillary plexus blocks. Only the infraclavicular site was associated with higher odds of infection when compared with the interscalene site, which is consistent with a previous net-ra analysis.[11] Since there is no plausible explanation for this result, we caution against overinterpretation of this finding and emphasize the need for further investigation.

The occurrence of Horner's syndrome was only documented in our registry in the context of interscalene plexus block, and we did not see this complication with supraclavicular or infraclavicular blocks—despite its description in the literature.[5 33] The comparatively low incidence of 0.5% may be attributed to only the clinically evident triadic Horner's syndrome being recorded as a complication. Respiratory insufficiency associated with regional anesthesia catheters was most frequently observed following interscalene plexus blocks. While phrenic nerve palsy is a common side effect, recent findings suggest that respiratory complications are more likely due to patient-specific factors.[34]

Limitations

The net-ra registry gathers anonymized routine data from various hospitals of several levels. The risk of underreporting and inaccuracy is difficult to estimate, but could be substantial; however, we assume that the rate of underreporting leading to missing values is at random. Since we rely on registry data, not all influencing factors that can be considered medically relevant may be available—therefore unmeasured confounding is possible and absolute risks may not be comparable with randomized controlled trials. Our observations relate only to the postoperative inpatient course and there was no telephone follow-up, so we cannot make inferences for complications that occur post-discharge. In particular, there is no follow-up for the neurological disorders after the end of treatment by the acute pain service, so that neither the final duration nor a causal relationship with regional anesthesia can be proven. Finally, during the 15-year registry inclusion period (2007–2022), there was presumably progress in medical, technical, and anesthetic methods that makes recent cases more relevant.

Conclusions

The axillary approach to the brachial plexus had the highest odds of block failure and a significant risk of catheter failure, presumably due to the anatomy of the axillary site, where four individual nerves must be identified and blocked. The risk of neurological disorders was also highest in the axillary site. However, specific complications (eg, pneumothorax, Horner's syndrome, and respiratory distress due to diaphragmatic paralysis) do not occur at this most distal puncture site. Therefore, none of the four block sites had a generally superior risk profile and the choice of block site should be primarily based on surgical and patient-related requirements.

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