Factors Associated with 30-Day Adverse Events After Brachial Plexus Neurolysis

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Purpose: This study aimed to identify factors associated with complication, hospital readmission, and reoperation in a 30-day postoperative period after brachial plexus neurolysis.

Methods: A retrospective case-control study was performed using the American College of Surgeons National Surgical Quality Improvement Program database by querying the Current Procedural Terminology code for brachial plexus neurolysis from 2011 to 2020. A cohort of 691 adult patients who underwent brachial plexus neurolysis was included. The outcome variables were 30-day postoperative complication, readmission, and reoperation. A bivariate screen was performed for explanatory variables associated with our outcome variables, and variables with a P value of <.05 in the bivariate screening were included in a multivariable logistic regression model.

Results: Of the 691 patients in our cohort, 20 (2.9%) developed a postoperative complication, 31 (4.5%) were readmitted, and 22 (3.2%) underwent reoperation during the 30-day postoperative period. Bivariate analysis showed that longer operative times were associated with complication, and concurrent rib resection was associated with readmission; no other variables met the inclusion criteria in a multivariable logistic regression model for complication and readmission. Multivariable logistic regression analysis showed that a lower body mass index and longer operative time were independently associated with readmission.

Conclusions: Episode-of-care postoperative complication and reoperation after brachial plexus neurolysis are associated with operative time, which may be partially related to surgical complexity, additional procedures, and/or surgeon experience. Rib resection procedures are associated with a higher risk of readmission.

Clinical relevance: Our findings may be applied to preoperative risk stratification and patient counseling. Our research questions the role of bony rib resection in the routine treatment of neurogenic thoracic outlet syndrome when soft tissue release alone may be successful. Future research is necessary to define risk profiles for different surgical indications and concomitant procedures.

Type of study/level of evidence: Prognostic III.

The annual incidence of brachial plexus surgery is increasing in the United States.1 Although indications for brachial plexus neurolysis in adults vary, common indications include treatment of traumatic brachial plexus injury and neurogenic thoracic outlet syndrome.2–4 In cases of traumatic brachial plexus injuries in adults, brachial plexus neurolysis is frequently performed in the setting of primary nerve reconstruction, often in conjunction with nerve transfer or nerve grafting.2,5,6 In cases of neurogenic thoracic outlet syndrome, brachial plexus neurolysis is performed after nonsurgical management has failed, often in conjunction with scalenectomy or first rib resection.3,4 The risk profile and complication rates of brachial plexus neurolysis vary in the published literature, and because this procedure is uncommonly performed,
factors associated with episode-of-care adverse events have not been robustly described.\textsuperscript{7,8}

Given this gap in knowledge, we sought to use a large national database to determine factors associated with adverse episode-of-care outcomes in patients who underwent this uncommon procedure. The aim of this study was to identify risk factors for 30-day postoperative complication, hospital readmission, and reoperation after brachial plexus neurolysis. Our null hypothesis was that there are no identifiable factors associated with our primary outcome—30-day postoperative complication after brachial plexus neurolysis.

Materials and Methods

Study design and patient identification

A retrospective case-control study was performed to identify factors associated with 30-day complication, readmission, and reoperation after brachial plexus neurolysis using the American College of Surgeons’ National Surgical Quality Improvement Program (NSQIP) database. National Surgical Quality Improvement Program is a validated and risk-adjusted database of patients aged \( \geq 18 \) years who underwent major surgical procedures in more than 700 hospitals in the United States and globally. The database collects pre- and postoperative data, including demographics, comorbidities, and 30-day postoperative adverse events, such as specific complications, hospital readmission, and reoperation.\textsuperscript{9}

The NSQIP database was queried to identify patients who underwent brachial plexus neurolysis from January 1, 2011, through December 31, 2020, using the Current Procedural Terminology code 64713 (neuroplasty, major peripheral nerve, arm or leg: brachial plexus). The resultant cohort of 691 adult patients who underwent brachial plexus neurolysis was included in the study. Surgeries with concurrent procedures, ranging from rib resections to nerve transfers, were not excluded in our final cohort in order to study concurrent procedures as explanatory variables.

Outcome variables

Our outcome variables were 30-day postoperative complication, hospital readmission, and reoperation. Complication was treated as a composite variable of all postoperative complications collected by the NSQIP database. The NSQIP database tracks the following 30-day postoperative complications: (1) superficial surgical site infection, (2) deep surgical site infection, (3) organ/space surgical site infection, (4) wound dehiscence, (5) pneumonia, (6) unplanned reintubation, (7) pulmonary embolism, (8) persistent ventilator requirement, (9) progressive renal insufficiency, (10) urinary tract infection, (11) stroke, (12) cardiac arrest, (13) myocardial infarction, (14) blood transfusion, (15) deep vein thrombosis, and (16) sepsis/septic shock. Detailed definitions for each 30-day complication are provided by NSQIP.\textsuperscript{9}

Explanatory variables

The following explanatory variables were analyzed: (1) age, (2) sex, (3) body mass index (BMI), (4) diabetes mellitus, (5) current smoking within 1 year of surgery, (6) functional status (independent, partial dependent, or totally dependent), (7) chronic obstructive pulmonary disease, (8) hypertension requiring medication, (9) chronic steroid or immunosuppressive therapy, (10) bleeding disorder, (11) wound classification (clean, clean/contaminated, contaminated, or dirty/infected), (12) American Society of Anesthesiologists classification, and (13) operative time.

Furthermore, using reported Current Procedural Terminology codes in the NSQIP database for concurrent procedures performed at the time of brachial plexus neurolysis, we were able to assess whether a concurrent procedure was performed. When appropriate, the concurrent procedure was subclassified as a rib resection (first or cervical) procedure, scalenectomy without bony rib resection, nerve reconstruction (suture, grafting, or transfer), or tumor resection.

Statistical analysis

Descriptive statistics were calculated for the final cohort. Medians and interquartile ranges were used to describe nonparametric continuous variables, and percentages were used to describe categorical variables. Statistical analyses were performed using complete datasets only, and missing or unknown data are given in Table 1. A bivariate screen was performed for explanatory variables associated with our outcome variables, employing the Mann-Whitney U test for nonparametric continuous explanatory variables and the Fisher exact test for categorical explanatory variables. Variables with a \( P \) value of \(<.05\) in the bivariate screen met the criteria for inclusion in a multivariable logistic regression model for our outcome variables. The standard significance criterion of \( \alpha = 0.05 \) was employed. Data computing and preparation were performed using R software (R Core Team), and statistical analyses were performed using SAS software (SAS Institute).

Results

Cohort characteristics

The study cohort was composed of 691 patients from the NSQIP database who underwent brachial plexus neurolysis from 2011 to 2020. The median age of the cohort was 38 years (interquartile range, 25–48 years), and 43% of the patients were men. The median BMI of the patients was 26.6. Most patients (61%) were American Society of Anesthesiologists classification 2, 4% of patients had diabetes mellitus, and 16% of patients were active smokers. The median operative time was 170 minutes.

Of the 691 patients in this cohort, 502 (72.7%) patients underwent a concurrent procedure at the time of brachial plexus neurolysis. Forty-two percent of patients underwent concurrent rib resection, 5% of patients underwent scalenectomy without bony rib resection, 5% of patients underwent nerve reconstruction, and 2% of patients underwent tumor resection (Table 1).

Complications

Of the 691 patients in our cohort, 20 (2.9%) patients developed a complication within the 30-day postoperative period (Table 2). In the bivariate analysis, longer operative times were associated with 30-day postoperative complication after brachial plexus neurolysis \((P < .05)\) (Table 1). No other variable met the criteria for inclusion in a multivariable logistic regression model; therefore, the bivariate analysis was the final statistical test performed for this outcome.

Readmissions

Data for hospital readmission were available for 687 of the 691 patients in our cohort, and 31 (4.5%) patients were readmitted to the hospital during the 30-day postoperative period. In the bivariate analysis, concurrent rib resection was associated with 30-day postoperative hospital readmission after brachial plexus neurolysis \((P < .05)\) (Table 1). No other variable met the criteria for inclusion in a multivariable logistic regression model; therefore, the bivariate analysis was the final statistical test performed for this outcome.
Table 1
Baseline Cohort Characteristics and Bivariate Analysis of Factors Association With 30-Day Complication, Readmission, and Reoperation Following Brachial Plexus Neurolysis

| Variable                      | Overall Cohort | Complication | No Complication | P value | Readmission | No Readmission | P value | Reoperation | No Reoperation | P value |
|-------------------------------|----------------|--------------|-----------------|---------|-------------|----------------|---------|-------------|----------------|---------|
| Number of patients, n         | 691            | 20           | 671             | 31      | 658         | 22             | 669     |
| Age (y), median (IQR)         | 38 (25–48)     | 30 (24–40)   | 38 (25–48)      | .06     | 35 (27–45)  | 38 (25–48)      | .7      | 34 (25–43)  | 38 (25–48)      | .7      |
| BMI, median (IQR), kg/m²      | 26.6 (23–31.4) | 27.0 (22.5–29.5) | 26.6 (23.3–31.5) | .6      | 26.4 (23.1–30.5) | 26.6 (23.3–31.4) | .5      | 23.6 (21.0–27.1) | 26.8 (23.4–31.5) | <.05    |
| Operative time (min), median (IQR) | 170 (124–216) | 203 (135–279) | 168 (123–214) | <.05    | 178 (143–214) | 168 (123–216) | .5      | 215 (147–281) | 168 (123–214) | <.05    |
| Male sex, n (%)               | 299 (43.3)     | 10 (50.0)    | 289 (43.1)      | .6      | 9 (29.0)    | 290 (43.9)      | .1      | 10 (45.5)   | 289 (43.2)      | .8      |
| ASA classification, n (%)     | 129 (18.7)     | 5 (25.0)     | 124 (18.5)      | .7      | 5 (16.1)    | 124 (18.9)      | .6      | 6 (27.3)    | 123 (18.4)      |        |
| 1                             | 419 (60.7)     | 11 (55.0)    | 408 (60.9)      | .5      | 21 (74.2)   | 396 (60.3)      | .1      | 12 (54.5)   | 407 (60.9)      |        |
| 2                             | 136 (19.7)     | 4 (20.0)     | 132 (19.7)      | .9      | 3 (9.7)     | 133 (20.2)      | .8      | 4 (18.2)    | 132 (19.8)      |        |
| 4                             | 6 (0.9)        | 0 (0)        | 6 (0.9)         | .2      | 0 (0)       | 6 (0.9)         | .9      | 0 (0)       | 6 (0.9)         |        |
| Wound classification, n (%)   | 677 (98.0)     | 19 (95.0)    | 658 (98.1)      | .09     | 29 (93.5)   | 648 (98.5)      | .2      | 22 (100.0)  | 655 (98.0)      | .9      |
| Clean                         | 9 (1.3)        | 0 (0)        | 9 (1.3)         |        | 1 (3.2)     | 8 (1.2)         |        | 0 (0)       | 9 (1.3)         |        |
| Clean/contaminated            | 3 (0.4)        | 0 (0)        | 2 (0.3)         |        | 1 (3.2)     | 2 (0.3)         |        | 0 (0)       | 3 (0.4)         |        |
| Dirty/infected                | 2 (0.3)        | 0 (0)        | 2 (0.3)         |        | 0 (0)       | 2 (0.3)         |        | 0 (0)       | 2 (0.3)         |        |
| Diabetes mellitus, n (%)      | 25 (3.6)       | 0 (0)        | 25 (3.7)        | .9      | 0 (0)       | 25 (3.8)        | .6      | 1 (4.5)     | 24 (3.6)        | .6      |
| Current smoker, n (%)         | 109 (15.8)     | 3 (15.0)     | 106 (15.8)      | -.9     | 5 (16.1)    | 104 (15.8)      | .9      | 0 (0)       | 109 (16.3)      | <.05    |
| COPD, n (%)                   | 8 (1.2)        | 1 (5.0)      | 7 (1.0)         | .9      | 0 (0)       | 8 (1.2)         | .9      | 0 (0)       | 8 (1.2)         | .9      |
| Hypertension, n (%)           | 106 (15.3)     | 3 (15.0)     | 103 (15.4)      | .9      | 4 (12.9)    | 102 (15.5)      | .9      | 22 (9.1)    | 104 (15.5)      | .6      |
| Steroids/immunosuppression, n (%) | 9 (1.3) | 0 (0) | 9 (1.3) | .9 | 1 (3.2) | 8 (1.2) | .3 | 0 (0) | 9 (1.3) | .9 |
| Bleeding disorder, n (%)      | 37 (5.4)       | 1 (5.0)      | 36 (5.4)        | .9      | 0 (0)       | 37 (5.6)        | .4      | 4 (18.2)    | 33 (4.9)        | <.05    |
| Functional status, n (%)      | 675 (98.3)     | 20 (100.0)   | 655 (98.2)      | .9      | 31 (100.0)  | 644 (98.5)      | .9      | 22 (100.0)  | 653 (98.2)      | .9      |
| Independent                   | 10 (1.5)       | 0 (0)        | 10 (1.5)        |        | 0 (0)       | 10 (1.5)        |        | 0 (0)       | 10 (1.5)        |        |
| Partially dependent           | 2 (0.3)        | 0 (0)        | 2 (0.3)         |        | 0 (0)       | 2 (0.3)         |        | 0 (0)       | 2 (0.3)         |        |
| Totally dependent            | 502 (72.7)     | 12 (60.0)    | 490 (73.0)      | .2      | 24 (77.4)   | 478 (72.6)      | .7      | 16 (72.7)   | 486 (72.6)      | .9      |
| Concurrent procedure, n (%)   | 290 (42.0)     | 7 (35.0)     | 283 (42.2)      | .6      | 19 (61.3)   | 271 (41.2)      | <.05    | 10 (45.5)   | 280 (41.9)      | .8      |
| Rib resection, n (%)           | 35 (5.1)       | 1 (5.0)      | 34 (5.1)        | .9      | 2 (6.5)     | 33 (5.0)        | .7      | 2 (9.1)     | 33 (4.9)        | .3      |
| Scaleneectomy, n (%)          | 35 (5.1)       | 0 (0)        | 35 (5.2)        | .6      | 0 (0)       | 35 (5.3)        | .4      | 0 (0)       | 35 (5.2)        | .6      |
| Nerve reconstruction, n (%)   | 11 (1.6)       | 1 (5.0)      | 10 (1.5)        | .3      | 0 (0)       | 11 (1.7)        | .9      | 0 (0)       | 11 (1.6)        | .7      |

ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; IQR, interquartile range.

* Data were partially missing or unknown for age (n = 1), BMI (n = 4), ASA classification (n = 1), functional status (n = 4), and readmission (n = 2).
Reoperations

Of the 691 patients in our cohort, 22 (3.2%) patients underwent reoperation within the 30-day postoperative period. In the bivariate analysis, BMI, operative time, smoking, and bleeding disorder were associated with reoperation and were included in our multivariable logistic regression model. Multivariable logistic regression analysis showed that a lower BMI (odds ratio, 0.913; 95% confidence interval, 0.835–0.999) and longer operative time (odds ratio, 1.003; 95% confidence interval, 1.000–1.006) were independently associated with 30-day reoperation after brachial plexus neurolysis (Table 3).

Discussion

Neurolysis of the brachial plexus is indicated in various clinical scenarios in the adult patient population, the most common being traumatic brachial plexus injuries and neurogenic thoracic outlet syndrome.2,3 Understanding the predictive factors for episode-of-care adverse events is important for risk stratification and patient counseling; however, brachial plexus neurolysis is an uncommonly performed procedure, and its risk profile is not well described. With that rationale, we used a heterogeneous patient cohort across 10 years in a large national database to assess risk factors for 30-day postoperative complication, hospital readmission, and reoperation after brachial plexus neurolysis. In this study, we found that longer operative times were associated with 30-day complication and reoperation; moreover, concurrent rib resection was associated with 30-day readmission, and lower BMI was associated with 30-day reoperation.

Our study demonstrated that a longer operative time is associated with a higher risk of 30-day complication and reoperation after brachial plexus neurolysis. In our study, operative time may reflect the technical difficulty of the surgery, concomitant procedures performed, and/or surgeon experience. This finding must be interpreted in the context of the limitations of a large database study with a heterogeneous case mix, which included both traumatic and nontraumatic indications for brachial plexus neurolysis and concomitantly indicated procedures. We did substratify our data on the basis of the concurrent procedures performed, and notably, undergoing a current procedure in itself was not associated with 30-day complications in our study. Surgeon volume and experience have been correlated with outcomes after hip, knee, shoulder, and elbow arthroplasty, and a longer operative time has been associated with higher rates of nerve injury, urinary tract infection, blood transfusion requirements, and overall complications in the 30-day postoperative period.13–15 Brachial plexus neurolysis is a relatively uncommonly performed surgery, and in a survey of recent hand surgery fellowship graduates in the United States, one-third of respondents reported no participation in brachial plexus surgery during training.15 Our findings support a critical assessment of hand fellowship educational goals to incorporate exposure to brachial plexus surgery. In addition, having a dedicated team with multiple surgeons involved in decision making and different procedure components can potentially decrease the total operative time. There may be a role for the establishment of supraregional brachial plexus surgery centers to optimize patient outcomes.

The association of lower BMIs with 30-day reoperation after brachial plexus neurolysis was unexpected. Body mass index may affect the size and positions of the nerves in the brachial plexus, but likely not to a considerable degree.16 After primary nerve reconstruction for traumatic brachial plexus injuries in adults, multiple studies have shown an association between higher BMIs and poorer motor recovery. This may be related to the added technical difficulty of surgery or to the additional strength required to lift the total weight of the upper extremity.17,18 Few studies have demonstrated an association between lower BMIs and 30-day postoperative adverse events.19 It is possible that the association of a lower BMI with reoperation is confounded by an unobserved variable. For instance, a lower BMI may represent malnutrition; unfortunately, data for preoperative serum albumin are incomplete in the NSQIP database, precluding the analysis of this variable in our study.

Our study has demonstrated a higher risk of 30-day hospital readmission when a rib resection procedure is performed at the time of brachial plexus neurolysis. The optimal treatment of neurogenic thoracic outlet syndrome remains controversial, and transaxillary first rib resection, supraclavicular first rib resection, and soft tissue release alone are 3 commonly performed surgical options. Soft tissue release alone is generally viewed as a less morbid procedure than bony rib resection. A prior systematic review has suggested that soft tissue release alone may have a higher success rate with fewer complications.20 Our findings further highlight the episode-of-care risks of rib resection and call into question its role in the routine treatment of neurogenic thoracic outlet syndrome.

This study has several limitations. First, this study is composed of a heterogeneous patient cohort. Common indications for brachial plexus neurolysis in adults include both traumatic brachial plexus injuries and thoracic outlet syndrome, and concomitant procedures are often performed. We were able to substratify and control for the effects of concurrent procedures to a degree; however, future studies are necessary to define the risk profile for each indication and when additional procedures are performed. It is likely that

### Table 2
Tabulated 30-Day Postoperative Complications After Brachial Plexus Neurolysis (N = 691)

| Complication                             | Number (n) |
|------------------------------------------|------------|
| Superficial surgical site infection      | 5          |
| Deep surgical site infection             | 0          |
| Organ/space surgical site infection      | 0          |
| Wound dehiscence                         | 1          |
| Pneumonia                                | 5          |
| Unplanned reintubation                   | 0          |
| Pulmonary embolism                       | 0          |
| Ventilator requirement                   | 0          |
| Renal failure                            | 0          |
| Urinary tract infection                  | 2          |
| Stroke                                   | 0          |
| Cardiac arrest                           | 0          |
| Myocardial infarction                    | 0          |
| Blood transfusion                        | 5          |
| Deep vein thrombosis                     | 3          |
| Sepsis/septic shock                      | 1          |
| Patients with complication(s)*           | 20         |

* The number denotes unique patients with 1 or more complications in the 30-day postoperative period. Patients who had more than 1 complication were counted only once for statistical analyses.

### Table 3
Multivariable Logistic Regression Analysis for Factors Associated With 30-Day Reoperation After Brachial Plexus Neurolysis (N = 691)

| Variable                           | Odds Ratio | 95% CI       | P value |
|------------------------------------|------------|--------------|---------|
| BMI *                              | 0.913      | 0.835 to 0.999 | <.05    |
| Operative time                     | 1.003      | 1.000 to 1.006 | <.05    |
| Current smoker                     | <0.001     | <0.001 to >999.999 | .9      |
| Bleeding disorder                  | 3.031      | 0.931 to 9.869 | .07     |

CI, confidence interval.

* Reference groups for continuous variables are –1 unit.
some adult traumatic brachial plexus injury cases in the NSQIP database were not captured by our query method using the Current Procedural Terminology code for brachial plexus neurolysis. For example, cases of distal nerve transfers alone without brachial plexus exploration would not have been captured by our methodology. Additionally, there may have been cases of brachial plexus nerve grafting in which neurolysis was not coded so as not to unbundle. In these ways, our study cohort may have been skewed toward a population of patients with neurogenic thoracic outlet syndrome. Second, retrospective studies using a large database are limited by the data available. For traumatic cases, the NSQIP database does not provide the mechanism of injury, pattern of brachial plexus injury, time from injury to surgery, or postoperative functional outcomes. Pertinent complications of brachial plexus neurolysis, such as nerve injury or apical pneumothorax, are not recorded in this database.\textsuperscript{5,21} Third, NSQIP collects postoperative adverse events only up to 30 days after surgery; therefore, our findings for the rates of complication, readmission, and reoperation may underestimate the true rates of these adverse events with longer follow-ups. Specifically for traumatic brachial plexus injuries, the follow-up period of NSQIP precludes us from drawing conclusions regarding reoperation for failed primary nerve reconstruction.

Although brachial plexus neurolysis procedures are uncommon, they can have profound impacts on patients’ functional status and carry a notable cost to society.\textsuperscript{1–5,15,22} In this NSQIP database study of brachial plexus neurolysis performed over a recent 10-year period, we identified patient-related and treatment-related factors associated with 30-day adverse events. Lower BMIs were associated with reoperation, concurrent rib resection was associated with readmission, and longer operative times were associated with complication and reoperation. Our findings add to the body of literature regarding the episode-of-care risks of rib resection for neurogenic thoracic outlet syndrome and call into question its role in the routine treatment of neurogenic thoracic outlet syndrome when soft tissue release alone may be successful. Future research is necessary to define risk profiles for different surgical indications and concomitant procedures.

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