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ORIGINAL ARTICLE
Peripheral Nerve

Procedure Costs of Peripheral Nerve Graft Reconstruction

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Background: Peripheral nerve injuries not repaired in an effective and timely manner may lead to permanent functional loss and/or pain. For gaps greater than 5mm, autograft has been the gold standard. Allograft has recently emerged as an attractive alternative, delivering comparable functional recovery without risk of second surgical site morbidities. Cost is an important factor when considering surgical options, and with a paucity of nerve repair cost data, this study aimed to compare allograft and autograft procedure costs.
Methods: A retrospective cross-sectional observational study using the US all-payer PINC AI Healthcare Database examined facility procedure costs and cost drivers in patients undergoing allograft or autograft repair of an isolated single peripheral nerve injury between January 2018 and August 2020. Inpatient repairs were limited to nerve-specific DRGs. Multivariable regression evaluated risk-adjusted procedure cost differences.
Results: Peripheral nerve graft repairs (n = 1363) were more frequent in the outpatient setting, and more than half involved the use of allograft nerve. Procedure costs for allograft and autograft repair were not significantly different in the outpatient ($P = 0.43$) or inpatient ($P = 0.71$) setting even after controlling for other risk factors. Operating room cost was significantly higher for autograft in outpatient ($P < 0.0001$) but not inpatient ($P = 0.46$), whereas allograft implant cost was significantly higher in both settings ($P < 0.0001$).
Conclusions: No significant differences in procedure costs for autograft and allograft repair in inpatient and outpatient settings were found using real-world data. Future research should explore longer-term costs. *(Plast Reconstr Surg Glob Open 2023; 11:e4908; doi: 10.1097/GOX.0000000000004908; Published online 10 April 2023.)*

INTRODUCTION

Traumatic peripheral nerve injuries encompass 1.5% of the ~35 million annual nonfatal trauma injuries[1]; the incidence in extremity trauma approaches 15% and is more commonly seen in upper extremity (eg, digital and radial nerves) injuries.[2–4] Younger men (mean age 38–42 years) are disproportionately impacted,[5–10] and these injuries can leave permanent loss of nerve function, impairing quality of life, ability to work, and activities of daily living.

Surgical intervention is necessary to restore nerve function and includes primary repair of nerve transection, reconstruction of nerve gaps, management of painful nerve conditions, and neuromas that are associated with neuropathic pain.[11,12] Effective surgical treatment requires tension-free coaptation of healthy nerve tissue. Direct repair with suture of a transected nerve is common; however, tension-free technique is not always possible with direct repair. A gap between nerve ends frequently exists due to substantial loss of nerve tissue from the injury, a zone of injury that requires debridement of damaged nerve tissue or in situations of delayed nerve repair or reconstruction. The length of the nerve gap dictates the

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optimal repair procedure type. In gaps of 5 mm or less, connector-assisted repair or a tensionless direct repair is effective. For gaps greater than 5 mm, nerve graft reconstruction provides the maximal recovery of function.[13]

Historically, the gold standard for peripheral nerve graft reconstruction has been nerve autograft.[11,14–16] However, use of this surgical technique can result in complications/sequelae at the donor nerve site, including cold intolerance, dysesthesias, sensory loss, neuroma formation, chronic nerve pain, infection, and scarring, and can be constrained when repairing extensive injuries due to a limited supply of donor nerve.[5,11,12,14,15,17,18]

Nerve allograft has been shown to be an acceptable alternative to nerve autograft. Introduced into clinical practice in 2007, nerve allograft includes the potential for reduced operative time, avoiding additional risks associated with the donor site (such as neuroma formation or infection), the use of regional rather than general anesthesia,[11,12] and off-the-shelf availability (in 15 mm to 70 mm length, and 1–2 mm to 4–5 mm diameter), contributing to ease of use.[12,14,15] In a published meta-analysis comparing meaningful recovery rates and postoperative complications after autograft, allograft, and conduit repair in nerve gaps greater than 5 mm and less than 70 mm, overall meaningful recovery for sensory and motor function was not significantly different between autograft and allograft across both short and long gaps. Meaningful recovery rates for autograft (81.6%) and allograft (87.1%) repairs were significantly higher compared with conduits (62.2%) in sensory short gap repairs (nerve gaps 5–30 mm). Complication rates were comparable for autograft and allograft but higher for conduit with regard to pain.[19]

Surgeons also benefit from comparative cost data to help support their choice of treatment. Currently, the published literature on health care costs of allograft and autograft procedures is limited. Previous studies have reported on inpatient and emergency room charges but not outpatient, although most procedures are currently done in this setting.[6,7,20] These studies did not compare costs by nerve repair type. Styron et al studied nerve graft procedure costs, comparing allograft and autograft in a Medicare population, though this population is not where the most peripheral nerve injuries occur. This study reported lower total costs of care for allograft versus autograft repair in the inpatient setting ($25,751 and $29,560, respectively) and similar costs for allograft versus autograft repair in outpatient settings ($13,143 and $12,635, respectively).[21]

The purpose of the present study was twofold: (1) examine the impact of nerve graft repair procedure type (allograft, autograft) on facility costs of care in inpatient and outpatient settings across US hospitals, using an all-payer database; and (2) examine the patient demographics, hospital characteristics, clinical characteristics, and health care costs for patients undergoing nerve graft repair procedures (allograft, autograft).

METHODS

A retrospective, observational, cross-sectional study of isolated single nerve graft repair utilizing the PINC AI Healthcare Database (PHD, formerly known as Premier Healthcare Database) was conducted. The PHD is a United States hospital-based, service level, all-payer, geographic diverse administrative database that includes data from inpatient hospital discharges and outpatient encounters. The database contains discharge files from more than 1 billion patient encounters, or one in every five inpatient and outpatient hospital discharges in the United States. Member hospital characteristics from the PHD show a distribution similar to that of the American Hospital Association, although the American Hospital Association has a greater number of smaller hospitals and PHD represents a greater percentage of hospitals in the south. Ambulatory surgery center PHD data are limited to hospital owned centers.[22] All data were statistically deidentified, compliant with the Health Insurance Portability and Accountability Act, and followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline.[23]

Facility data on healthcare resource utilization were collected during the episode of care (defined as the date of admission to discharge). Facility episode of care total and component costs data were categorized based on Medicare UB-04 revenue codes embedded in the PHD's charge master procedure description. Most hospitals reported procedural costs, which were calculated based on relative value units assigned by the hospital cost accounting systems. The OR cost was the sum of costs assigned by the hospital to revenue codes for OR services, and includes both fixed and variable costs (eg, room use, labor hours). Costs for anesthesia, radiology, laboratory, blood products, and cardiology were not included in OR total cost, rather they were categorized under other revenue codes. Cost totals include facility procedure costs only and do not include costs or payment to the surgeons. Granular line item or individual costs within the revenue code could not be analyzed (eg, the line-item product costs that make up the revenue code costs for implants). In hospitals that did not report costs, costs were calculated from charges that were converted using the cost-to-charge ratio based on the Medicare cost report. To address cost outliers that may skew results, cost outcome variables were winsorized at the 95th percentile; outliers that were higher than the value

Takeaways

Question: Are procedure costs the same for allograft and autograft peripheral nerve graft reconstruction?

Findings: A retrospective, observational study examined the impact of nerve graft repair procedure type and patient, hospital, and clinical characteristics on procedure costs in inpatient and outpatient settings across US hospitals among autograft and allograft peripheral nerve repair cases. There was no significant difference in risk adjusted mean total cost between autograft and allograft nerve repair procedures for inpatients and outpatients after controlling for all other factors.

Meaning: Allografts are a cost comparable alternative to autografts for peripheral nerve repair procedures.

of 95th percentile were replaced by the value of the 95th percentile. Costs were adjusted to 2020 US dollars based on the Medical Care Consumer Price Index from the US Bureau of Labor Statistics.

The study includes inpatient and outpatient (hospital outpatient departments and hospital-affiliated ambulatory surgery centers) autograft and allograft peripheral nerve repair cases with a discharge date between the index hospitalization period of January 1, 2018 and August 31, 2020. Allograft specific ICD-10-PCS and CPT billing codes were established on January 1, 2018.

Peripheral autograft and allograft nerve repair were defined as cases with an allograft or autograft repair, without a same day breast reconstruction, oral maxillofacial/head and neck, neurectomy, or any concomitant nerve repair. ICD-10-PCS (inpatient) or CPT (outpatient) procedure codes were used to identify inclusion and exclusion criteria. (**See Appendix A, Supplemental Digital Content 1,** which lists the ICD-10-PCS and CPT procedure codes used to identify peripheral allograft and autograft nerve repair procedures, **http://links.lww.com/PRSGO/C476**.)

To analyze comparable autograft and allograft peripheral nerve repairs, additional exclusion criteria were applied to limit confounders and variability caused by multiple nerve repairs or multiple other procedures. Autograft and allograft cases excluded those that had billed more than one code in their respective procedure code lists and excluded any cases with add-on nerve/cable codes. To exclude inpatient cases with additional non-nerve related procedures, cases were limited to those billed with the Medicare Severity Diagnosis Related Group peripheral, cranial nerve, and other nervous system procedure codes 040 (with major complication or comorbidity), 041 (with complication or peripheral neurostimulator), and 042 (without complication or comorbidity/major complication or comorbidity).

Descriptive analysis of the distribution of patient demographic, hospital, and clinical characteristics by treatment type (autograft or allograft) and setting (inpatient or outpatient) was performed. Chi-square (χ^2) tests were used to test for statistical differences between autograft and allograft patients for dichotomous or categorical variables. A *P* value less than 0.05 for a two-sided test was considered statistically significant.

Multivariable analysis was conducted for inpatients and outpatients separately. The outcomes examined were total cost of care, implantable cost, operating room (OR) cost, and room and board (R&B) cost (for inpatients only). The key independent variable was nerve procedure type (allograft, autograft) and a number of a priori covariates were controlled for in the regressions, including patient characteristics (gender, age group, self-reported race and ethnicity, primary insurance payer), hospital characteristics (urban/rural population served, teaching status, geographical region, bed size), location of nerve injury (hand/wrist, forearm, lower leg, shoulder, abdomen, cranial). (**See Appendix B, Supplemental Digital Content 2,** which lists the ICD-10-CM diagnosis codes used to classify nerve injury by location, and clinical characteristics including the Charlson-Deyo Comorbidity Index, **http://links.lww.com/PRSGO/C477**.)[24] (**See Appendix C, Supplemental Digital Content 3,** which lists the Charlson Comorbidity Index (CCI) diagnosis and procedure codes, **http://links.lww.com/PRSGO/C478**.) Generalized linear model regressions with gamma variance and log link functions were used to model OR, R&B, and total costs incurred during the index hospitalization. Generalized linear model regression with a Tweedie distribution was used to model implantable costs. The Tweedie distribution can be employed for compound Poisson-gamma distributions and is useful to model outcomes that contain a combination of zero and positive values.[25] Recycled prediction[26,27] was used to calculate the regression predicted cost outcomes for each of the nerve repair types following the generalized linear model regressions by using the estimated coefficients of the study covariates where all patients were assumed to receive a graft repair type and the adjusted costs were predicted holding all covariates at their actual values. Statistical analysis was performed using SAS, v9.4 (SAS Institute Inc., Cary, N.C.).

RESULTS

From January 1, 2018 to August 31, 2020, a total of 247 outpatient autograft and 1014 outpatient allograft nerve repair cases met all selection criteria, and 22 inpatient autograft nerve repairs and 80 inpatient allograft nerve repairs met all selection criteria. The ratio of autograft to allograft repairs was approximately one to four in both the outpatient and inpatient settings. These final cohorts were used for comparisons for the inpatient and outpatient populations (Fig. 1).

The outpatient descriptive data indicated comparable autograft and allograft characteristics with a few notable statistically significant differences. (**See table 1, Supplemental Digital Content 4,** which shows outpatient demographic, hospital, and clinical characteristics stratified by nerve graft repair type, **http://links.lww.com/PRSGO/C479**.) The location of injury with wrist/hand procedures occurred more frequently among allograft cases, whereas lower leg, upper arm, and cranial nerve saw higher proportions treated with autograft ($P < 0.05$). Allograft procedures occurred in hospitals with larger bedsizes ($P = 0.0309$) and were more likely to take place in an ambulatory surgery center ($P < 0.001$). Proportionally younger patients ($P = 0.0129$) and female patients ($P = 0.0042$) received allografts. Autografts had a higher CCI score than allografts ($P = 0.0004$) but only 1.48% of allografts versus 5.67% of autografts had a score higher than three.

The inpatient descriptive data documented a statistical difference between autograft and allograft in geographic region and race. (**See table 2, Supplemental Digital Content 5,** which shows inpatient demographic, hospital, and clinical characteristics stratified by nerve graft repair type, **http://links.lww.com/PRSGO/C480**.) Autografts were proportionally more likely to be done in the Midwest and Northeast ($P = 0.0026$) and were performed more frequently on non-White patients ($P = 0.0287$).

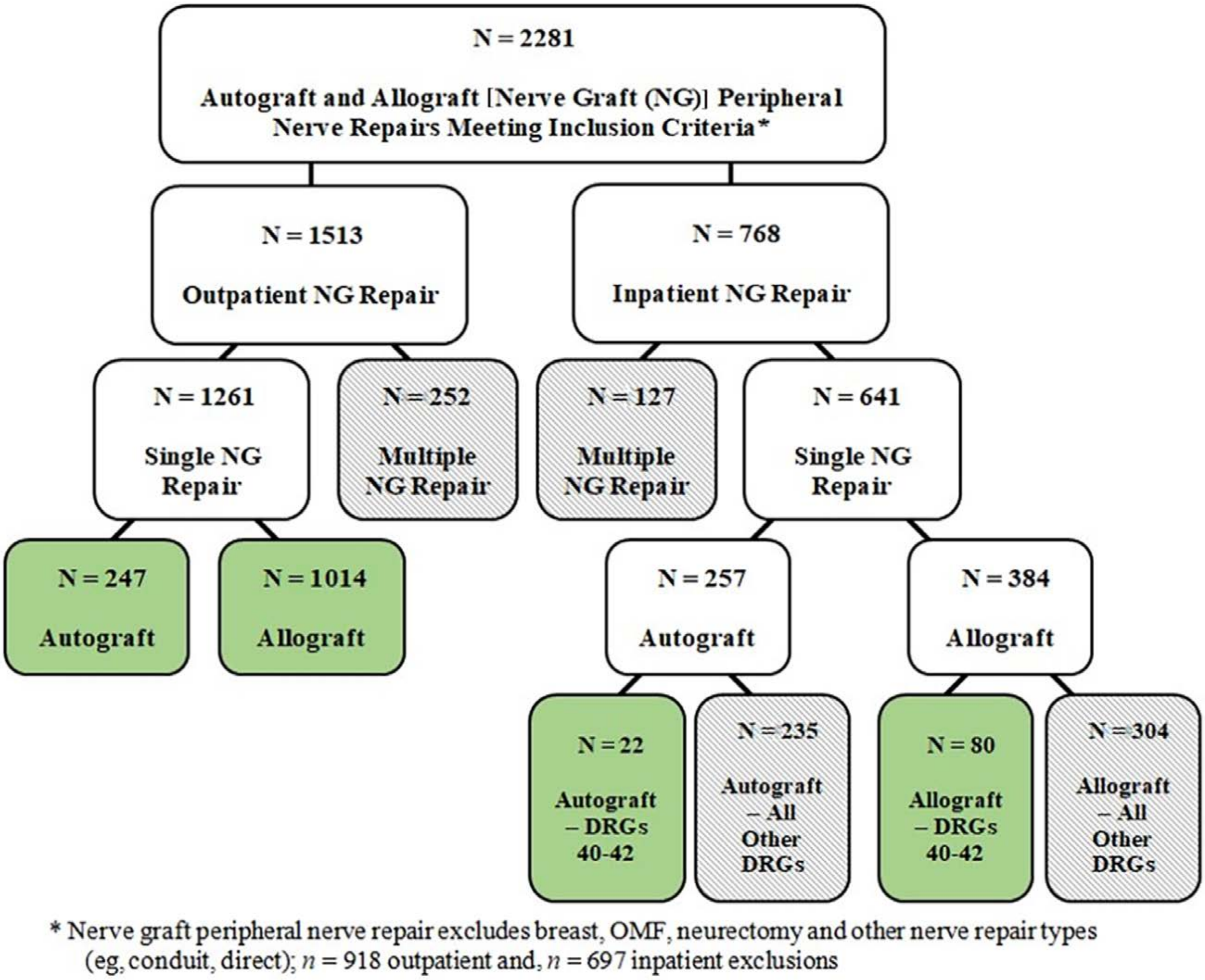

Fig. 1. Patient selection flow chart: autograft and allograft nerve repair procedures study.

The descriptive outpatient costs show comparable average total costs between autografts ($10,178) versus allografts ($9732). Autografts saw higher OR costs ($4850 versus $3447), whereas allografts saw higher implant costs ($3398) compared with autografts ($1808; Fig. 2).

The descriptive inpatient costs show comparable average autograft total costs per episode of care ($25,950) versus allograft ($24,005). Autograft saw comparable R&B costs ($5280 versus $3947) with longer length of stay (5.2 versus 3.2 days), and OR costs ($7582 versus $6789). Allograft implant cost ($5263) was significantly higher than autograft ($1956; Fig. 3).

Outpatient Multivariable Analysis

Outpatient multivariable analyses were conducted with total cost of care, implantable cost, and OR cost as the dependent variables. Risk-adjusted mean predicted costs based on recycled prediction for allograft and autograft nerve repair procedures are shown in Figure 4. Among outpatients, there was no significant difference in risk-adjusted mean total cost between autograft versus allograft nerve repair procedures ($9621 and $9874, P = 0.43) after controlling for all other factors. Mean implantable cost was significantly lower for autograft versus allograft nerve repair procedures ($1709 and $3449, $P < 0.0001$), whereas mean OR cost was significantly higher for autograft versus allograft nerve repair procedures ($4282 and $3583 respectively, $P < 0.0001$).

Irrespective of nerve graft repair type, many outpatient covariates were significantly associated with costs. (**See table 3, Supplemental Digital Content 6,** which shows results of multivariable regression analysis of component costs of care among outpatients receiving allograft and autograft nerve repair procedures, **http://links.lww.com/PRSGO/C481**.) Outpatient total cost, implant, and OR costs were significantly associated with insurance type, nerve injury location, ambulatory surgery center setting of care, gender, and ethnicity ($P < 0.05$). Total cost and implant costs were also significantly associated with geographic region, whereas implant cost was associated with CCI, age, and race ($P < 0.05$).

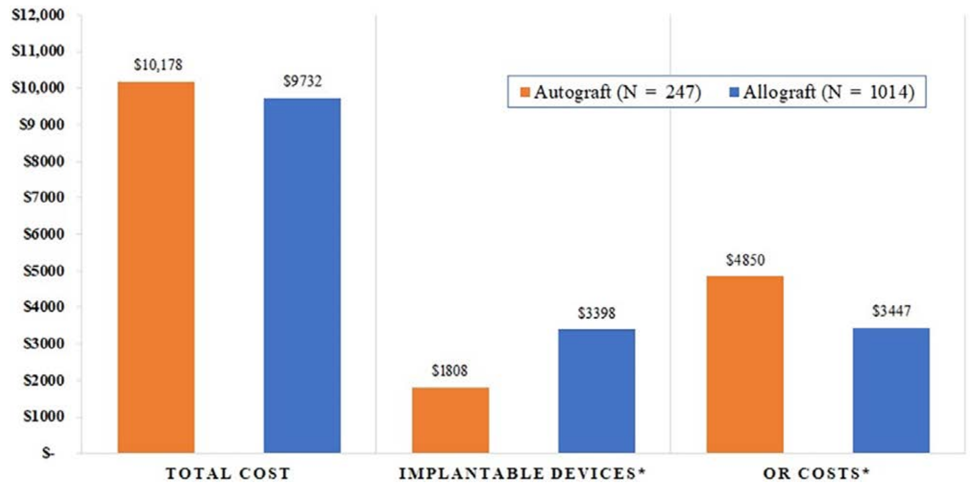

Fig. 2. Outpatient descriptive costs of nerve graft repair type (n = 1261).

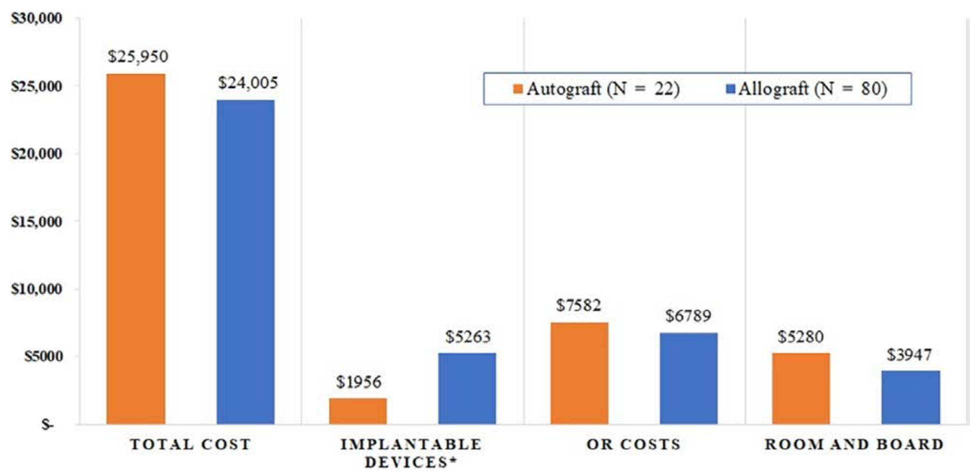

Fig. 3. Inpatient descriptive costs of nerve repair graft type (n = 102).

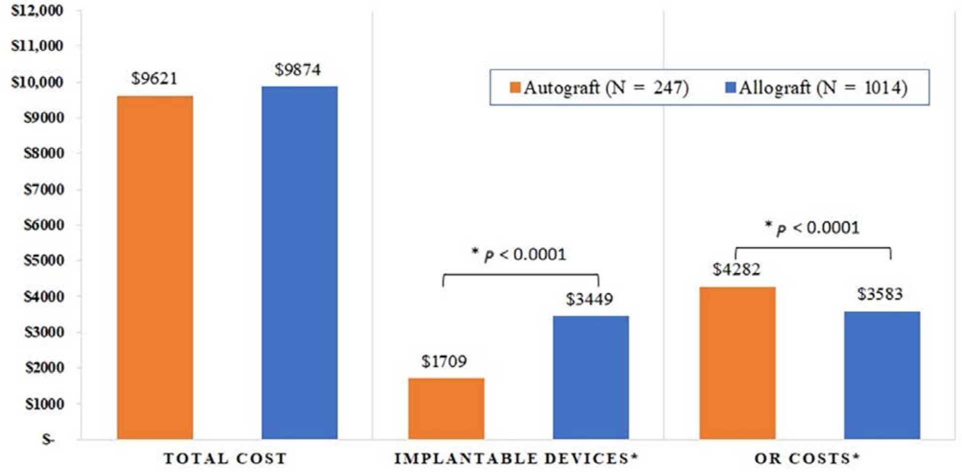

Fig. 4. Outpatient mean predictive regression costs of nerve graft repair type (n = 1261).

Inpatient Multivariable Analysis

Inpatient multivariable analyses were conducted with total cost of care, implantable cost, OR cost, and R&B cost as the dependent variables. Risk–adjusted mean predicted costs based on recycled prediction for allograft and autograft nerve repair procedures are shown in Figure 5. Among inpatients there was no statistical difference between mean autograft versus allograft total cost ($23,694 and $24,733, $P = 0.71$) after controlling for all other factors. Mean implantable cost was significantly lower for autograft versus allograft nerve repair procedures ($1758 and $5404, $P < 0.0001$). There were no statistically significant differences between autograft versus allograft nerve repair procedures in mean OR cost ($7497 and $6843, $P = 0.46$), or R&B cost ($5008 and $4626, $P = 0.67$).

Irrespective of nerve graft repair type, many inpatient covariates were significantly associated with total cost, implant, OR, and R&B costs. (**See table 4, Supplemental Digital Content 7,** which shows results of multivariable regression analysis of component costs of care among inpatients receiving allograft and autograft nerve repair procedures, **http://links.lww.com/PRSGO/C482**.) Race was significantly associated with inpatient total cost, implant, OR, and R&B costs ($P < 0.05$). Ethnicity and hospital size was also significantly associated with total cost, OR, and R&B costs ($P < 0.05$); additionally, total cost, implant, and R&B costs were affected by insurance type and geographic region while total costs, OR, and R&B costs were associated with nerve injury location and CCI ($P < 0.05$). Finally, total cost and R&B costs were associated with Medicare Severity Diagnosis Related Group, whereas R&B cost was also significantly associated with teaching status and age ($P < 0.05$).

DISCUSSION

Although historically autograft nerve repair has been the gold standard for peripheral nerve injuries, it is revealing that autografts were used less frequently than allografts in the PHD dataset. We observed the same trend across all peripheral nerve graft cases (including non-isolated and non-DRG 040-042 nerve graft repairs). Only 563 autograft cases were identified in the PHD to allograft's 1718 cases. The PHD is an all-payer, geographically diverse administrative database that contains discharge files from one in every five inpatient and outpatient hospital discharges in the United States, and has shown nerve allograft repair to be the most utilized procedure for nerve graft repairs. This is likely due to the potential drawbacks of nerve autografts including harvest site complications, increased surgical time, and associated OR costs.

To our knowledge, this is the first study that provides real-world evidence using a large, all-payer database to examine the impact of nerve graft repair procedure type and patient demographics, hospital characteristics, and clinical characteristics on costs of care in inpatient and outpatient settings across US hospitals. We found no differences in total adjusted costs-of-care based on recycled prediction for allograft and autograft nerve repair procedures, even after controlling for other risk factors. Mean OR cost was significantly lower for allograft versus autograft nerve repair procedures in outpatient settings and directionally lower, although not statistically significantly different, among inpatient cases. Differences in adjusted costs reflect differences, in part, in OR time. The mean predicted OR time was significantly higher for autograft versus allograft nerve repairs in both inpatient and outpatient settings (315.6 versus 301.9 minutes for inpatients and 211.7 versus 171.2 minutes for outpatients respectively), after adjusting for payer type, location of injury, Medicare Severity Diagnosis Related Group (for inpatients), hospital teaching status, urban versus rural setting, hospital bed size, US region, patient comorbidities, age, gender, race, and ethnicity ($P < 0.001$). This is consistent with the clinical literature, given the potential for increased OR time and the need for a harvest site for autograft nerve repair procedures.[5,11,14] There was no significant difference in mean R&B cost between autograft and allograft nerve repair procedures with average costs

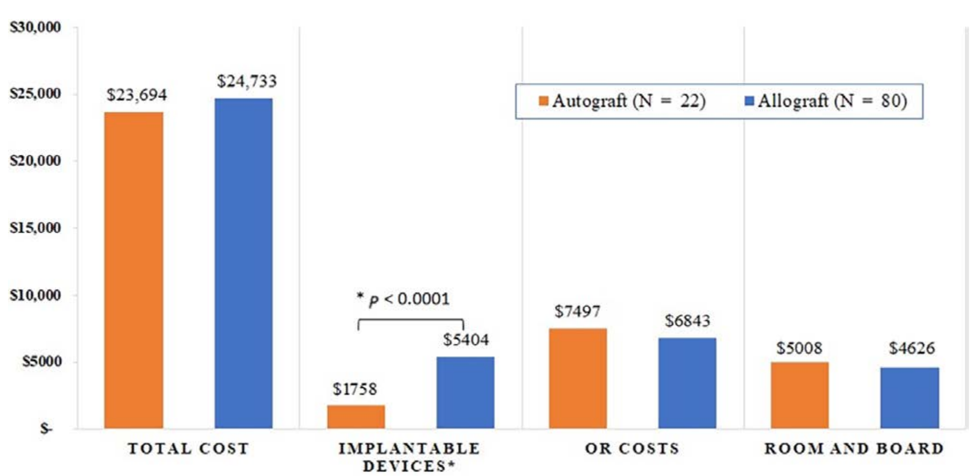

Fig. 5. Inpatient mean predictive regression costs of nerve graft repair type (n = 102).

directionally lower, although not statistically significant, for allograft nerve repairs. The Lans et al study reported lower total costs of care for allograft versus autograft repair in the inpatient setting ($25,751 and $29,560 respectively) and similar costs for allograft versus autograft repair in outpatient settings ($13,143 and $12,635, respectively) from an analysis of the 2018 Medicare Standard Analytic File. However, it is important to note that compared with the current study, the Lans study was conducted with Medicare fee-for-service hospital claims, and, in addition, multivariable analysis was not conducted to explore adjusted cost differences between the nerve repair types.[19]

Not surprisingly, among inpatients and outpatients, mean implantable cost was significantly higher for allograft versus autograft nerve repair procedures but this was offset by savings in OR and R&B costs among allograft cases. A higher implantable cost was also observed among inpatient versus outpatient allograft nerve repair cases. Allograft costs vary by length and diameter, and it is likely that inpatient cases experienced more serious, proximal injuries with larger nerve gaps compared with outpatient cases. Inpatient cases saw a higher proportion of cases occurring in non-wrist/hand injuries among allograft nerve repair procedures (59% versus 45%). Additionally, larger nerves are more likely to require an additional strand. Unlike in the allograft outpatient group, inpatient procedure codes do not differentiate between cases with an "add on" allograft strand and could not be addressed. Therefore, our methodology and statistical analysis stratified by inpatient versus outpatient setting, given these anticipated differences in cost components across treatment settings.

The PHD is a hospital administrative database and not an electronic health records system, and the identification of clinical procedures relies on the accuracy of the hospital-reported procedure codes and hospital charge master descriptions. This study does not examine or integrate nerve repair functional outcomes and makes no assertions on the effectiveness of nerve graft reconstruction.

This study examined direct costs of care associated with the index hospital visits and does not include any direct or indirect health care costs resulting from potential visits related to postsurgical complications, follow-up treatment, rehabilitation, or disability. This is also a needed area for future study, because there are virtually no studies on longer-term costs of care for nerve injuries.[28] Future studies on multiple nerve repairs would be of interest, as the cost analysis of the study was limited to single nerve repairs.

In summary, our findings on health care costs comparing allograft with autograft nerve repairs, along with the clinical outcomes of allografts documented in prior published studies on functional sensory and motor outcomes, add to the evidence base that allografts represent a cost comparable alternative for peripheral nerve repair procedures. Having information on procedural costs can help support surgeon choice of high-value interventions.

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DISCLOSURES

Dr. Greenberg is an Axogen educational consultant and owns Axogen stock. He is also a board member of the Global Nerve Foundation. Dr. Endress is an Axogen consultant. Dr. Styron is an Axogen consultant. Dr. Emont is a Principal Research Scientist and full-time employee of PINC AI Applied Sciences, Premier Inc., Charlotte, North Carolina, which received funding from Axogen Inc. to conduct the study. He reported stock ownership in Premier Inc. during the conduct of the study. Dr. Cao is a Senior Principal of Applied Research and full-time employee of PINC AI Applied Sciences, Premier Inc., Charlotte, North Carolina, which received funding from Axogen Inc. to conduct the study. She reported stock ownership in Premier Inc. during the conduct of the study. Mr. Park is the Director of Health Economics at Axogen Inc. and owns Axogen stock. This study was sponsored and funded by Axogen Corporation, Alachua, Florida.

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