

Neural Monitoring for Robotic Abdominal Wall Reconstruction

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ABSTRACT

Introduction: Positioning-related neural injuries are an inherent risk in surgery, particularly in robotic-assisted abdominal wall reconstruction because of unique patient positioning and increased operative times. The implementation of intraoperative neurophysiological monitoring should be considered in such cases.

Methods: This was a two-armed study with one prospective intervention group and one retrospective control group. All patients underwent robotic abdominal wall reconstruction at an academic center. The prospective arm underwent robotic reconstruction from January through July 2019. The retrospective database reviewed patients who underwent the same procedure from August 2015 through July 2018. Factors assessed included: demographics (age, gender, body mass index, comorbidities), surgical details (American Society of Anesthesiologists class, procedure, operative time, positioning), outcomes (length of stay, 30-d readmission, reoperation), and any new-onset intraoperative or postoperative neuropathy. Patients were seen in the clinic postoperatively at weeks 1 and 6.

Results: Ten patients were included in the prospective arm. All received intraoperative neurophysiological monitoring using somatosensory evoked potentials. They were compared with 47 patients in the retrospective arm who underwent surgery without intraoperative neurophysiological

monitoring. One position-related neural response from baseline was detected intraoperatively in the prospective arm; however, there were no peripheral neurological symptoms present postoperatively. Two patients in the control group developed transient peripheral neuropathies that resolved within 6 weeks. Demographics, surgical procedures, and length of surgery were similar in both groups. The prospective group had a higher rate of preoperative neuropathy and intraoperative use of vasopressors.

Conclusion: Incorporation of neurophysiological monitoring in robotic surgery is feasible and may lead to the prevention and reduction in positioning-related injuries.

Key Words: Patient safety; Position-related injury; Intraoperative neurophysiological monitoring; Somatosensory evoked potentials; Robotic surgery; Robotic abdominal surgery

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INTRODUCTION

Position-related neural injuries are an inherent risk in surgery. The incidence of peripheral nerve injury varies with surgical procedure and positioning. The current incidence of neuropathy following robotic-assisted surgery (RAS) has been reported as high as 6.6%.^{1,2} Most injuries are transient, with complete resolution weeks to months following surgery, yet 22.7% of nerve injuries have been reported to persist longer than 6 months. Incidents of permanent neuropathy have been reported.^{2,3}

Known risk factors for positioning injuries resulting in nerve damage include increased operative time (>4 h), a history of smoking, a history of illness associated with neuropathy (e.g., diabetic neuropathy), and an elevated body mass index (BMI; >35 kg/m²), particularly in patients with greater muscle mass indices.²⁻⁴ A lower BMI (<20 kg/m²) has also been associated with a greater risk for neuropathy in procedures performed in the lithotomy position.^{3,5}

Intraoperative neurophysiological monitoring (IONM) using somatosensory-evoked potentials (SSEP) is a safe, highly sensitive, and noninvasive tool for detecting neural injury.⁶ The technique was first described in the 1980s by

Perot and over the years has evolved in clinical application for neurological, spinal, vascular, and thyroid surgeries.⁷ IONM delivers objective and real-time data, thereby allowing the surgeon and staff to intervene in an effort to reduce the potential for position-related injuries.⁸

Robotic abdominal wall reconstruction is a rapidly evolving technique that offers patients' unique advantages over open surgery.⁹ In our early experience with this technique at our institution, two of our patients developed transient postoperative neuropathies that were believed to be secondary to position-related nerve injuries. These injuries served as sentinel events that were the impetus for this study. To our knowledge, there are no published studies that have looked at IONM and positional injuries specifically in robotic-assisted abdominal wall reconstruction (r-AWR). This study serves as a pilot study to evaluate the feasibility and efficacy of implementing neural monitoring in an attempt to detect and decrease the incidence of position-related neural injuries on high-risk patients undergoing robotic abdominal wall reconstruction. The unique patient position of lumbar extension with arms tucked often utilized during r-AWR may predispose high-risk patients to position-related neural injuries. We aim to heighten awareness of this potentially serious injury as the utilization of the robotic platform for AWR becomes increasingly prevalent.

METHODS

Recruitment

This was an institutional review board–approved, two-armed study with one prospective intervention group and one retrospective control group. The prospective data were acquired from patients who underwent r-AWR from January through August 2019 with a single surgeon (D.K.H.) at an academic tertiary care center. Independent demographic variables included age, BMI, gender, race, and medical comorbidities (hypertension, hyperlipidemia, obstructive sleep apnea, osteoarthritis, diabetes mellitus, tobacco abuse, peripheral neuropathy, and any notable spinal deformities). Surgical details included the procedure performed, total operating time, patient position, length of hospital stay, American Society of Anesthesiologist (ASA) class, use of intraoperative vasopressors, blood transfusion, and estimated blood loss.¹⁰ Demographics, surgical procedure, and length of surgery were similar in both groups. We attempted to select patients in the prospective group who were at higher risk for intraoperative neural injury. Those patients with extremes of BMI, a smoking history, a history of spinal stenosis or

deformity, persons with diabetes, or patients with preexisting neuropathy were specifically selected to undergo intraoperative neural physiological monitoring. Postoperatively, patients were seen daily by the surgeon until discharge and scheduled for outpatient follow-up at 1–2 wk and 6 wk. Additional or unscheduled visits were also documented. During all follow-up visits, patients were asked about new-onset numbness, tingling, or weakness in both upper and lower extremities.

The retrospective cohort arm was selected from a database of patients who underwent r-AWR by the same surgeon from January 2015 through July 2018. Patients who met the same inclusion criteria with regard to age, BMI, and type and length of operative procedure and those with similar risk factors for position-related neural injury were culled. The data for these variables were reported. These patients did not receive IONM.

Procedure

The IONM services were supplied by Physiologic Assessment Services, LLC (Mineola, New York) and run by a board-certified provider of the American Society of Neurophysiological Monitoring. Technological supervision, interpretation, and diagnostic and therapeutic suggestion were observed intraoperatively.⁸ A real-time connection with the monitoring physician was established and maintained throughout the operative procedure by the monitoring neurophysiologist. Any observations noted by the IONM monitoring technologist during the procedure were immediately brought to the attention of the anesthesiologist and surgeon in the operating room.

Upper-extremity SSEPs were stimulated using bipolar surface electrodes placed bilaterally at each wrist. Sterile subdermal recording electrodes were placed at Cz', Fpz, C3', C4', and C5' spinous process for recording cortical and subcortical (brainstem) responses. Lower-extremity SSEPs were stimulated using bipolar surface electrodes placed bilaterally at each ankle. An event log with the tracing was collected approximately every 1–2 min throughout the surgical procedure and at any point in which the patient or operating table position was changed (**Figure 1**). Change in baseline was defined as a latency increase of 10% and an amplitude decrease by 50%.

Statistical Analysis

Descriptive statistics (mean \pm standard deviation and median for continuous variables; frequencies and percentages for categorical variables) were calculated separately by group.

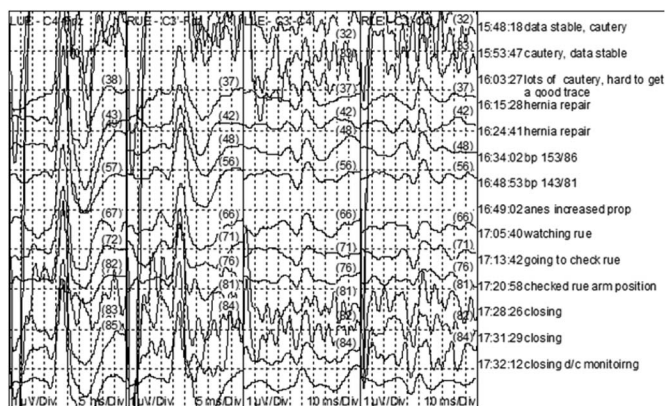


Figure 1. The event log and monitoring report are shown in real-time connection during the operative procedure and actively maintained by the monitoring neurophysiologist at the bedside.

The two groups were compared using the Fisher’s exact test for categorical variables and the Mann-Whitney test, the nonparametric counterpart to the two-sample *t* test, for continuous data.

A result was considered statistically significant at the *P* < .05 level of significance. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Patient characteristics, intraoperative findings, surgical procedure details, and postoperative morbidities are reported in **Tables 1-4**.

A total of 47 procedures in the retrospective and 10 procedures in the prospective group were compared. All patients underwent r-AWR using bilateral retrorectus release with or without transversus abdominis release (**Table 1**). In addition to abdominal wall reconstruction, 60% of patients in the prospective group underwent concom-

itant inguinal hernia repair, as opposed to 12.8% in the retrospective group. The rate of panniculectomy (20% vs. 0%, *P* < .028) was also higher in the prospective group than in the retrospective group. Operative time was the same in both groups (**Table 3**).

The age, demographics, and BMI were similar between the two arms (**Table 2**). The length of hospital stay between both arms were similar (*P* < .348), and the difference in readmission and reoperation rates were not statistically significant. All but one patient were placed in the supine position.

The rate of preoperative peripheral neuropathy (20% vs. 0%, *P* < .028) and intraoperative use of vasopressors (40% vs. 0%, *P* < .001) was higher in the prospective group. The rate of tobacco usage, osteoarthritis, spinal deformity, and ASA grade were also higher in the prospective group. None of these differences had a value of *P* < .05 and therefore were not statistically significant.

Estimated blood loss >50 mL occurred in 8.5% of patients in the retrospective group and was zero or negligible in all patients in the prospective group. No patients received a blood transfusion.

Two patients (4.3%) in the retrospective arm experienced transient nerve injury because of bilateral ulnar nerve neuropraxia (**Table 4**). Both patients were obese persons with diabetes, and one patient had a history of a lumbar herniation. Neither had preoperative peripheral neuropathy. The operative times for both patients exceeded 4 h. Both patients underwent r-AWR using transversus abdominis release. One patient had bilateral transient paresthesia in the ulnar distribution and weakened grip strength postoperatively that resolved by week 6. The other patient had numbness and tingling in the ulnar distribution of both hands that resolved within 24 h.

Table 1.
Surgical Procedure by Procedure Type

Variables	Retrospective (n = 47)	Prospective (n = 10)	<i>P</i> Value
Bilateral transversus abdominis muscle release	22 (48.81%)	4 (40.0%)	.658
Unilateral transversus abdominis muscle release	4 (8.51%)	0 (0.0%)	
Bilateral retrorectus repair	21 (44.7%)	6 (60.0%)	
Panniculectomy ^a	0 (0.0%)	2 (20.0%)	.028
Bilateral inguinal repair ^a	2 (4.26%)	4 (40.0%)	.002
Unilateral inguinal repair ^a	4 (8.51%)	2 (20.0%)	

^aSecondary procedure performed at time of abdominal wall reconstruction.

Table 2.
Patient Characteristics for Both Study Arms

Variables ^a	Retrospective (n = 47)	Prospective (n = 10)	P Value
Age (y)	60.2 ± 12.3 (median = 62)	61.9 ± 13.9 (median = 64)	.522
BMI (kg/m ²)	34.8 ± 6.8 (median = 34)	33.4 ± 6.9 (median = 31)	.469
Race			.530
Asian	1 (2.1%)	0 (0.0%)	
Black	1 (2.1%)	1 (10.0%)	
Hispanic	4 (8.5%)	0 (0.0%)	
White	41 (87.2%)	9 (90.0%)	
LOS (days)	1.5 ± 1.7 (median = 1)	1.1 ± 1.1 (median = 1)	.348
Smoking			
Former	27 (57.5%)	5 (50.0%)	.223
Never	18 (38.3%)	3 (30.0%)	
Current	2 (4.2%)	2 (20.0%)	
Medical comorbidities			
HTN	31 (66.0%)	5 (50.0%)	.473
HLD	14 (29.8%)	6 (60.0%)	.141
OA	9 (19.2%)	5 (50.0%)	.099
OSA	6 (12.8%)	1 (10.0%)	1.000
DM	17 (36.2%)	3 (30.0%)	1.000
GERD	11 (23.4%)	5 (50.0%)	.120
Preoperative peripheral neuropathy	0 (0.0%)	2 (20.0%)	.028
Spinal deformity or radiculopathy	16 (34.0%)	4 (40.0%)	.728

HTN, hypertension; HLD, hyperlipidemia; OA, osteoarthritis; OSA, obstructive sleep apnea; DM, diabetes mellitus; GERD, gastroesophageal disease.

^aContinuous measures are presented as mean ± SD (median); categorical variables are reported as n (percentage).

One patient in the prospective arm was noted to have an identified change in waveform using IONM (**Figure 2**). This patient had a history of a spinal fusion 2 years prior for lumbar degenerative disc disease. The patient's surgery was less than 4 h. A slight decrease in amplitude was noted from SSEP at the right ulnar nerve. The arm was untucked and repositioned, which restored the amplitude of the tracing to baseline. The patient did not have any immediate postoperative numbness or tingling. No neuropathic symptoms were noted during postoperative follow up visits.

DISCUSSION

Nerve injury after robotic abdominal wall reconstruction is a frightening and potentially devastating event for both the patient and physician. This could lead to increased hospital length of stay, increased overall recovery time, and increased need for additional rehabilitation resources (e.g., occupa-

tional, physical). Quality of life may be significantly affected as well. Although an uncommon event, proper precautions should be taken to avoid subsequent injury. Therefore, as RAS becomes increasingly prevalent among surgical subspecialties, early recognition and understanding of perioperative peripheral nerve injury (PPNI) can assist in optimizing patient safety, mitigating legal claims and creating a higher standardization in the surgical community.

The basic mechanisms of injury for PPNI include compression, stretch, ischemia, and direct nerve trauma.^{11,12} Stretch injuries are the most common type and can occur with intraoperative shifting and sliding.¹² With improper positioning, the traction force of the inherent elasticity of the nerve's capacity exceeds its stretch ability, resulting in injury. This can be seen during initial patient positioning when excessive arm abduction with external rotation and posterior shoulder dis-

Table 3.
Perioperative Findings and Details for Both Arms

Variables ^a	Retrospective (n = 47)	Prospective (n = 10)	P Value
Mean total operative time (min)	249.6	249.8	
Estimated blood loss (cc)			.027
Minimal	16 (34.0%)	10 (100.0%)	
<50 cc	19 (40.4%)	0 (0.0%)	
≥50 cc	11 (23.4%)	0 (0.0%)	
300 cc	1 (2.1%)	0 (0.0%)	
1	1 (2.1%)	0 (0.0%)	.663
2	24 (51.1%)	4 (40.0%)	
3	21 (44.7%)	6 (60.0%)	
4	1 (2.1%)	0 (0.0%)	
Use of pressors	0 (0.0%)	4 (40.0%)	.001
Supine	46 (97.9%)	10 (100.0%)	1.000
Dorsal lithotomy	1 (2.1%)	0 (0.0%)	

^aData are presented as n (percentage).

Table 4.
Postoperative Morbidities Among Patients in Both Study Arms

Variables	Retrospective	Prospective	P Value
24-h postoperative neuropathy	2 (4.3%)	0 (0.0%)	1.000
1- to 2-wk postoperative neuropathy	1 (2.1%)	0 (0.0)	
6 weeks after operative neuropathy	0 (0.0%)	0 (0.0%)	
LOS (days)	1.5 ± 1.7 (median = 1)	1.1 ± 1.1 (median = 1)	.348
30-day readmission	2 (4.3%)	0 (0.0%)	1.000
30-day reoperation	1 (2.1%)	0 (0.0%)	1.000
Unscheduled visit	0 (0.0%)	1 (10.0%)	.175

placement places considerable stretch on the brachial plexus.¹¹ With compression, the underlying mechanism is controversial and may result from the disruption of vascular flow and decreased perfusion. This leads to temporary ischemia and loss of conduction. More severe compression may be explained by endoneurial edema, causing elevated intraneural pressure that impairs the blood-nerve barrier. The damage in flow leads to demyelination and subsequent axonal degeneration but is reversible if addressed in a timely manner.^{11,13}

At our institution, two cases of transient upper-extremity neuropraxia following r-AWR served as sentinel events for the investigation of position-related nerve injury in this patient population. Both patients were morbidly obese,

were positioned with their arms tucked and placed in lumbar extension. Operative time was longer than 4 h in both instances. In addition, during portions of the procedure, the operating table was rotated to both left and right sides; rotating the operating table toward the contralateral side of the myofascial release being performed facilitated exposure of the operative field by allowing the viscera to fall away from the abdominal wall. This technique is sometimes used in obese patients. An undesirable result of rotational positioning is that it partially shifts the weight of the abdomen onto the ipsilateral arm. In r-AWR, the ulnar nerve's proximity to the medial epicondyle places it at the highest risk of compression nerve injury after prolonged immobilization. The exact mechanism of ulnar

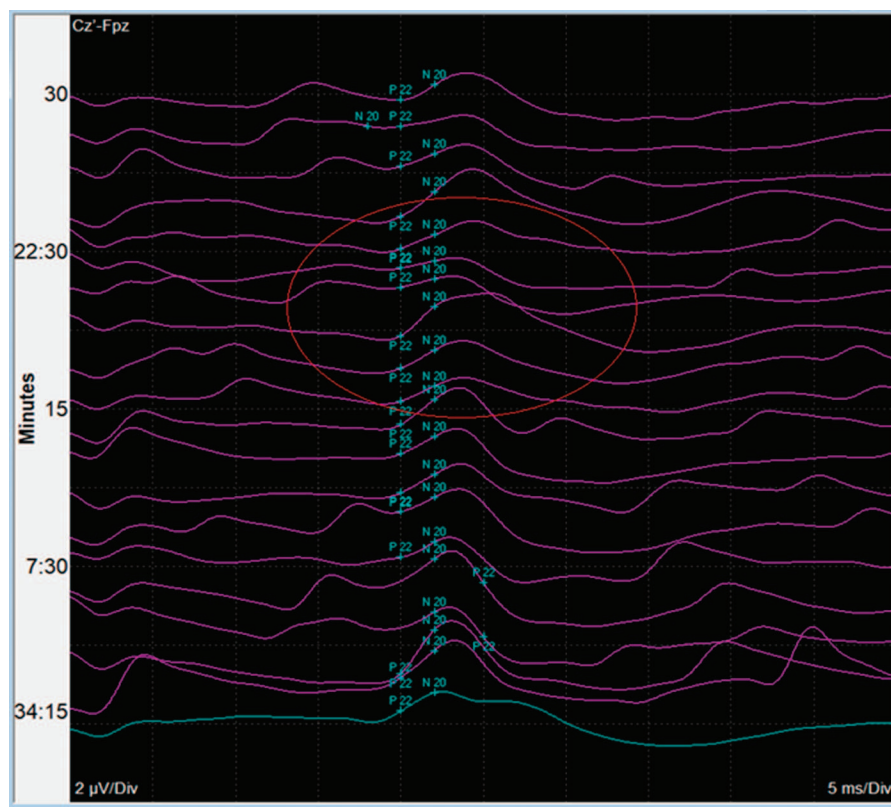


Figure 2. The tracing highlights the one patient in the prospective arm noted to have SSEP changes. The circled region shows a slight decrease in amplitude. During this time the surgeon was notified and the arm position was checked by removing it from a tucked position and repositioning it. The amplitude returned to normal after repositioning.

injury in these two patients is not clear. Etiologies include compression of the ulnar nerve from inadequate padding, excessive compressive force applied to the nerve from patients' obesity and rotational positioning, prolonged operative time, or a combination of the above.

Cases of transient lower extremity sensory and motor neuropathy after r-AWR have also been reported on the International Hernia Collaborative.¹⁴ These patients had a history of spinal disc disease and were placed in lumbar extension during surgery. Lumbar extension is often used in r-AWR to provide for proper spacing between trocars in an attempt to avoid internal and external collisions of the robot arms or instruments during surgery (**Figure 3**). Lumbar extension increases the angle between the costal margin and iliac crest, thereby lengthening the distance between these two structures and allowing more room for trocar placement. This is particularly important on the robotic da Vinci Si system when the patient has a short torso or when trocars need to be placed very lateral on the abdominal wall. The Xi robotic platform allows for more flexibility in trocar placement.

The unique position of lumbar extension sometimes required for r-AWR also has the potential to alter neural foraminal size and cause transient nerve root compression.^{15,16} We have developed a practice of avoiding lumbar extension whenever possible. Whereas there is no literature that specifically looks at the outcomes of this modified supine positioning to our knowledge, we strongly recommend caution be taken with patients that have a history of spinal injury or deformity, degenerative disc disease, or previous spinal surgery.

In the prospective intervention group, one patient developed a transient upper-extremity neural response toward the end of their procedure. The arm was repositioned, and SSEP returned to normal. The change in amplitude on SSEP at the right ulnar nerve detected on IONM was likely secondary to nerve compression. Although it cannot be certain, we believe that early detection of these changes and patient repositioning likely avoided potential nerve injury. Alternatively, the changes may have been artifactual, possibly related to poor contact of the electrode with the skin and/or extremity compression. Further studies using a larger cohort of patients



Figure 3. This is a typical position of a patient undergoing r-AWR, with the bed arms tucked and flexed to create the lumbar extension. Lumbar extension is often used to provide proper spacing between trocars to avoid internal and external collisions of the robotic arms during surgery.

will need to be performed to determine the efficacy of IONM in preventing postoperative nerve injury during robotic abdominal reconstruction. No untoward events occurred as a result of IONM in this study. Complications of hematoma, skin laceration, infection, or allergic reaction associated with SSEP IONM are rare.

In all instances during the prospective trial, the neurophysiologist was able to establish monitoring without delaying the surgical start time. Peripheral electrodes were placed before the induction of anesthesia simultaneously with the placement of electrocardiographic electrodes, pulse oximetry monitors, and sequential compression stockings. Scalp electrodes, cable positioning, and final setup was achieved after intubation during foley insertion, cautery ground pad placement, and final patient repositioning. This process allowed for seamless integration of IONM with the established presurgical intraoperative patient preparation protocol.

PPNI involves a complex interplay between patient risk factors, neuronal reserve, and intraoperative prevention measures.¹⁷ Preoperative patient selection and counseling remain integral prior to offering patients RAS. Patients with comorbid medical conditions including diabetes mellitus and smoking are at increased risk of neural injury secondary to compounded neuronal injury from metabolic and hypoxic insult.¹⁸ Other reported risk factors include male gender, extremes of BMI, operative time longer than 4 h, and higher functional ASA class.^{5,12,19} Obesity is known to increase the risk of neuropraxia from increased compression and bony

prominences; compression can cause ischemic insult and subsequent injury to the nerve. Mills et al.² report that patients who underwent robotic urologic procedures with multiple comorbidities, therefore higher ASA, were strongly associated with peripheral nerve injury ($P = .003$). The presence of these risk factors should guide the operating surgeon and team to consider the potential pitfalls that could affect patient outcome.

Ferullo¹⁹ suggests that a preoperative risk assessment tool may assist surgeons in stratifying high-risk and vulnerable patient groups to potentially minimize nerve injury. In addition to an assessment, a secondary nursing care plan in the perioperative setting to address and evaluate the patient could be incorporated simultaneously. During operations longer than 4 h, there is an intraoperative evaluation of the patient's positioning, revisiting early protection precautions (e.g., safety devices and padding), checking peripheral tissue perfusion, and ensuring adequate palpable pulses bilaterally.²⁰ Patient positioning and repositioning during RAS can increase the risk for nerve injury. Despite the patient being optimized prior to the start of the procedure, intraoperative shifts can alter the contact pressure; downward or lateral slipping during the case can lead to additional stretch, compression, and increase the risk of injury.

RAS has increased the possibilities for performing minimally invasive surgery on higher-risk patients with previous anatomical barriers. The characteristics of this patient population suggest that risks may not be modifiable despite preoperative consideration and that PPNI is likely multifactorial.²¹ Traditionally, abdominal wall reconstruction and large incisional hernias were performed in an open fashion. The complexity of the surgery and patient population can be technically challenging for the surgeon. These technical challenges are amplified as surgeons ascend their learning curve. As such, the surgeon's focus may be diverted toward completing the procedure and away from the awareness of potential position-related nerve injury.

At this time, IONM is indicated for spinal surgery, intracranial procedures, and thyroidectomies and is controversial with vascular procedures including carotid endarterectomies and aortic procedures.²² We recommend that it be considered for patients that meet high preoperative risk assessment for position-related neural injuries during r-AWR. This recommendation is based on two observations. First, intraoperative monitoring may allow early detection of injury and thereby enable real-time modification of the procedure and patient positioning to avoid injury. Second, with increased utilization of the robotic platform for AWR, more patients will likely suffer position-related nerve injuries if the incidence of injuries remains stable. A heightened

awareness of these injuries is important, particularly as surgeons progress along their learning curve.

Limitations

The limitations of this study include a nonrandomized and small cohort of patients. Whereas a control group does allow for a more realistic comparison, the inherent nature of a small sample denies the generalizability to a clinically meaningful application. Further longitudinal, larger cohort studies are needed to assess the incidence of neuropraxia for patients that undergo r-AWR surgery.

CONCLUSION

Surgeons should increase their awareness of position-related neural injuries and discuss the risk of such injuries with their patients. IONM has a proven efficacy in detecting and decreasing position-related neural injuries during certain surgeries. The unique positioning and extended operating times necessary to complete r-AWR are inherent risk factors for position-related neural injuries. As the implementation of r-AWR increases, the number of patients who suffer position-related neural injuries will likely increase. The utilization of IONM during r-AWR is feasible, may decrease the risk of position-related injuries, and will increase the awareness of such injuries. Consideration should be given to standardizing the use of IONM for all patients with multiple preoperative risk factors undergoing robotic assisted surgery.

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