S ORIGINAL ARTICLE

Intraoperative nerve monitoring during total shoulder arthroplasty surgery

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ABSTRACT

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Conflicts of interest

None declared.

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Background Nerve injury is an acknowledged complication of total shoulder arthroplasty (TSA). Although the incidence of postoperative neurological deficit has been reported to be between 1% and 16%, the true incidence of nerve damage is considered to be higher. The present study aimed to identify the rate of intraoperative nerve injury during total shoulder arthroplasty and to determine potential risk factors.

Methods A prospective study of nerve conduction in 21 patients who underwent primary or revision TSA was carried out over a 12-month period. Nerve conduction was monitored by measuring intraoperative sensory evoked potentials (SEP). A significant neurophysiological signal change was defined as either a unilateral or bilateral decrease in SEP signal of $\geq 50\%$, a latency increase of $\geq 10\%$ or a change in waveform morphology, not caused by operative or anaesthetic technique.

Results Seven (33%) patients had a SEP signal change. The only significant risk factor identified for signal change was male sex (odds ratio 15.00, 95% confidence interval). The median nerve was the most affected nerve in the operated arm. All but one signal change returned to normal before completion of the operation and no patient had a persisting postoperative clinical neurological deficit.

Conclusions The incidence of intraoperative nerve damage may be more common than previously reported. However, the loss of SEP signal is reversible and does not correlate with persisting clinical neurological deficits. The median nerve appears to be most at risk. Monitoring SEPs in the operated limb during TSA may be a valuable tool during TSA.

INTRODUCTION

Nerve dysfunction is one of several recognized and reported complications of total shoulder arthroplasty (TSA). A small number of studies have reported clinically-diagnosed nerve injury rates after shoulder arthroplasty, with a reported incidence of between 0.6% and 16.7% [1–5]. The rate of intraoperative nerve injury may be higher than reported because these studies failed to identify subtle or subclinical neurological deficits that would only be seen with neurological monitoring.

A number of causes of intraoperative nerve deficits have been identified, including extrusion of cement, nerve lacerations and incorporation of the nerve into suture lines [6,7]. However, little is known about the other physiological effects on neural structures during TSA; for example, the affects of ischaemia, traction of nerves as a result of arm positioning/retraction and the relationship of these with other factors, such as operative time, blood loss and patient age.

To our knowledge, only one study performed by Nagda et al. has examined intraoperative nerve dysfunction during shoulder arthroplasty using intraoperative nerve monitoring (IONM) [1]. This demonstrated a 57% rate (17 patients) of IONM alerts in 30 patients with five developing new postoperative neurologic deficits, all of which resolved within 6 months [1].

Intraoperative nerve monitoring of peripheral and central nerves is an established practice, particularly in spinal surgery in which sensory evoked potentials (SEP) and motor evoked potentials (MEP) are used to identify neurological compromise [8]. SEPs are also used for monitoring nerves during peripheral nerve hip, vascular and neurocerebral surgery [9–15].

The present study aimed to assess the incidence of nerve dysfunction during TSA using IONM and to identify possible pre-operative and/or intraoperative nerve injury risk factors.

MATERIALS AND METHODS

After receiving ethical approval, adult patients (aged >18 years) undergoing primary or revision elective TSA between January 2009 and January 2010 were invited to participate in the present study. Because the aim was to investigate new intraoperative deficits, we did not exclude patients with pre-existing neurological deficits. No specific exclusion criterion was specified, apart from patients who received any form of brachial plexus nerve block for intraoperative pain management.

A power calculation was carried out to identify the optimum study sample size using statistical models described by Machin et al. [16] (Table 1). Given the paucity in the literature with

respect to the incidence of nerve alerts when IONM is used for TSA, the percentage incidence and error calculated in the study by Nagda et al. was used for our power calculations [1].

Participant gender, age, body mass index (BMI), co-morbidities (in particular diabetes mellitus), diagnosis for surgery, stage of surgery (primary or revision), prior shoulder surgery, pre- and postoperative neurology (characterized as altered sensation or power of the shoulder/limb), the prosthesis type, operation time and operative blood loss were all recorded. We were specifically interested in measuring the alterations in intraoperative neurological function; however, detailed assessment, both pre-operatively and a day 1 post-operative neurological assessment, was performed in a standard (consistent) fashion by the junior doctor and, subsequently, by other medical and physiotherapy staff in the outpatient setting if symptoms demanded.

A standard surgical procedure was used, which included a standard deltopectoral approach in a semi-beach chair position with the use of an arm board where required. The conjoint tendon was not routinely released. The axillary nerve was visualized in all cases but not mobilized, other than to ensure its safety during inferior capsular release. The non-operative limb was placed alongside the patient's body with padding at the elbow and maintenance in approximately 20° to 30° flexion and slight internal rotation. A variety of implants were used and the procedure was performed by one of three experienced consultant shoulder surgeons. No regional anaesthesia was used, and anaesthetic techniques were consistent for all cases.

During the procedures, interleaved SEPs were elicited through suprathreshold monophasic square-wave bipolar transcutaneous electrical stimulation (0.2 milliseconds pulse width, 2.7 Hz to 4.1 Hz, 30 Hz to 1000 Hz band-pass, 10 mA to 25 mA, 50 ms timebase, averaged 100 times) over the median, ulnar and superficial radial nerves at the wrists. Unilect electrodes (Unomedical, Stonehouse, UK) and wires (Viasys Healthcare, Warwick, UK) covered with sterile drapes (Molnlycke Health Care, Goteborg, Sweden) were used to stimulate the nerves. Neurophysiological signals were recorded from Neuroline (Ambu, Ballerup, Denmark) surface electrodes at the C2/3 cervical intervertebral space, after preparation with Nuprep (Viasys Healthcare) abrasive gel and wiped with an alcohol swab (Uhs, Enfield, UK). Reference and ground electrodes were placed on the patient's forehead. Electrode impedance was $<3\text{ k}\Omega$.

Throughout the procedure, SEP signals were measured at intervals of 4 min to 5 min to baseline levels by a neurophysiological technologist. A significant signal change was defined as a unilateral or bilateral, sustained change in the SEP signals (decrease in trace amplitude of $\geq 50\%$, and/or a $\geq 10\%$ latency increase and/or a change in waveform morphology) that was not considered to be a result of technical or anaesthetic conditions. A persistent change indicated an increased likelihood of neurological deficit. If the trace recovered to near baseline levels, a reduction in the likelihood of neurological deficit was considered. A return to baseline after a significant change did

Table 1 Sample size/power calculations assuming the study by Nagda et al. was measured with error and was included in the uncertainty around the reported 57% [1]

Hypothesized trace changes in the operated arm	57% [1]	57% [1]
Hypothesized trace changes in the control arm	0%	0%
Probability of detecting this difference (power)	90%	80%
Significance level	5%	5%
Sample size required	30	15

not exclude potential postoperative deficit, although the prognosis was better. The SEP signals were analyzed as either normal or abnormal with no attempt to assess a scale of abnormality.

When a SEP signal change occurred, the surgical team were alerted, characteristics of the nerve change (sudden/gradual, amplitude decrease, latency increase), time, arm position and operative stage were documented. Any arm position was permitted in the standard operative technique, although the abduction/internal rotation, abduction/external rotation, and abduction/extension/any rotation positions were specifically studied. No difference in SEP activity between arm positions was noted. Monitoring, averaging and storage of signals were performed using the MEE-1000A system (Nihon Kohden, Tokyo, Japan). Statistical analysis was performed using univariate binary logistic regression analysis and Fisher's exact test using SPSS, version, 10 (SPSS Inc., Chicago, IL, USA).

RESULTS

Out of a possible 41 patients, 21 were recruited from our tertiary unit (Table 2). The 20 patients who were not included either opted to have a pre-operative nerve block or did not consent to participate. Of the 21 patients who participated in the study, seven (33%) had a significant neurophysiological signal change.

In these seven patients, four had a significant neurophysiological signal change in the operative arm only, one in the non-operative arm, and two on both arms. In the six patients (29%) who had a change in the operated side, the median nerve was found to be the most commonly affected (5/6), followed by the superficial radial nerve (2/6). Three patients (14%) had a signal change on the non-operated arm, with the ulnar nerve being the only nerve affected in all cases (Table 3).

In all but one case, nerve signals returned to baseline by the end of the procedure. No patient had a new postoperative neurologic injury, including the patient whose nerve signal change had not returned to normal.

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Table 2 Participant information

Sex	Male 7 (33%); Female 14 (67%)
Age (years)	Median 58, (33 to 83)
Body mass index	Average 28 (17 to 44)
Operation	Primary 12 (57%); Revision 9 (43%)
Diagnosis	Trauma 9 (43%); Osteoarthritis 7(33%); Other 5 (24%)
Previous surgery of the shoulder, including rotator cuff repairs	13 (62%)
Operation time (minutes)	Average 144 (71 to 240)
Intraoperative blood loss (mL)	Median 475 (50 to 2000)
Pre-operative neurology	Operated side 6 (29%); Non-operated side 0
Implants	Custom computer-assisted design/computer-assisted manufacturing (CAD/CAM) 8 (38 %); Bayley Walker 7 (33%); Other 6 (29%)

Table 3 Summary of patient results

Patient	Operated side			Non-operated side		
	Median	Ulnar	Superficial radial	Median	Ulnar	Superficial radial
1	X					
2	X		x		x	
3					x	
4	X					
5	X					
6			x			
7	X	x			x	
Total	7	5	1	2	3	

X, nerve alert at this site.

Univariate binary logistic regression analysis was used to determine whether the measured variables were associated with signal changes. Male sex was associated with signal changes (odds ratio 15.00, 95% confidence interval) compared to female sex ($p = 0.017$).

The operating surgeon, age, BMI, pre-existing diabetes, diagnosis, previous surgery, presence of pre-operative neurology, prosthesis used, length of procedure and intraoperative blood loss were not found to be associated with signal changes on both the operated and non-operated sides. Given the small number of signal changes, Fisher's exact test was also performed, which further confirmed that gender of the patient was the only variable associated with signal changes in the operated arm alone ($p = 0.048$).

Changes in the neurophysiological signal could not be attributed to a particular position of the limb, stage during surgery or physiological parameter (e.g. blood pressure). There were no adverse outcomes or complications resulting from the study or IONM.

DISCUSSION

The present study has successfully utilized SEP monitoring during TSA and has demonstrated that SEPs can be used to detect intraoperative nerve dysfunction during TSA. As with spinal cord monitoring, the benefit of monitoring is to give the surgeon greater guidance. However, it is only of real use if actions can be taken to reverse potential neurological compromise. The observed rate of signal change confirms the theory that intraoperative nerve dysfunction is more common than is currently appreciated. It also demonstrates that nerve dysfunction detected intraoperatively tends to recover and generally leaves no clinically evident neurological deficit.

Although our results suggest a high incidence of nerve impairment in the operated limb (29%), other studies, including that by Nagda et al. (57%), report higher values [1]. This may be a result of the different intraoperative monitoring methods employed and/or factors related to patient demographics and selection criteria. One particular factor that may have had a significant role in this observation was our decision to exclude patients who underwent regional anaesthesia. Nerve dysfunction following nerve blocks is well documented and uncertainty remains with regard to the aetiology of new postoperative neurological deficit following nerve blocks [3,17–20]. Patients with an absolute requirement for regional anaesthesia were therefore excluded from the study. Although this decision meant that we studied relatively fewer patients, informed consent was not gained from 20 patients in whom the advantages of an interscalene nerve block for intraoperative and postoperative analgesia were considered (by the patient) as paramount. We consider that the remaining patients represented the spectrum of case-mix seen in this centre and we do not think that the exclusion of the 20 patients detracts from the essential findings of the present study.

When analysing the variables incorporated into the present study, we were only able to identify male gender as a risk factor for signal change during TSA. This finding is of course of limited benefit, and the reason behind it needs to be investigated further, especially because patient BMI and other patient-related factors were not found to be statistically significant. Analysis of all the nerve trace changes recorded showed that only one failed to return to the baseline reading before the end of the operation. This patient, who had an obstetric brachial plexus palsy, did not exhibit any additional postoperative clinical neurological deficit. The decision to include this patient in the present study was made because we were looking for a change in intraoperative neurological status and to assess whether it is reversible. A prior neurological injury might be expected to be more susceptible to

show intraoperative change in SEP, although this case suggests that the intraoperative manipulation of the arm does not increase the risk of a double-hit phenomena.

Little is known about the possible effect of limb positioning on intraoperative nerve function. Direct traction of nerves is known to influence nerve conduction and limb positioning has been shown to cause traction, therefore influencing conduction [7]. Uncertainty remains over the effect on nerve conduction caused by increasing the degree and/or the duration of traction. Increasing the degree of traction leads to a quicker and more intense reduction in nerve conduction and also to suboptimal nerve recovery in an animal model [21]. Whether this loss of nerve conduction is caused by direct mechanical traction of the nerve, by a compromise in the intrinsic neural vasculature or by both is unclear, although, when a peripheral nerve is stretched, concomitant stretching of the local blood vessels can lead to decreased blood flow within the nerve [22].

We were unable to correlate specific limb positions to nerve dysfunction, most likely because the traction exhibited was probably insufficient to cause detectable alterations during the time that the limb was held in the abnormal position.

We speculate that the median nerve may have been the most effected by virtue of its specific anatomy in relation to the axillary artery to which it is closely applied, and thus 'fixed' *in situ*, by comparison with neighbouring nerves of the plexus that have a greater laxity in a medial-lateral direction and so may avoid injury through distortion or distraction during TSA. Kleinrensink et al. found that nerve tension in the distal part of the median, ulnar and radial nerves was transmitted upwards to the cords of the brachial plexus [23]. Furthermore, Williams et al. noted that positioning of the head in a neutral position may help minimize traction on the upper trunk of the brachial plexus as a result of manipulation of the arm during TSA [24].

Ulnar neuropathy is a recognized complication of suboptimal positioning of the arm during surgery [25–27]. The fact that the non-operated arm was always in the same position during TSA in the present study may therefore account for this result, with localized compression of the ulnar nerve at the elbow being the most likely aetiology for this observed change. Williams et al. recommended that the non-operative arm be positioned with the elbow flexed and without any pressure on the ulnar nerve. In the present study, despite padding being applied to the non-operative arm at the start of the surgery, the signal change, along with recovery following arm repositioning, confirms the theory that padding alone may not be sufficient to prevent nerve dysfunction. Elbow flexion may therefore also cause persistent hypoperfusion in the critical zone of the nerve at the cubital tunnel [24].

The present study did not identify any specific features to help identify certain patient populations or operative techniques that may put patients at postoperative neurological risk. It did, however, demonstrate the vulnerability of nerves during TSA, and those nerves most at risk. It also highlights the importance of positioning of the contralateral limb. The fact that the clinically relevant postoperative deficit is relatively rare

highlights the capability of nerve dysfunction to recover during the intraoperative period and not to lead to any sustained deficit. Future studies may use other IONM modalities such as free-run electromyography and MEPs to help better identify abnormal nerve signal characteristics intraoperatively during TSA.

Conclusions

The results of the present study suggest that intraoperative nerve monitoring can be used during total shoulder arthroplasty to monitor nerve dysfunction. We have demonstrated that nerve conduction changes do occur on both the operated and non-operated limb, which has previously gone unreported in the literature. The benefit of the role of IONM during TSA to assess pre- and intraoperative nerve injury risk needs to be explored further.

The key points of the present study are that: (i) IONM can be used during TSA and can detect nerve signal change; (ii) a neurophysiological signal change of the upper limb can occur on the operative and non-operative limb; and (iii) when a nerve signal change does occur, it tends to recover during the operative period and, as such, it is not linked to a new postoperative neurological deficit of the limb.

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