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Clinical Study

Use of electromyography to predict likelihood of recovery following C5 palsy after posterior cervical spine surgery

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Abstract

BACKGROUND: C5 palsy affects approximately 5% to 10% of patients undergoing cervical spine surgery. It has a significant negative impact on patient quality-of-life outcomes and healthcare costs. Although >80% of patients improve, some are left with persistent, debilitating deficits. Our objective was to examine if electrodiagnostic testing could be used to successfully identify patients likely to experience complete, partial, and no recovery.

METHODS: Patients undergoing posterior cervical decompression and fusion at a single institution over a 10-year period were identified. Those experiencing postoperative C5 palsy were included. Outcomes examined included motor recovery of the affected deltoid as a function of time, and changes in electrodiagnostic testing as a function of time since injury. Electrodiagnostic testing included electromyography and was sub-analyzed by time of acquisition postinjury. Deltoid strength was graded on manual motor testing using the 5-point medical research council grading system.

RESULTS: Of 77 patients experiencing C5 palsy, 29 had postoperative electrodiagnostic testing. Patients experiencing complete recovery on average achieved functional (4/5) strength by 6-weeks post injury and 4+ per 5 strength by 6-months. Those experiencing partial recovery only achieved antigravity strength (3/5) by 6-weeks and low-function (4−/5) strength by 6-months. Electrodiagnostic testing performed 6-weeks to 6-months postinjury demonstrated that those experiencing complete recovery were more likely to have normal motor unit (MU) recruitment than those experiencing partial (p<.001) or no recovery (p=.008). The presence of ≥2+ fibrillation on tests acquired ≤6-weeks of injury identified patients unlikely to experience any recovery with a positive predictive value (PPV) of 88.9%. The presence of normal MU recruitment on tests acquired 6-weeks to 6-months postinjury identified patients likely to experience complete recovery with a PPV of 87.5%.

CONCLUSIONS: Electrodiagnostic testing may be a valuable means of differentiating between patients with C5 palsy likely to experience complete, partial, or no recovery. Testing between 6-weeks and 6-months post onset may aid in identifying those least likely to have a complete recovery. No MUs at 4 to 6-months, or reduced units with strength that is not improving, portends a poor

FDA device/drug status: Not applicable

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long-term outcome. In this population, peripheral nerve transfers may be considered sooner.

Keywords: C5 palsy; Postoperative complication; Cervical spine surgery; Electromyography; Nerve conduction study; Electrophysiology

Introduction

C5 palsy is a common complication of cervical spine surgery, documented to occur in 0.5% to 2% of anterior surgeries [1−3] and 8% to 12% of posterior surgeries [4,5]. Since its first description by Scoville in 1961 [6], multiple hypotheses have been advanced to explain the pathophysiology of C5 palsy. These include intraoperative iatrogenic [6] or thermal injury [7], root traction injury caused by posterior cord displacement [8,9], segmental cord dysfunction [10], or ischemia [11], reperfusion injury [12], and brachial plexitis. However, the evidence for each of these hypotheses is equivocal. It is possible that C5 palsy represents a mixture of etiologies with a similar clinical presentation rather than a unique disease pathology [13].

Consistent with this, some patients experience full recovery of function following C5 palsy, whereas others do not [14]. Among the subset that do not recover, distal nerve transfers may aid in recovery of elbow flexion, arm abduction, and shoulder stability [3]. These interventions, however, become substantially less effective with prolonged time from injury onset [15]. Yet, peripheral nerve transfers that are performed too early, may decrease the opportunity for natural regeneration and recovery [16]. Some have proposed using severity of manual motor testing (MMT) to predict postoperative recovery [16] However, physical examination is subject to variability across providers, may miss subtle signs of nerve root injury [17] and of nerve regeneration, which are better detected on electrophysiological testing [13]. Electromyography (EMG) can be used to grade injury severity and monitor muscle reinnervation following nerve root injury [13]. The use of postoperative electrophysiology testing in C5 palsy has been briefly described in rare case reports [18,19], although there have been no larger reports of EMG use in this patient population. Here we examine the electrophysiological changes in patients with C5 palsy following cervical spine decompression surgery. Our objective was to determine if EMG can be used to identify those patients least likely to naturally improve, in order to facilitate earlier referral and peripheral nerve intervention.

Methods

We retrospectively reviewed the electronic medical records at a single tertiary care institution to identify patients who underwent posterior cervical decompression that spanned the C4−5 levels between January 2007 and December 2017. We identified all patients that developed C5 palsy postoperatively and included only those that were monitored postoperatively with EMG. Consistent with prior studies, we defined C5 palsy as worsened postoperative deltoid and/or bicep weakness on MMT when compared with baseline without worsening of myelopathy symptoms [4,8,11,16]. Included patients were older than 18 years and underwent surgery for degenerative disease pathology. Those undergoing surgery for tumor, infectious disease, or trauma were excluded. Institutional review board approval was obtained before the study. Variables collected included demographics, presenting symptoms, operative details, and the postoperative course including the time course of improvement in strength and the associated electrodiagnostic test characteristics for the deltoid innervated by the injured nerve. Electrodiagnostic testing comprised EMG and nerve conduction studies. EMG results included fibrillations, fasciculations, and positive sharp waves (PSWs), motor unit (MU) recruitment, and MU duration. Strength of the affected deltoid was graded using the Medical Research Council 5-point grading system. EMG results were graded as follows. Fibrillations were graded as 0 (normal), 1, 2, or 3; PSWs were graded as 0 (normal), 1, 2, or 3; fasciculations were graded as present or not; MU recruitment was graded as normal, mildly reduced, reduced, or severely reduced and/or absent; and MU duration was graded as normal, 1+, 2+, or 3+.

Statistical analysis

Data were collected using Microsoft Excel (Redmond, WA, USA) and summarized as mean ± standard deviation for continuous data and proportions for categorical and dichotomous data. Statistical testing was performed using Statistica version 13.3 (TIBCO, Palo Alto, CA, USA). Between group comparisons were made using *t* tests for continuous variables, chi-square tests for categorical variables, and Fisher exact tests for dichotomous variables. Electrophysiological testing data was compared between patients experiencing complete, partial, and no recovery using chi-square analyses. Chi-square tests and Fisher-exact tests were used to examine differences between individual groups. Sub-analyses were performed to look at differences in electrophysiology parameters between groups for tests acquired ≤6-weeks following palsy onset, 6-weeks to 6-months following onset, and ≥6-months following onset.

Results

We identified 77 patients who experienced postoperative C5 palsy, of whom 29 had one or more postoperative electrophysiology tests and were included in the final analysis.

Among included patients, mean age was 64.5±7.6 years, 79.3% were male, mean number of instrumented vertebrae was 6.2±1.5, mean number of laminectomy levels was 4.1±1.2, and mean operative duration was 257±98 minutes. Mean time to C5 palsy onset was 2.9±2.4 days, average trough deltoid strength on MMT was 2.3±1.2, and 34.4% of palsies were bilateral. Thirteen (44.8%) patients experienced complete recovery and 37.9% experienced partial recovery, as defined by their clinical examination. The rest did not demonstrate any meaningful recovery. No significant differences were seen between those patients who had EMG and/or nerve conduction studies versus those who did not (Table 1).

Modeling motor recovery

Examination of patient motor strength as a function of time showed three distinct recovery curves for those experiencing complete, partial, and no recovery, as demonstrated in Figure. Logistic models were fitted to each patient group. For the complete recovery group, strength was approximated as $MMT = 2.83 + 0.81 \times \log_{10}$ (time in days) and for the partial recovery group, strength was approximated as $MMT = 2.01 + 0.65 \times \log_{10}$ (time in days). The curve modeling recovery in those experiencing no meaningful improvement had no appreciable slope. Evaluation of these models demonstrated that at 6-weeks postinjury, the average patient experiencing complete recovery was at 4 per 5 strength (4.14) and the average patient experiencing partial recovery was at 3 per 5 strength (3.07). At 6-months, patients in the complete and incomplete groups were 4+ per 5 (4.66) and 4− per 5 (3.48), respectively. At 12-months, patients in the complete and incomplete groups were 5 per 5 (4.96) and 4− per 5 (3.68). Of affected deltoids that ultimately achieved 4+ per 5 or 5 per 5 strength, 35% had achieved 4+ per 5 strength by 6-weeks postinjury, 64% by 4-months postinjury, and 79% by 6-months postinjury. Only 13% of affected deltoids that achieved 4+ per 5 strength required more than 1-year to achieve this level of recovery. When examining outcomes based upon deltoid strength at 6-weeks postinjury, patients with deltoids of <4 per 5 strength had significantly poorer recovery relative to those that were 4 per 5 or better ($p<.001$). Compared with those who were ≥4 per 5 strength at 6-weeks, those <4 per 5 strength were significantly less likely to achieve complete (36.2 vs. 83.0%; $p<.001$) or any recovery (77.6 vs. 97.9%; $p=.02$).

Electrophysiological data

Tables 2−5 shows the electrophysiological data as measured by time of acquisition and extent of patient recovery. Across all electrophysiology studies, significant differences were noted between groups in the number of fibrillations ($p=.023$), the presence ($p=.030$) and number of PSWs ($p=.002$), and the presence ($p<.001$) and extent of MU

Table 1
Demographics in C5 palsy patients with and without postoperative EMG

	All palsy N=77	No EMG N=48	+ EMG N=29	p
Demographics				
Age	64.4±9.2	64.4±10.1	64.5±7.6	.96
BMI (kg/m^2)	29.1±5.8	28.9±5.9	29.5±5.7	.64
Gender (male)	52 (67.5)	29 (60.4)	23 (79.3)	.13
Race (white)	52 (67.5)	33 (68.8)	19 (65.5)	.95
Current smoker	14 (18.2)	8 (16.7)	6 (20.7)	.76
Preoperative C5 radiculopathy	25 (32.5)	15 (31.3)	10 (34.4)	.81
Follow-up (mo)	17.6±23.6	16.9±21.0	19.0±27.9	.71
Radiographic				
C4/5 foraminal diameter (mm)	2.5±0.8	2.7±0.9	2.4±0.5	.31
C4/5 AP diameter (cm)	0.71±0.22	0.72±0.23	0.69±0.21	.70
Operative detail				
Laminectomy levels	4.2±1.1	4.3±1.0	4.1±1.2	.51
Fusion levels	6.2±1.6	6.2±1.6	6.2±1.5	.94
Foraminotomy	28 (36.4)	15 (31.3)	13 (44.8)	.33
Duration (min)	265±106	269±111	257±98	.64
Blood loss (mL)	369±282	334±245	427±333	.21
C5 palsy characteristics				
Days to onset	3.5±3.1	3.8±3.4	2.9±2.4	.19
Trough deltoid strength	2.6±1.3	2.8±1.2	2.3±1.2	.08
Resolution				.49
Complete	37 (48.1)	24 (50.0)	13 (44.8)	
Partial	31 (40.3)	20 (41.7)	11 (37.9)	
None	9 (11.7)	4 (8.3)	5 (17.2)	

BMI, body mass index; cm, centimeter; kg, kilogram; m, meter; min, minute; mL, milliliter; mm, millimeter; mo, month.

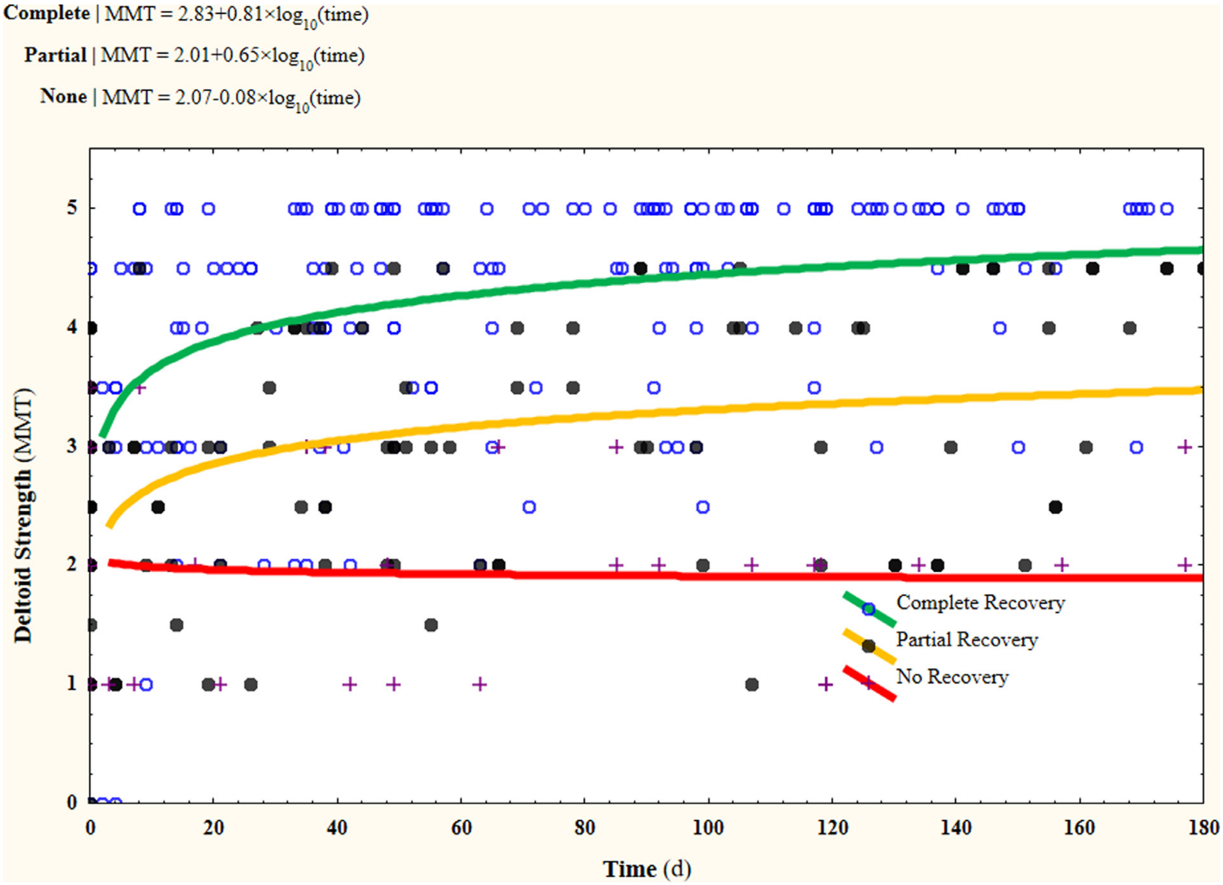

Figure. Plot of deltoid strength recovery as a function of time in patients who experienced complete, partial, and no meaningful recovery. Logarithmic curves are fitted to each of the three groups, where green represents patients who experienced full recovery, yellow represent patients who experienced partial recovery, and red represents patients who experienced no recovery.

recruitment (p=.002). Between group comparisons showed that patients experiencing complete recovery were far more likely to have normal MU recruitment than those experiencing partial (76.4% vs. 31.8%; p=.002) or no recovery (76.4% vs. 16.7%; p<.001). Those experiencing complete recovery also had less severe reductions in MU recruitment relative to those experiencing partial (p=.012) and no recovery (p=.003). There was no difference in MU recruitment between those experiencing partial and no recovery. Between group comparisons also showed patients experiencing partial recovery had significantly fewer fibrillations and PSWs than those experiencing no recovery. Those experiencing complete recovery were also less likely to have PSWs on electrophysiology testing than those experiencing no recovery (17.6% vs. 61.1%; p=.015).

Sub-analyses by time of acquisition

Examination of tests acquired within 6-weeks of injury showed significant differences between groups in the proportion of patients with abnormal MU recruitment (p=.011) and the number of PSWs detected on testing (p=.031). Between group comparisons showed that patients experiencing partial recovery were less likely to have ≥2+ fibrillations relative to those experiencing no recovery (9.1% vs. 57.1%; p=.033). Using the threshold of ≥2+ fibrillations had a sensitivity of 57.1% and a positive predictive value (PPV) of 88.9% for experiencing no meaningful recovery of function. Of those with a severe reduction or absence of MU recruitment, 80% experienced no recovery.

Tests acquired between 6-weeks and 6-months of injury showed significant differences between groups in the proportion of patients with PSWs (p=.048), the proportion of patients with abnormal MU recruitment (p<.001), the proportion of patients with abnormal MU duration (p=.006), and the average reduction in MU recruitment (p<.001). Between group comparisons showed that relative to those experiencing partial recovery, those experiencing complete recovery were less likely to have PSWs (0% vs. 50%; p=.044), less likely to have abnormal MU recruitment (0% vs. 90%; p<.001), and less likely to have abnormal MU duration (0% vs. 60%; p=.035). Those experiencing complete recovery also had a less severe mean reduction in MU recruitment (p=.004). Comparisons between those experiencing complete and partial recovery demonstrated

Table 2
Comparison of EMG findings (at all time points) for patients with complete, partial, and no recovery

	Complete(n=17)	Partial(n=27)	None(n=18)	p(All groups)	p(C vs. P)	p(C vs. N)	p(P vs. N)
Fibrillations							
Yes vs. no	4	8	10	.109	.735	.086	.127
Absent	13	18	8	.023	.935	.079	.020
Mild	2	5	1				
Moderate	2	3	5				
Severe	0	0	4				
Positive sharp waves							
Yes vs. no	3	12	11	.030	.101	.015	.373
Absent	14	14	7	.002	.148	.032	.020
Mild	0	6	1				
Moderate	3	6	5				
Severe	0	0	5				
Fasciculations							
Yes vs. no	0	2	0	.23	.511	>.99	.505
Motor unit recruitment							
Nml vs. Abnl	13	7	3	<.001	.002	<.001	.489
Nml	13	7	3	.002	.012	.003	.256
↓	0	1	1				
↓↓	4	18	10				
↓↓↓/ Ø	0	1	4				
Motor unit duration							
Nml vs. Abnl	12	16	8	.73	.745	.176	.359
Nml	12	16	8	.59	.783	.716	.310
1+	3	3	5				
2+	2	4	1				
3+	0	1	0				

Ø, no units; ↓, mildly reduced; ↓↓, reduced; Abnl, abnormal; Bicep, biceps brachii; delt, deltoid; dur, duration; EMG, electromyography; fasc, fasciculation; fib, fibrillations; fu, follow-up; L, left; LFU, last follow-up; MMT, manual motor testing; mo, month; MU, motor testing; Musc, muscle; Nml, normal; postop, postoperative follow-up time; N, no; PSW, positive sharp waves; pt, patient; R, right; Rec, motor unit recruitment; Spon Act, spontaneous activity; Str, strength; TTI, time to improvement; wk, week; Y, yes.

Table 3
Comparison of EMG findings (at <6weeks) for patients with complete, partial, and no recovery

	Complete(n=8)	Partial(n=12)	None(n=14)	p(all)	p(C vs. P)	p(C vs. N)	p(P vs. N)
Fibrillations							
Yes vs. no	2	3	9	.092	>.99	.183	.111
Absent	6	8	5	.067	.842	.062	.087
Mild	2	2	1				
Moderate	0	1	4				
Severe	0	0	4				
Positive sharp waves							
Yes vs. no	1	5	9	.064	.177	.031	.435
Absent	7	6	5	.031	.445	.115	.073
Mild	0	2	0				
Moderate	1	3	4				
Severe	0	0	5				
Fasciculations							
Yes vs. no	0	0	0	>.99	>.99	>.99	>.99
Motor unit recruitment							
Nml vs. Abnl	6	3	2	.011	.070	.008	.623
Nml	6	3	2	.081	.159	.032	.603
↓	0	1	1				
↓↓	2	7	7				
↓↓↓/ Ø	0	1	4				
Motor unit duration							
Nml vs. Abnl	5	8	7	.711	>.99	>.99	>.99
Nml	5	8	7	.123	.136	.990	.167
1+	3	0	3				
2+	0	2	0				
3+	0	0	0				

Ø, no units; ↓, mildly reduced; ↓↓, reduced; Abnl, abnormal; EMG, electromyography; Nml, normal.

Table 4
Comparison of EMG findings (at 6 weeks to 6 months) for patients with complete, partial, and no recovery

	Complete(n=7)	Partial(n=10)	None(n=3)	p(all)	p(C vs. P)	p(C vs. N)	p(P vs. N)
Fibrillations							
Yes vs. no	0	3	3	.258	.228	.300	>.99
Absent	7	7	2	.489	.466	.459	.923
Mild	0	1	0				
Moderate	0	2	1				
Severe	0	0	0				
Positive sharp waves							
Yes vs. no	0	5	2	.048	.044	.067	>.99
Absent	7	5	1	.189	.175	.120	.955
Mild	0	2	1				
Moderate	0	3	1				
Severe	0	0	0				
Fasciculations							
Yes vs. no	0	0	0	>.99	>.99	>.99	>.99
Motor unit recruitment							
Nml vs. Abnl	7	1	0	<.001	<.001	.008	>.99
Nml	7	1	0	<.001	.004	.019	.955
↓	0	0	0				
↓↓	0	9	3				
↓↓↓/ Ø	0	0	0				
Motor unit duration							
Nml vs. Abnl	7	4	0	.006	.035	.008	.497
Nml	7	4	0	.075	.090	.019	.478
1+	0	3	2				
2+	0	2	1				
3+	0	1	0				

Ø, no units; ↓, mildly reduced; ↓↓, reduced; Abnl, abnormal; EMG, electromyography; Nml, normal.

Table 5
Comparison of EMG findings (at >6 months) for patients with complete, partial, and no recovery

	Complete(n=2)	Partial(n=5)	None(n=1)	p(all groups)	p(C vs. P)	p(C vs. N)	p(P vs. N)
Fibrillations							
Yes vs. no	2	2	0	.202	.429	.333	>.99
Absent	0	3	1	.066	.072	.392	.896
Mild	0	2	0				
Moderate	2	0	0				
Severe	0	0	0				
Positive sharp waves							
Yes vs. no	2	2	0	.202	.429	.333	>.99
Absent	0	3	1	.066	.072	.392	.896
Mild	0	2	0				
Moderate	2	0	0				
Severe	0	0	0				
Fasciculations							
Yes vs. no	0	2	0	.45	>.99	>.99	>.99
Motor unit recruitment							
Nml vs. abnl	0	3	1	.202	.429	.333	>.99
Nml	0	3	1	.202	.552	.392	.896
↓	0	0	0				
↓↓	2	2	0				
↓↓↓/ Ø	0	0	0				
Motor unit duration							
Nml vs. Abnl	0	4	1	.030	.067	.333	>.99
Nml	0	4	1	.030	.112	.392	>.99
1+	0	0	0				
2+	2	0	0				
3+	0	0	0				

Ø, no units; ↓, mildly reduced; ↓↓, reduced; Abnl, abnormal; EMG, electromyography; Nml, normal.

that those with complete recovery were less likely to have abnormal MU recruitment (0% vs. 100%; p=.008) or duration (0% vs. 100%; p=.008). They also had less severe reductions in MU recruitment (p=.019) and less severe prolongation of MU duration (p=.019). Using normal MU recruitment as a diagnostic criterion for identifying patients likely to experience complete versus partial or no recovery showed a sensitivity of 75% and PPV of 54.5% on tests acquired within 6-weeks of injury and 100% and 87.5%, respectively for tests acquired between 6-weeks and 6-months of injury. Using this same criterion of normal MU recruitment for diagnosing complete versus partial or no recovery had a negative predictive value of 91.3% for tests acquired within 6-weeks and 100% for tests acquired between 6-weeks and 6-months post-injury. There were no significant differences between those experiencing partial and no recovery.

Only 8 patients had tests acquired ≥6-months after injury. Examination of these tests showed significant differences in MU duration between groups, but none of the between group comparisons were significant. None of the other parameters differed significantly between groups.

Discussion

Postoperative C5 palsy following cervical spine surgery occurs in approximately 5% to 10% of patients; >80% of patient will demonstrate nearly complete functional improvement [1−3,11,16,20,21]. The majority of patients improve within 6-months; however, a significant number of individuals exhibit significant recovery beyond that timepoint [16]. Identifying the minority of patients that will not demonstrate spontaneous recovery remains an important area of clinical research. Here we provide the first detailed analysis of electrophysiology testing changes in patients with C5 palsy following posterior cervical decompression as a means of identifying those patients unlikely to experience meaningful recovery.

Logistic modeling of deltoid strength improvement following injury suggests that both patients experiencing complete (60%) and partial recovery (29%) are likely to have recovered by at least 1 motor grade by 6-weeks following injury. Additionally, the models suggest that physical examination may be able to differentiate patients experiencing complete recovery from those experiencing only partial recovery at both the 6-week and 6-month timepoints. At 6-weeks those experiencing complete recovery are likely to have achieved functional (4/5) motor strength, whereas those with partial recovery will have only achieved antigravity (3/5). Importantly, examination of ultimate recovery as a function of strength at the 6-week follow-up demonstrated that those who were <4 per 5 strength were significantly less likely to achieve complete or any recovery by last follow-up. This suggests that patients achieving little to no recovery within 6-weeks of injury are less likely to achieve good long-term results.

Electrophysiological data suggests that tests acquired in the 6-week to 6-month time period are of the greatest utility to distinguish patients likely to experience complete versus partial recovery. Those experiencing complete recovery were far less likely to have abnormal MU recruitment or duration. In those experiencing complete recovery, only 23.5% of all EMGs demonstrated abnormal MU recruitment and 29.4% showed abnormal MU duration. By contrast, electrophysiology testing acquired within 6-weeks of injury appears most valuable for differentiating those likely to experience partial recovery from those unlikely to improve. Those experiencing partial recovery were far less likely to have ≥2+ fibrillations on EMG relatively to those experiencing no recovery. Consequently, these data suggest that those with ≥2+ fibrillations on early (≤6 weeks) electrophysiological testing are less likely to experience meaningful recovery. Repeat testing should be performed (at least once) between 6-weeks and 6-months of injury. If MU recruitment is normal on this repeat test, the patient is more likely to experience complete recovery. Patients showing a severe reduction or absence of MU recruitment on early testing (≤6 weeks) are much less likely to experience meaningful recovery and earlier referral to peripheral nerve surgery should be considered.

Although previous publications have investigated the etiology of C5 palsy, only a small proportion of studies address prognostic factors correlated with postoperative improvement. Multisegment paresis involving more than the C5 root, change in or loss of somatic sensation, degree of posterior cord shift, preoperative motor deficit, postoperative spinal cord T2 hyperintensity, and female gender have all been implicated as possible factors correlating with worse outcomes; however, the most consistently implicated factor is a MMT grade ≤2 postoperatively [1,3,16,22−24]. The largest series, a retrospective review of 77 patients with postoperative C5 palsies [16] demonstrated a significantly shorter time to recovery for patients with MMT grade 4+ per 5 weakness compared with MMT grade 4 per 5 or grade ≤ 3 weakness (median time to recovery 85, 137.5, and 177 days, respectively). Furthermore, patients with MMT grade ≤ 2 postoperatively had a <50% chance of achieving complete recovery. In a meta-analysis of patients with postoperative C5 palsy, Sakaura et al. [11] reported that 96.4% of patients with MMT grade ≥3 had complete recovery, whereas this was true for only 71.0% with MMT grade ≤2. Imagama et al. [8] noted 29 per 43 patients (67.4%) with MMT grade ≤2 had complete resolution of symptoms in a subsequently completed cohort of patients. Although further investigation is necessary to elucidate additional factors consistently associated with postoperative outcomes, a more precise delineation of expected functional recovery may be possible with electrodiagnostic evaluation of this subset of patients.

Electrodiagnostic studies provide an objective assessment of peripheral neuropathies and have demonstrated promise as a clinical adjunct to track patients most likely to demonstrate recovery. Significant attention has been devoted to evaluating intraoperative neuromonitoring (somatosensory evoked potentials [SSEPs], motor evoked potentials [MEPs], EMG) as a modality to predict or prevent postoperative deficit. Whereas SSEPs do not reliably correlate with postoperative weakness, MEPs are likely prognostic of acute motor deficit [25−31]. MEP alerts in the deltoid or bicep were identified by Oya et al. [29] to be 100% sensitive and 98.4% specific for acute postoperative C5 palsy after laminoplasty. However, in their series, delayed C5 palsy was also seen with no abnormal findings on intraoperative neuromonitoring. Similarly, in a review of 644 cases, Spitz et al. reported 5 patients who developing delayed C5 palsy (later than postoperative day 2) with no significant intraoperative SSEP, MEP, or EMG changes [30]. Multiple other authors have similarly reported that IONM is unable to reliably predict delayed C5 palsy, suggesting this may provide evidence that the nerve injury occurs in the perioperative, rather than intraoperative, period [21,25,31].

Few studies have investigated postoperative electrodiagnostic evaluation for patients with C5 palsy. In a case report by Tucker et al. [18], the authors describe two patients who had nascent potentials on EMG completed after 3.5 months that made a significant recovery. Interestingly, both patients exhibited rhomboid sparing suggesting injury beyond the dorsal scapular nerve (classically arising from the C5 nerve root). A pattern consistent with a brachial plexopathy was also observed in 5 per 17 (29%) patients with EMG results in a heterogenous cohort of patients with delayed postoperative palsies after cervical spine surgery [32].

Our cohort demonstrated poor subsequent functional recovery for patients with severely reduced or no MU recruitment on EMG completed 4 to 6 months postoperatively. By more accurately predicting the minority of individuals who will not have a spontaneous recovery by approximately 4 to 6 months, it is possible to offer earlier nerve transfer operations to promote functional recovery. The optimal timing of surgical intervention is before 6 months after injury given the time-dependent, and irreversible changes that occur in the motor end plate; the longer a muscle remains denervated the lower the likelihood of successful reinnervation [33]. Most commonly cited nerve transfers to restore shoulder abduction and external rotation include distal spinal accessory nerve to the supra-scapular nerve (80% motor recovery MMT grade ≥3 in 577 patients) as well as a triceps branch transferred to the axillary nerve [33−35]. In cases of C5 palsy with significant deficit of elbow flexion, a single or double fascicular nerve transfer from the median/ulnar nerve to the musculocutaneous nerve branches has been described with good outcomes (MMT grade ≥4) [36]. Single fascicular transfer for elbow flexion may facilitate recovery via the transfer for one elbow flexor muscle (ie, brachialis) with simultaneously awaiting spontaneous recovery of the more proximal elbow flexor (ie, biceps) [37].

The data of the present study supports that by using the EMG results between 4and 6 months, one may predict if the patient is likely to demonstrate spontaneous functional recovery. At the same time, this time interval would also allow one to determine those patients unlikely to recover and thereby facilitate earlier nerve transfer interventions. Preoperative nerve root function [14] and postoperative severity of palsy also aid in understanding expected postoperative recovery [16]. Use of such a treatment paradigm for patients with significant C5 motor weakness following cervical spine surgery, may lead to superior outcomes.

Limitations

The present study has several limitations. First, Although the present report is the largest study of electrodiagnostic studies in patients with C5 palsy, the overall number of patients with available data was quite small and there was no standardized protocol for intraoperative care or postoperative management of C5 palsy. This increased the heterogeneity and biased the data. However, comparison to the remaining patients in the cohort finds no significant differences in terms of demographics, injury severity, or degree of functional recovery. Consequently, these results are likely to be applicable to the larger cohort. Multiple statistical analyses were made, however, given the preliminary and exploratory nature of the study, we felt it would be appropriate to maintain statistical significance at $p<.05$. Future validation studies should consider statistical correction for multiple comparisons. Additionally, the standard for recovery was motor strength on MMT. This testing is subject to variability in intrarater and inter-rater reliability. Although the latter is reduced by the same provider serially following each patient, intrarater reliability cannot be completely eliminated. It is possible that surgeon or patient optimism on serial follow-up examinations may have given a false impression of improvement. Alternatively, patients may have become better at compensating for their deficit on exam with increasing follow-up. The limited number of EMGs obtained beyond 6 months postoperatively makes analysis of this time frame underpowered. Lastly, the electrodiagnostic data relies on neurologist interpretation, which injects a degree of subjectivity. Although the fact that the present data were gathered from tests by multiple different neurophysiologists may eliminate some of this observer bias, it cannot be eliminated completely.

Conclusion

Here we provide the largest examination of functional and electrophysiological recovery in patients experiencing C5 palsy following posterior cervical decompression. We find that patients likely to experience complete recovery have generally achieved functional (4/5) strength by 6 weeks postinjury, whereas those experiencing partial recovery have only achieved antigravity strength. On electrodiagnostic testing, the presence of abundant fibrillations on early testing (<6 weeks postinjury) identifies patients unlikely to experience meaningful recovery with a PPV of 88.9%. Persistent abnormal motor recruitment on tests between 6-weeks and 6-months postinjury identifies patients likely to experience incomplete or no recovery with a sensitivity of 92.3%. These electrodiagnostic findings may help clinicians identify patients unlikely to experience meaningful recovery early on, thereby expediting referral to peripheral nerve specialists and increasing the likelihood of successful treatment.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.spinee.2020.10.001.

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