Value of Free-Run Electromyographic Monitoring of Extraocular Cranial Nerves during Expanded Endonasal Surgery (EES) of the Skull Base

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Abstract

Objective   To evaluate the value of free-run electromyography (f-EMG) monitoring of extraocular cranial nerves (EOCN) III, IV, and VI during expanded endonasal surgery (EES) of the skull base in reducing iatrogenic cranial nerve (CN) deficits.

Design   We retrospectively identified 200 patients out of 990 who had at least one EOCN monitored during EES. We further separated patients into groups according to the specific CN monitored. In each CN group, we classified patients who had significant (SG) f-EMG activity as Group I and those who did not as Group II.

Results   A total of 696 EOCNs were monitored. The number of muscles supplied by EOCNs that had SG f-EMG activity was 88, including CN III = 46, CN IV = 21, and CN VI = 21. There were two deficits involving CN VI in patients who had SG f-EMG activity during surgery. There were 14 deficits observed, including CN III = 3, CN IV = 2, and CN VI = 9 in patients who did not have SG f-EMG activity during surgery.

Conclusions   f-EMG monitoring of EOCN during EES can be useful in identifying the location of the nerve. It seems to have limited value in predicting postoperative neurological deficits. Future studies to evaluate the EMG of EOCN during EES need to be done with both f-EMG and triggered EMG.

Keywords
► electromyography
► lower cranial nerves
► expanded endonasal surgery

Introduction

Extraocular cranial nerve (EOCN) electromyographic monitoring during conventional skull base surgeries has been used to reduce the incidence of postoperative neurological deficits by detecting impending cranial nerve (CN) injury.[1–6] Free-run EMG (f-EMG) is a continuous recording of EMG activity characterized as spikes, bursts, and neurotonic discharges during surgery secondary to unintended activation of the muscles supplied by the CN. Neurotonic discharges[7] during f-EMG recordings have been a reliable predictor of postoperative paralysis after skull base surgery. Triggered EMG (t-EMG) is a compound muscle action potential (CMAP) in response to voluntary stimulation of CNs during skull base surgery. The change in the threshold of stimulation to elicit a CMAP[8] during facial nerve surgery may be a predictor of

postoperative CN paralysis. f-EMG and t-EMG responses can be recorded during surgery to localize EOCN.[4] To date it has been difficult to correlate all or some type of f-EMG activity to predict postoperative deficits. Diplopia following intra-operative dissection of EOCN is a known complication. This leads to loss of stereoscopic vision and often requires mono-ocular occlusion, leading to secondary amblyopia.[5,6] Hence, f-EMG and t-EMG can be very valuable if its utilization allows for prediction and prevention of postoperative EOCN paraly-sis. Various techniques have also been used for placement and recording both f-EMG and t-EMG discharges. These include placement of bipolar needles manually, or single-shafted bipolar needles using orbital ultrasound[4] or image guidance.[1] Surface recording using pad electrodes[9] and ring electro-des[6,10] in the muscles have also been attempted.

Expanded endonasal surgery (EES) is a minimally invasive technique for skull base surgery that involves the use of an endoscope and complex neuronavigational systems with neurosurgery and otolaryngology working together during all phases of surgery.[11–15] Using the principles of EES, we are able to access the ventral skull base from the crista galli to odontoid in the sagittal plane and as lateral as the middle fossa with minimal residual postoperative complications.[16] Based on the location of the tumor, the approach can be classified into transcribriform, transdorsum sellae, and trans-clival. Although minimally invasive, EES still carries a poten-tial risk for injury to neurovascular structures, including the internal carotid arteries, anterior cerebral arteries, and CNs III–XII[12–14] depending on the approach and location of the tumor. Our primary aim of this paper was to evaluate the value of f-EMG monitoring of EOCN during EES in reducing iatrogenic EOCN deficits.

Materials and Methods

Study Design
We retrospectively reviewed all consecutive cases of EES at our institution between 2000 and 2008. The total number of patients monitored during EES was 990. Patients who did not have intraoperative EMG monitoring data or patients who did not have EMG monitoring due to technical reasons were excluded from this study. Patients who did not have a documentation of postoperative neurologic status were also excluded. Using these criteria, a total of 200 patients were identified as having at least one EOCN monitored during the operation. Included patients in our study for each EOCN were CN III: 153, CN IV: 135, and CN VI: 187. One patient might have more than one nerve monitored. This study was approved by the quality assurance committee for retrospec-tive review of data on human subjects at the University of Pittsburgh.

Neurophysiologic Monitoring
Continuous f-EMG activity was recorded using pairs of sub-dermal needle electrodes placed 1 cm apart in the orbit in the location of the muscle groups innervated by EOCN. Our technique involves a simple approach to placing bipolar needles after gently moving the globe away from the orbit

using our fingers: place two needles with the sharp edges directed toward the bony aspect of the orbit, and repeat the procedure for all the other nerves. f-EMG monitoring of CN III involved placement in the medial rectus muscle, CN IV by placement in the superior oblique muscle, and CN VI by placement in the lateral rectus. The needle length was 13 mm long with a diameter of 0.4 mm manufactured by Rhythmlink (Columbia, South Carolina, USA). Physician over-sight and interpretation was performed using a combined onsite and remote model utilized by University of Pittsburgh Medical Center (UPMC). In all cases, a board-certified neuro-physiologist was onsite and immediately available for inter-pretation and consultation, and physician (neurologist) oversight, supervision, and interpretation were performed in-person or remotely. The oversight physician provided supervision to four to five cases simultaneously on average, with a maximum of eight cases.

Anesthesia
Short-acting neuromuscular junction blocking medications were used for intubation. No additional paralytic agent was administered, particularly during f-EMG monitoring. Neuro-muscular junction blockade was tested by using a standard train of four twitches. The patient was maintained using a balanced anesthetic technique using inhalational and IV agents during the procedure.

Alarm Criteria
No detectable f-EMG activity was considered baseline in each case. Detection of nerve manipulation, compression, stretch, and/or permanent injury was based on changes from baseline recordings. All instances of f-EMG activity, regardless of type (spikes, bursts, neurotonic discharges), were made audible and were also immediately reported to the surgeon and recorded in the patient record. Henceforth, this EMG activity will be called "EMG alerts." SG f-EMG activity when present for prolonged periods of time, or prolonged activities with small interruptions for a single lower CN, were reported as one alert. Recordings were made continuously during all stages of surgery after incision. The settings were bandpass filters set at 3 to 1,000 Hz, with a gain of 5,000, a time base of 100 milliseconds, and a sensitivity of 50 microvolts. All EMG activity was made audible to the surgeon via a loudspeaker connected to the collection unit. In our study we did not consider EMG activity during irrigation as significant.

Medical Record Review
Medical records of all patients who had EES were reviewed to determine if any new neurologic deficits were present after the surgical procedures. The medical records were reviewed independently without knowledge of their intraoperative EMG changes. Any new postoperative deficits were consid-ered to be iatrogenic intraoperative injuries. Deficits were classified as transient or permanent. Transient deficits had documented evidence in medical records of complete im-provement to baseline. Permanent deficits were defined as those that did not improve to baseline in subsequent follow-up visits. All EOCN deficits were documented by

ophthalmologists. Similarly, the intraoperative records were reviewed to look for EMG discharges; all 200 were reviewed independently without the knowledge of postoperative neurologic outcome.

Demographic and Patient Data

We compiled all demographic, diagnostic, and surgical information on the patients who had any EOCN EMG monitoring. These data were analyzed with each individual CN. Each EOCN was segregated; patients who had significant f-EMG activity during the surgery were classified as Group I and patients who did not have significant f-EMG activity during the surgery were classified as Group II. The need for CN monitoring was determined by the surgeon and the neurophysiologist based on the pathology and a perceived risk of injury to EOCN. The purpose of the comparative analysis was to identify variables, which were significantly different between the two groups. Data were presented as mean ± standard deviation for continuous variables and proportion for categorical variables. Chi-square tests or Fisher exact tests were used for categorical variable comparisons. The analyses were performed by SAS 9.13.

Data Analysis

EMG alerts were annotated in the technologist's log for all instances where EOCN f-EMG activity was observed. EMG alerts were considered significant if EMG activity information was conveyed to the surgeons. This was followed by estimating the number of EMG alerts per nerve, which is provided to the surgeon during the case. Correlation to any EMG alerts and postoperative neurological deficits was performed. For data analysis, the number of nerves monitored for each CN was calculated by adding unilateral as "one" and bilateral as "two" nerves monitored. Furthermore, the data from the two groups were tabulated to compare and correlate the number of transient and permanent deficits in the patients who were monitored.

Results

Demographic and Patient Data

The total number of patients who had at least one EOCN monitored was 200. Of 200 patients, 44% were male and 56% female. All the patients had surgery between 2000 and 2008. Twenty-five percent of patients underwent surgery before 2006 and 75% underwent surgery after 2006. There is no significant difference between the demographic or surgical information between the two groups. Meningioma was the most common diagnosis in both groups. The other diagnoses included pituitary tumor, chordoma, angiofibroma, chondrosarcoma, and others. Transclival was the most common EES approach, followed by transellar and transplanum. More than one approach was performed in some cases. During such instances, we referred to the primary approach. Further subgroup analysis was performed to identify the differences in demographic and patient data for each specific EOCN. No clinically significant variables like age, sex, procedure, diagnosis, number of stages, or presence of neurological deficits was present when both groups were compared (►Table 1).

Monitoring EOCN

Monitoring of at least one EOCN was performed in 200 patients. CN III was monitored in 153 patients. CN IV was monitored in 135 patients. CN VI was monitored in 187 patients (►Table 2).

SG f-EMG Activity and EOCN Deficits

A total of 696 EOCNs were monitored in 200 patients. The percentage incidence of EOCN deficit in nerves with significant activity is 2.27% and percentage incidence of EOCN deficit in nerves without significant activity is 2.30%. The details of individual EOCNs monitored, SG f-EMG activities, and their postoperative nerve deficits are as follows (►Table 2): 88 cranial nerves had significant f-EMG activity in the muscles supplied by them.

1. CN III: A total of 153 patients had 219 nerves monitored during surgery. There were 46 nerves (21%) that displayed SG f-EMG activity. No deficits were present in the group with SG activity, and three permanent EOCN deficits were observed in the group without SG f-EMG activity.

2. CN IV: A total of 135 patients had 192 nerves monitored during surgery. There were 21 nerves (11%) that displayed SG f-EMG activity. No postoperative EOCN deficits were observed in the group with SG f-EMG activity and two postoperative EOCN deficits in the group without SG f-EMG activity.

3. CN VI: A total of 187 patients had 285 nerves monitored during surgery. There were 18 nerves (7%) that displayed

Table 1 Demographic and Patient Data of Monitored Patients

Number of patients monitored	200	100%
Sex		
Male	88	44%
Female	112	56%
Surgical approach		
Transellar	51	26%
Transclival	91	46%
Transplanum	13	6.50%
Transcavernous	12	6.00%
Transpterygoidal	12	6.00%
Others	21	10.50%
Year of surgery		
2000–2005	50	25%
2006–2008	150	75%
Diagnosis		
Meningioma	43	22%
Chordoma	25	13%
Pituitary tumor	37	18.50%
Chondrosarcoma	6	3.00%
Angiofibroma	12	6.00%
Others	77	37.50%

Table 2 Data Indicating the Cranial Nerve Monitored and Postoperative Outcome

Cranial nerves	III	IV	VI		V	VII	IX	X	XI	XII
Total number of patients monitored	153	135	187		16	39	32	35	14	32
Total number of nerves monitored	219	192	285		24	63	55	61	24	59
Side monitored										
Right	43	40	41		3	9	5	5	2	2
Left	44	38	48		5	6	4	4	2	3
Both	66	57	98		8	24	23	26	10	27
Total number of patients with significant activity	39	20	18		1	10	6	6	2	2
Number of cranial nerves with significant activity	46	21	21		1	15	8	10	4	3
Total cranial nerve deficits in patients with significant activity	0	0	2		0	0	0	0	0	0
Transient	0	0	0		0	0	0	0	0	0
Permanent	0	0	2		0	0	0	0	0	0
Total number of patients without significant activity	114	115	169		15	29	26	29	12	30
Number of cranial nerves without significant activity	173	171	264		23	48	47	53	20	56
Total cranial nerve deficits in patients without significant activity	3	2	9		0	0	1	1	0	1
Transient	0	1	2		0	0	0	0	0	0
Permanent	3	1	7		0	0	1	1	0	1

SG f-EMG activity. There were two permanent EOCN deficits in patients who had SG f-EMG activity. A total of two transient and seven permanent CN VI deficits were observed in the group without SG f-EMG activity.

Clinical Information on EOCN Deficits

A total of 608 nerves did not display SG f-EMG discharges. Among these nerves, a total of 14 CN deficits were noted. Three deficits were seen in CN III, two in CN IV, and nine in CN VI (►**Table 7**). Patient's initials are marked in parentheses.

- Patient (SR) underwent surgery for removal of pituitary adenoma. This patient did have permanent right CN III, IV, and VI deficit after her first stage of EES. No SG f-EMG activity was observed from any CN monitored.
- Patient (SD) underwent surgery for removal of chondrosarcoma. The patient had permanent right CN III deficits and temporary right CN IV deficit after her first stage of EES. No SG f-EMG activity was present in either of the nerves or the CN VI monitored.
- Patient (PR) had a left CN III deficit with no SG f-EMG activity in CN III or IV.
- There were nine CN VI deficits, in which two CN VI deficits were transient and seven were permanent. One patient had CN III, IV deficits as described above. Another patient had bilateral CN VI palsy, with one temporary and one permanent deficit. The other six deficits were all only CN VI. The common diagnosis in this group with CN VI deficits is pituitary tumor; the common approach to the tumor has been transellar approach. There were five patients with CN VI deficits after stage 1, three CN VI deficits after stage 2, and one after stage 4.

The incidence, mean and standard deviation, and range of significant activity during surgery in each individual CN group is also calculated and shown in the table (►**Table 3**).

Further analysis was performed by comparing the group with significant activity and the group without significant activity during EOCN monitoring. There were no significant differences in their age, sex, period of surgery, number of stages, procedures, neurological deficits, laterality, or EMG alerts for CN III, IV, and VI (►**Tables 4–6**).

In addition to monitoring EOCN, we also monitored lower CNs (VII, IX, X, XI, XII) in some cases during the same EES procedures (►**Table 2**). No CN deficits were seen in patients who had SG f-EMG activity. Three lower cranial deficits were seen in one patient who also had CN VI palsy. No SG f-EMG activity was present in any one of the nerves.

Discussion

EOCN EMG monitoring has been used during traditional skull surgery to identify the EOCN and prevent postoperative EOCN deficits. f-EMG is a continuous recording of EMG activity characterized by spikes, bursts, and neurotonic discharges secondary to unintended activation of the CN supplying extraocular musculature. Neurotonic discharges,[7] a high-frequency discharge f-EMG, have been predictive of postoperative paralysis after skull base surgery. The f-EMG activity can reflect the proximity of CNs during EES, hence providing value in the operating field and potentially reducing the incidence of iatrogenic injury.

The incidence of EOCN deficit between patients who had SG f-EMG activity during surgery (2.27%) and patients who did not have SG f-EMG activity during surgery (2.30%) is not

Table 3 Data Show Incidence of Free-run Electromyographic Activity in the Extraocular Cranial Nerve

Cranial nerve	III	IV	VI
Number of patients monitored	153	135	187
Number of nerves monitored	219	192	285
Number of nerves with significant activity	46	21	21
Incidence of significant activity	21%	11%	7%
Mean and standard deviation for EMG alerts per nerve	3.4 ± 3.08	2.10 ± 1.49	2.22 ± 1.59
Median and range for EMG alerts per nerve	3 (1–14)	1 (1–6)	2 (1–6)
Free-run EMG activity observed in patients with CN deficits	0	0	2

Abbreviations: CN, cranial nerve; EMG, electromyelography.

significantly different. Manipulation of the EOCN by dissecting instruments and drilling can evoke f-EMG activity including bursts, spikes, or neurotonic discharges. There appears to be no correlation between the type of manipulation and the discharges that were recorded.[7] It also appears that the f-EMG activity provides continuous feedback on the location of the nerve. This feedback resulted in a more cautious approach to dissection of the tumor and hence may prevent neurological deficits in EOCNs that had SG f-EMG activity during surgery. It is recognized that sudden complete transection of a nerve does not produce any f-EMG activity.[17,18] It is also possible that the absence of the f-EMG alerts provides a false sense of security, promoting a more aggressive resection resulting in increased risk of nerve injury.

We regarded any change in f-EMG activity above baseline as significant activity and immediately relayed the EMG alert to the surgery team. The f-EMG alerts were very useful in indicating the proximity to a CN. The mean number of EMG alerts of each EOCN varied from 2.1 to 3.4 during each procedure (►Table 3). It is unclear if the amount of EMG alerts conveyed to the surgeon is of any value in predicting CN deficit. This might be secondary to the fact that, once significant activity is relayed to the surgeon, he or she will take a conservative approach to safeguard the nerve. The incidence of SG f-EMG activity for each CN, a percentage of total nerves with significant activity to the number of nerves monitored, were 21%, 11%, and 7% for CN III, IV, and VI, respectively. There was no correlation between the incidence of SG f-EMG activity and postoperative EOCN deficits.

In our series, 21% of monitored CN III had SG f-EMG activity during the procedure. CN III generated most alerts when compared with CNs IV and VI. CN VI was also the most common nerve monitored. Incidentally, this was the nerve with the smallest number of EMG alerts (7%) during surgery,

Table 4 Statistical Analysis of Different Variables in Cranial Nerve III

Cranial nerve III		SG = no		SG = yes		
		n	row %	n	row %	p Value
Sex	Female	51	71.83	20	28.17	
	Male	59	74.68	20	25.32	0.693
Stage	1	85	72.03	33	27.97	
	2 to 8	24	77.42	7	22.58	0.547
Procedure	TRANSCLIVAL	38	65.52	20	34.48	
	TRANSSELLAR	36	75.00	12	25.00	
	Others	36	81.82	8	18.18	0.174
Year of surgery	2000–2005	17	68.00	8	32.00	
	2006–2008	93	74.40	32	25.60	0.509
ND	No	170	78.70	46	21.30	
	Yes	3	100	0	0.00	1.000
		SG = no		SG = yes		
		mean	SD	mean	SD	p Value
	Age	51.21	17.88	44.91	16.79	0.055

Abbreviations: ND, neurological deficit; SD, standard deviation; SG, significant activity.

Table 5 Statistical Analysis of Different Variables in Cranial Nerve IV

Cranial nerve IV						
		SG = no		SG = yes		
		N	row %	n	row %	p Value
Sex	female	54	87.10	8	12.90	
	male	52	81.25	12	18.75	0.369
Stage	1	83	84.69	15	15.31	
	2 to 8	22	81.48	5	18.52	0.768
Procedure	TRANSCLIVAL	37	77.08	11	22.92	
	TRANSSELLAR	39	90.70	4	9.30	
	others	30	85.71	5	14.29	0.198
Year of surgery	2000–2005	14	82.35	3	17.65	
	2006–2008	92	84.40	17	15.60	0.733
ND	no	169	88.95	21	11.05	
	yes	2	100.00	0	0.00	1.000
		SG = no		SG = yes		
		mean	SD	mean	SD	p Value
	Age	48.34	17.28	49.25	21.56	0.835

Abbreviations: ND, neurological deficit; SD, standard deviation; SG, significant activity.

as well. Anatomical location and the intracranial course of CN III, IV, and VI can explain this phenomenon. But the exact reason for this difference could be related to the size and direction of tumor growth, involvement of the CNs, and approach to the tumor removal. This is supported by the absence of cross-correlation of the incidence of SG f- EMG discharges between EOCNs. It is interesting to note that CN VI had the most deficits and the lowest level of SG f-EMG activity. EES involves a midline approach to tumors through the nose. It is possible that minimal manipulation of the tumor resulted in EMG activity during the procedure. The increased alerts could be a protective effect against excessive

Table 6 Statistical Analysis of Different Variables in Cranial Nerve VI

Cranial Nerve VI						
		SG = no		SG = yes		
		n	row %	n	row %	p Value
Sex	female	78	91.76	7	8.24	
	male	89	89.90	10	10.10	0.663
Stage	1	126	91.30	12	8.70	
	2 to 8	40	88.89	5	11.11	0.570
Procedure	TRANSCLIVAL	76	88.37	10	11.63	
	TRANSSELLAR	46	95.83	2	4.17	
	others	45	90.00	5	10.00	0.411
Year of surgery	2000–2005	29	82.86	6	17.14	
	2006–2008	138	92.62	11	7.38	0.100
ND	no	255	93.07	19	6.93	
	yes	9	81.82	2	18.18	0.190
		SG = no		SG = yes		
		mean	SD	mean	SD	p Value
	Age	47.75	18.82	43.09	17.70	0.329

Abbreviations: ND, neurological deficit; SD, standard deviation; SG, significant activity.

Table 7 Clinical Extraocular Cranial Nerve Deficits in Individual Patients

Patient #	Age	Sex	Diagnosis	Surgery	CN monitored	Side monitored	Nerve deficit
1	62	Male	Clival chordoma	Transclival	VI	Bilateral	VI left
2	69	Female	Meningioma	Transclival	VI	Right	VI right
3	34	Female	Meningioma	Transclival	VI	Bilateral	VI right
4	48	Female	Pituitary adenoma	Transellar	VI	Bilateral	VI bilateral
5	64	Female	Pituitary adenoma	Transcavernous	IV&VI	Right side in both	IV & VI right in both
6	22	Male	Pituitary adenoma	Transclival Transellar–zone 4	VI	Right	VI right
7	13	Male	Angiofibroma	Transpterygoidal	VI	Bilateral	VI right
8	13	Male	Angiofibroma	Transpterygoidal	IV	Bilateral	IV left
9	66	Male	Pituitary adenoma	Transellar	III	Left	III left
10	58	Female	Pituitary adenoma	Transellar	III	Right	III right
11	53	Male	Pituitary adenoma	Transclival, Transplanum–Transclival	VI	Bilateral	VI left
12	30	Female	Pituitary adenoma	Transellar	VI	Right	VI right
13	59	Female	Pituitary adenoma	Transcavernous	III&VI	Bilateral in both	III &VI right in both

Abbreviation: CN, cranial nerve.

manipulation or just an epiphenomenon due to the anatomical nature of their CN III course. We believe that the surgical techniques are modified secondary to the EMG alerts.

f-EMG has been used to identify EOCN and prevent postoperative deficits. Schlake et al used both f-EMG and t-EMG to identify EOCN III and IV and to predict postoperative deficits.[4] A total of 18 CNs were monitored; however, not all nerves could be identified using t-EMG. There was no correlation between EMG activity and neurological deficits. A similar study by Sekhar et al demonstrated the usefulness of t-EMG in identifying EOCN.[5] There was no relationship between EMG activity and postoperative nerve deficits. Sekiya et al used t-EMG to monitor 22 EOCN; no f-EMG was performed.[10] Changes in the threshold of stimulation to obtain a CMAP response may be useful to predict postoperative nerve injury.[8] Loss of CMAP during surgery can indicate transection of a nerve during surgery. Kawaguchi et al found a correlation between increased threshold and postoperative nerve injury.[2] It appears t-EMG can be used to identify EOCN during traditional skull base surgery. The f-EMG, irrespective of classification, does not correlate with postoperative EOCN deficits. Similarly, in our study we found no direct correlation between EMG activity and postoperative EOCN deficits.

We had a total of 14 EOCN deficits in patients who did not have SG f-EMG activity. There were nine CN VI deficits. Two CN VI deficits were transient and seven were permanent. The common diagnosis in this group with CN VI deficits is pituitary tumor, the common approach to the tumor has been transellar approach. There were five patients with CN VI deficits after stage 1, three CN VI deficits after stage 2, and one after stage 4. Previous surgery and radiotherapy would

have made dissection of the region of the tumor very difficult due to adhesions. The deficits also may be explained by inadvertent sharp transection of the monitored nerve during surgery.[18,19] Radiation could have also modified the EMG response secondary to inadvertent stimulation. Spontaneous EMG activity will occur if the nerve is subjected to stretching, traction, or injury. If the nerve is transected abruptly, there will be only brief or no EMG activity as described by Harper et al.[20] Lack of f-EMG activity should not provide a false sense of security about the state or proximity of the CN. Using t-EMG to localize the CNs during tumor resection may potentially help prevent nerve injuries in these types of cases. These results also emphasize the limitation of just using f-EMG during EES. We have modified our approach for monitoring and are consistently using t-EMG in addition to f-EMG in our practice to identify EOCN and to prevent iatrogenic CN deficits.

We further analyzed the data to see if any particular variable is significantly different between two groups. Variables considered were gender, stage of surgery, year of surgery, and surgical approach. We considered age because older patients are more prone to succumb to postoperative morbidity and there is a high risk for stroke, which can lead to various nerve deficits. The year the surgery took place is considered because we found a learning curve effect on EES with SSEP monitoring.[21] None of the variables was significantly different in either group (►Tables 4–6).

This study did have limitations. Only f-EMG was monitored during the surgery and no t-EMG monitoring was performed. f-EMG is clearly an unintentional evoked EMG response and hence it is less specific. Additionally, we only monitored cases

that were at high risk for CN injury. In our entire series, we had 990 patients who underwent EES. We did have CN deficits in patients who were not monitored, so the current strategy to identify patients for f-EMG might have to expand to include more patients. Our analysis included deficits in patients recorded after surgery. It is possible some deficits were not clearly documented. The technique of placing needles in the extraocular muscles to record EMG is not standardized. It is possible that our technique of placing needles is not very sensitive to record f-EMG and hence had limited value in predicting postoperative deficits.

Conclusions

- EOCN f-EMG monitoring during EES can provide useful information to identify the location of the CN. This may also be used to alert the surgeon to make adjustments during the procedure, which can prevent EOCN injury.
- EOCN f-EMG seems to have limited value in predicting postoperative neurological deficits. Absence of EMG activity during the procedure should not provide a false sense of security about the state or proximity of the CN.
- If and when possible, CMAP with t-EMG should be elicited to check the integrity of EOCN. Further studies to evaluate the EMG of EOCN during EES procedures need to be done with both f-EMG and t-EMG.
- We advocate a comprehensive approach to neurophysiological monitoring during EES, including somatosensory-evoked potentials, f-EMG, t-EMG of CNs II–XII, brain stem auditory–evoked potentials, and electroencephalogram depending on the location of the neural structures at risk and the approach being used.

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