Value of Free-Run Electromyographic Monitoring of Lower Cranial Nerves in Endoscopic Endonasal Approach to Skull Base Surgeries

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Abstract

Objective The main objective of this study was to evaluate the value of free-run electromyography (f-EMG) monitoring of cranial nerves (CNs) VII, IX, X, XI, and XII in skull base surgeries performed using endoscopic endonasal approach (EEA) to reduce iatrogenic CN deficits.

Design We retrospectively identified 73 patients out of 990 patients who had EEA in our institution who had at least one 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 We monitored a total of 342 CNs. A total of 62 nerves had SG f-EMG activity including CN VII = 18, CN IX = 16, CN X = 13, CN XI = 5, and CN XII = 10. No nerve deficit was found in the nerves that had significant activity during procedure. A total of five nerve deficits including (CN IX = 1, CN X = 2, CN XII = 2) were observed in the group that did not display SG f-EMG activity during surgery.

Conclusions f-EMG seems highly sensitive to surgical manipulations and in locating CNs. It seems to have limited value in predicting postoperative neurological deficits. Future studies to evaluate the EMG of lower CNs during EEA procedures need to be done with both f-EMG and triggered EMG.

Keywords

- electromyography
- lower cranial nerves
- endoscopic endonasal approach
- skull base surgery

Introduction

Cranial nerve (CN) electromyographic (EMG) monitoring during conventional skull base surgeries has been used to reduce the postoperative neurological deficits by detecting impending CN injury.¹ 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 a CN. Neurotonic discharges¹ during f-EMG recordings have been a 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 CN during skull base surgery. The change in the threshold of stimulation to elicit a

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CMAP²⁻⁴ during facial nerve surgery may be a predictor of postoperative CN paralysis. Monitoring a change in t-EMG threshold alone cannot predict postoperative neurological deficits.^{5,6} Intraoperative f-EMG has been used to preserve CN VII⁷⁻⁹ during skull base surgery. It is also used to identify and map the lower CNs (LCNs) (IX to XII)¹⁰⁻¹⁴ during tumor resection. F-EMG and t-EMG do not appear to provide reliable prognostic information about the integrity of extraocular^{15,16} and LCNs.^{10,13}

The endoscopic endonasal approach (EEA) is a minimally invasive novel technique for skull base surgery that involves the use of an endoscope and complex neuronavigational systems with neurosurgery and otolaryngology working together during the surgery.¹⁷⁻²¹ Using EEA, we are able to access the entire ventral skull base from the crista galli to odontoid and as lateral as the middle fossa with minimal residual postoperative complications.²² Based on the location of the tumor, the approach can be classified into transcribiform, transdorsum sellae, and transclival. Although minimally invasive, it carries significant potential risk of injury to neurovascular structures including the internal carotid arteries, anterior cerebral arteries, and CNs III to XII¹⁸⁻²⁰ depending on the approach and location of the tumor. Our primary aim in this article was to evaluate the value of f-EMG monitoring of LCN during EEA in reducing iatrogenic CN deficits.

Materials and Methods

Study Design

We retrospectively reviewed all consecutive cases of EEA at our institution between 2000 and 2008. The total number of patients who underwent EEA 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 73 patients were identified as having at least one LCN monitored during their operation. Included were monitoring for CN VII: 47, CN IX: 44, CN X: 50, CN XI: 22, and CN XII: 39. In this study, one patient might have more than one nerve monitored. This study was approved by the quality assurance committee for retrospective review of data on human subjects at the University of Pittsburgh.

Neurophysiologic Monitoring

Continuous f-EMG activity was recorded using pairs of subdermal needle electrodes placed 1 cm apart in the muscle groups innervated by the LCN. The needle's length was 13 mm with a diameter of 0.4 mm manufactured RHYTHM-LINK® (Columbia, SC, USA). For monitoring of the facial nerve (CN VII), bipolar needle electrodes were placed in orbicularis oculi, orbicularis oris, and mentalis muscles ipsilateral to the operative side. Motor component of glossopharyngeal (CN IX) was monitored by placing bipolar leads after endotracheal intubation in the soft palate.^{10,13} Recurrent laryngeal (CN X) component of the vagus nerve was monitored by placing

bipolar electrodes in the cricothyroid muscles below the thyroid cartilage.^{10,13,23-25} Monitoring spinal accessory nerve (CN XI) was accomplished by placing bipolar electrodes in the trapezius muscle.¹⁴ Monitoring of hypoglossal nerve (CN XII) involves placing bipolar needles in the tongue muscles after intubation.

Physician oversight and interpretation were performed using a combined on-site and remote model used at UPMC. In all cases, a board certified neurophysiologist (American Board of Neurophysiological Monitoring) was on-site, in person available for interpretation and consultation while physician (neurologists) oversight, supervision, and additional interpretation were performed in person or remotely. The oversight physician provided supervision for four to five cases simultaneously on an 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. Neuromuscular junction blockade was tested by using a standard train of four twitches. The patient was maintained using a balanced technique using inhalational and IV agents during the procedure.

Alarm Criteria

No detectable EMG activity was considered to be baseline in each case. Detection of nerve manipulation, compression, stretch, and permanent injury was based on changes from baseline recordings. All instances of EMG activity, regardless of type (spikes, bursts, or neurotonic discharges) were considered significant (SG). SG f-EMG discharges were made audible to and immediately reported to the surgeon and recorded in the patient's record. Henceforth, this EMG activity is called "EMG alerts." SG f-EMG activity when present for prolonged periods of time or prolonged activities with small interruptions for a single LCN was reported as one alert. Recordings were made continuously during all stages of surgery after incision. In our study, we did not consider EMG activity during irrigation of the surgical field as being significant.

Medical Record Review

Medical records of all the patients included in the study were reviewed to determine if any new neurologic deficits were present after the surgical procedure. Medical records were reviewed independently without the knowledge of the intraoperative EMG events. Any new postoperative extra ocular cranial nerve motor deficits were considered to be iatrogenic intraoperative injuries. Deficits were classified as transient or permanent. Transient deficits had documented evidence in medical records to complete improvement to baseline. Permanent deficits were defined as those which did not improve to baseline at subsequent follow-up visits. All CN deficits were documented by a neurologist. Similarly, the intraoperative records were reviewed independently to define legitimate EMG discharges in all the 74 patients without the knowledge of the postoperative neurologic outcome.

Demographic and Patient Data

Demographic, diagnostic, and surgical information on all the patients were compiled into two groups and compared. Patients who had SG f-EMG activity were classified in group I and patients who did not have any SG f-EMG activity were classified in group II. The need for CN monitoring was determined by the surgeon based on the pathology and a perceived risk of injury to LCN. The purpose of the comparative analysis was to identify variables which were significantly different between the two groups.

Data Analysis

EMG alerts were annotated in the technologist's log for all instances where LCN activity was observed. EMG alerts are considered significant if EMG activity information is conveyed to the surgeons. We estimated the number of alerts per nerve 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 the unilateral as "one" and bilateral as "two" nerves monitored. Furthermore, the data from two groups were tabulated to study the number of transient and permanent deficits.

Data were presented as mean $\pm$ standard deviation for continuous variables and proportion for categorical variables. *t* tests were used to evaluate group differences for continuous variables. Chi-square tests or Fisher's exact tests were used for categorical variable comparisons. The analyses were performed with SAS 9.13 software (SAS Institute, Cary, NC, USA).

Results

Demographic and Patient Data

The total number of patients who had at least one LCN monitored was 73. Of the 73 patients, 59% were male and 41% were female. All patients had surgery between the year 2000 and 2008. Meningioma was the most common diagnosis followed by chordoma, chordosarcoma, angiofibroma, pituitary tumor, and others. The most common skull base approach used was transsellar (48%) followed by transclival, transplanum, and others (**► Table 1**).

Monitoring LCN

Monitoring of at least one LCN was performed in 73 patients, with one patient having more than one CN monitored. CN VII was monitored in 47 patients. CN IX was monitored in 44 patients. CN X was monitored in 50 patients. CN XI was monitored in 22 patients. CN XII was monitored in 39 patients.

LCN Deficits and f-EMG Activity

A total of 342 LCNs were monitored in 73 patients. A total of 62 of 342 LCNs showed SG f-EMG activity. The details of individual CNs monitored, their SG activity, and postoperative nerve deficits are as follows (**► Table 2**):

1. CN VII: A total of 47 patients had 76 nerves monitored during surgery. There were 18 nerves which displayed

Table 1 Demographic and Patient Data who had LCN Monitoring

No. of Patients Monitored	73	%
Sex		
Male	43	59
Female	30	41
Procedure done		
Transsellar	35	48
Transclival	9	12
Transplanum	12	16.44
Transcribriform	8	10.96
Others	9	12.33
Year of Surgery		
2000–2005	27	37
2005–2008	46	63
Diagnosis		
Meningioma	20	27
Chordoma	15	20
Pituitary tumor	2	2.74
Chondrosarcoma	5	6.85
Angiofibroma	3	4.11
Cholesterol granuloma	2	2.74
Paraganglioma	2	2.74
Others	24	32.88

LCN, lower cranial nerve.

SG f-EMG activity and no new CN deficits were observed in either the groups.

2. CN IX: A total of 44 patients had 76 nerves monitored during surgery. There were 16 nerves which displayed SG f-EMG activity. One patient had a new CN deficit in the group which did not show SG activity.
3. CN X: A total of 50 patients had 86 nerves monitored during surgery. There were 13 nerves which displayed SG f-EMG activity. There were two new CN deficits in the group who had no SG activity. Both CN deficits were permanent.
4. CN XI: A total of 22 patients had 36 nerves monitored during surgery. There were five nerves which displayed SG f-EMG activity and there were no new CN deficits in either group.
5. CN XII: A total of 39 patients had 68 nerves monitored during surgery. There were 10 nerves which displayed SG f-EMG activity. There were two nerve deficits in group who no SG activity. Both nerve deficits were permanent.

A total of 280 LCN out of 342 LCN monitored did not show any SG f-EMG activity. Of these, a total of five LCN deficits were noted. All deficits were present in only two patients, who had clival chordomas.

Table 2 Data Indicating the Cranial Nerve Monitored and Postoperative Outcome

Cranial Nerves	VII	IX	X	XI	XII	III	IV	V	VI
Total number of patients monitored	47	46	50	22	41	25	21	13	54
Total number of nerves monitored	76	80	86	36	72	37	32	22	92
Side monitored									
Right	10	5	5	3	3	8	7	1	8
Left	8	7	9	5	7	5	3	3	8
Both	29	34	36	14	31	12	11	9	38
Total number of patients with significant activity	14	12	8	3	8	4	2	0	6
No. of CNs with significant activity	18	16	13	5	10	5	2	0	6
Total CN deficits in patients with significant activity	0	0	0	0	0	0	0	0	1 ^a
Total number of patients without significant activity	33	34	42	19	33	21	19	13	47
No. of CNs without significant activity	58	64	73	31	62	32	30	22	84
Total CN deficits in patients without significant activity	0	1	2	0	2	0	0	0	4
Permanent	0	1	1	0	1	0	0	0	4
Transient	0	0	1	0	1	0	0	0	0

^aPermanent deficit.

CN, cranial nerve.

One patient was a 59-year-old woman with chondrosarcoma with significant mass effect on the pons, requiring multiple stages of EEA. The tumor was irregular in shape and measured 4.6 cm × 4.5 cm in the axial plane, and 6.5 cm in the coronal plane. Postoperatively, she had a deficit of left CN IX, X, and XII. The deficits that were present after the first stage were permanent.

The second patient was a 67-year-old woman with a recurrent chordoma. This was an irregular tumor measuring 3.5 cm × 2.3 cm in the axial plane and 4 cm in the coronal plane. Postoperatively, she had deficits of her left CN X and XII, both of which were permanent. This was her second stage for EEA, after radiation therapy.

The incidence, mean, median, standard deviation, and range of SG f-EMG activity and alerts during surgery in each individual CN group are calculated and shown in ►Table 3.

Further analysis was performed in both groups, taking into consideration characteristics such as age, gender, stage of

surgery, and CN deficits. All the characteristics were similar between those with SG f-EMG activity and those without SG f-EMG activity in CNs VII, X, XI, and XII. However, in CN IX, our data showed that those who had a transclival procedure had a much higher incidence of SG f-EMG activity (66.7%, $p = 0.026$), and those with surgeries performed after 2006 also had a higher incidence of SG f-EMG activity than those who had surgeries done in earlier years (37.9% vs. 5.9%, $p = 0.034$) (►Tables 4–8).

Monitoring other CNs

Monitoring of other CNs is given below:

1. CN III: A total of 25 patients had 37 nerves monitored during surgery. There were five nerves with SG f-EMG activity. No cranial deficits were present in either of the groups.
2. CN IV: A total of 21 patients had 32 nerves monitored during surgery. There were two nerves with SG f-EMG

Table 3 Data Show Incidence of f-EMG Activity in the EO CN during EEA

Cranial Nerves	VII	IX	X	XI	XII
No. of patients monitored	47	46	50	22	41
No. of nerves monitored	76	80	86	36	72
No. of nerves with significant activity	18	16	13	5	10
Incidence of significant activity	23%	20%	15%	13%	14%
Mean and SD for EMG alerts per nerve	3.3 ± 2.3	3.3 ± 2.9	1.6 ± 0.9	1.6 ± 0.9	7.2 ± 6
Median and range for EMG alerts per nerve	3 (1–7)	2.5 (1–7)	1 (1–3)	1 (1–2)	4 (1–17)
f-EMG activity observed in patients with CN deficits	0	0	0	0	0

CN, cranial nerve; EEA, endoscopic endonasal approach; EMG, electromyography; f-EMG, free-run electromyography; SD, standard deviation.

Table 4 Statistical Analysis of Different Variables in Groups with and without SG f-EMG Activity for Cranial Nerve VII

Cranial Nerve VII						
		SG = No		SG = Yes		
		<i>n</i>	Row %	<i>n</i>	Row %	<i>p</i> Value
Sex	Female	12	63.16	7	36.84	0.384
	Male	21	75.00	7	25.00	
Stage	1	21	67.74	10	32.26	0.742
	2–8	12	75.00	4	25.00	
Procedure	Transclival	3	60.00	2	40.00	
	Transsellar	13	68.42	6	31.58	
	Others	17	73.91	6	26.09	0.736
Year of surgery	2000–2005	16	88.89	2	11.11	
	2006–2008	17	58.62	12	41.38	0.027
ND	No	33	70.21	14	29.79	
	Yes	0	—	0	—	—
		SG = No		SG = Yes		
		Mean	SD	Mean	SD	<i>p</i> Value
	Age	44.49	18.07	53.00	16.38	0.137

f-EMG, free-run electromyography; ND, neurological deficit; SD, standard deviation; SG, significant.

activity. No CN deficits were present in either of the groups.

3. CN V: A total of 18 patients had 28 nerves monitored during surgery. There was one patient with SG f-EMG activity. No CN deficits were present in either of the groups.
4. CN VI: A total of 53 patients had 90 nerves monitored during surgery. There were six nerves with SG f-EMG

activity. One permanent CN deficits were present in the group. There were four nerve deficits in the group without SG f-EMG discharges. The nerve deficits were permanent.

Discussion

CN EMG monitoring has been used during conventional skull base surgery to identify the CNs and prevent postoperative

Table 5 Statistical Analysis of Different Variables in Groups with and without SG f-EMG Activity for Cranial Nerve IX

Cranial Nerve IX						
		SG = No		SG = Yes		
		<i>n</i>	Row %	<i>n</i>	Row %	<i>p</i> Value
Sex	Female	13	61.90	8	38.10	
	Male	21	84.00	4	16.00	0.089
Stage	1	18	72.00	7	28.00	
Procedure	Transclival	2	33.33	4	66.67	
	Transsellar	15	71.43	6	28.57	
	Others	17	89.47	2	10.53	0.026
Year of surgery	2000–2005	16	94.12	1	5.88	
	2006–2008	18	62.07	11	37.93	0.034
ND	No	33	76.74	10	23.26	
	Yes	1	100.00	0	0.00	1.000
		SG = No		SG = Yes		
		Mean	SD	Mean	SD	<i>p</i> Value
	Age	46.40	19.43	48.59	24.91	0.757

f-EMG, free-run electromyography; SD, standard deviation; SG, significant.

Table 6 Statistical Analysis of Different Variables in Groups with and without SG f-EMG Activity for Cranial Nerve X

Cranial Nerve X						
		SG = No		SG = Yes		p Value
		n	Row %	n	Row %	
Sex	Female	17	77.27	5	22.73	0.277
	Male	25	89.29	3	10.71	
Stage	1	23	88.46	3	11.54	0.456
	2–8	19	79.17	5	20.83	
Procedure	Transclival	4	57.14	3	42.86	0.146
	Transsellar	19	86.36	3	13.64	
	Others	19	90.48	2	9.52	
Year of surgery	2000–2005	18	94.74	1	5.26	0.134
	2006–2008	24	77.42	7	22.58	
ND	No	39	82.98	8	17.02	1.000
	Yes	2	100.00	0	0.00	
		SG = No		SG = Yes		p Value
		Mean	SD	Mean	SD	
	Age	45.33	20.65	51.99	21.89	0.411

f-EMG, free-run electromyography; SD, standard deviation; SG, significant.

deficits.²⁶ Free-run EMG is a continuous recording of EMG activity characterized by spikes, bursts, and trains,²⁷ secondary to unintended activation of a CN. Neurotonic discharges, a high-frequency discharge f-EMG, have been a predictor of postoperative paralysis after skull base surgery.²⁷ f-EMG activity can reflect proximity to a CN during EEA hence

providing value in the operating field. In our study, no postoperative CN deficits were observed in the group which showed SG f-EMG activity during surgery. We regarded any change in 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

Table 7 Statistical Analysis of Different Variables in Groups with and without SG f-EMG Activity for Cranial Nerve XI

Cranial Nerve XI						
		SG = No		SG = Yes		p Value
		n	Row %	n	Row %	
Sex	Female	9	81.82	2	18.18	1.000
	Male	10	90.91	1	9.09	
Stage	1	11	84.62	2	15.38	1.000
	2–8	8	88.89	1	11.11	
Procedure	Transclival	5	83.33	1	16.67	1.000
	Transsellar	5	100.00	0	0.00	
	Others	9	81.82	2	18.18	
Year of surgery	2000–2005	4	100.00	0	0.00	1.000
	2006–2008	15	83.33	3	16.67	
ND	no	19	86.36	3	13.64	—
	yes	0	—	0	—	
		SG = No		SG = Yes		p Value
		Mean	SD	Mean	SD	
	Age	46.98	22.96	46.30	29.56	0.964

f-EMG, free-run electromyography; SD, standard deviation; SG, significant.

Table 8 Statistical Analysis of Different Variables in Groups with and without SG f-EMG Activity for Cranial Nerve XII

Cranial Nerve XII						
		SG = No		SG = Yes		
		<i>n</i>	Row %	<i>n</i>	Row %	<i>p</i> Value
Sex	Female	13	81.25	3	18.75	1.000
	Male	18	78.26	5	21.74	
Stage	1	18	81.82	4	18.18	0.709
	2–8	13	76.47	4	23.53	
Procedure	Transclival	4	57.14	3	42.86	0.135
	Transsellar	12	75.00	4	25.00	
	Others	15	93.75	1	6.25	
Year of surgery	2000–2005	10	83.33	2	16.67	1.000
	2006–2008	21	77.78	6	22.22	
ND	No	29	78.38	8	21.62	1.000
	Yes	2	100.00	0	0.00	
		SG = No		SG = Yes		
		Mean	SD	Mean	SD	<i>p</i> Value
	Age	46.43	22.42	41.40	25.50	0.585

f-EMG, free-run electromyography; SD, standard deviation; SG, significant.

the CN. We postulate that this could have led to modification of technique and careful dissection potentially leading to decreased CN deficits.

Prass and Lüders classified different types of EMG discharges as bursts, spikes, and trains. Manipulation of the CN by dissecting instruments and drilling can evoke f-EMG activity including bursts, spikes, or trains. There was no correlation between the type of manipulation and the discharges that were recorded.²⁷ They concluded that bursts and spike EMG activity were probably due to CN stimulation by various mechanisms and may not have a relationship to nerve injury. Romstöck et al characterized the EMG discharges as spikes, bursts, and trains. They further differentiated trains into A, B, and C.¹ They concluded that bursts could be precisely attributed to contact activity, the A train could be correlated with postoperative nerve deficits, and the B and C trains as irrelevant.^{1,27,28} Our alarm criterion was conservatively developed based on some of the above studies.

In addition to monitoring LCN, we also monitored extra-ocular CNs and CN V in some cases during the same EEA procedures. The results of monitoring f-EMG were similar to the LCN group. Patients who displayed SG f-EMG discharges during surgery did not have any CN deficits, except in CN VI. In the group without SG f-EMG discharges, no CN deficits were noted for CNs III, IV, and V. There were four cases of CN VI deficits in patients; all of the deficits were permanent.

The mean number of EMG alerts for each CN varied from 1.6 to 7.2 during each procedure (►Table 3). EMG alerts, regardless of type, were made audible to and immediately reported to the surgeon. The number of alerts conveyed to the surgeon did not predict CN deficit. The incidence of SG f-EMG activity for each CN and a percentage of the total nerves with

significant activity to the number of nerves monitored were 23, 20, 15, 13, and 14% for CNs VII, IX, X, XI, and XII, respectively (►Table 3). There was no correlation between the incidence of activity and postoperative CN deficits.

EMG activity in general appears to be helpful in identifying proximity of the nerve; no single nerve is protected from injury. The amount of EMG activity might be secondary to location of tumor relative to the nerve, the size of the tumor, the stage of the procedure, and/or previous radiation. The above results might be secondary to the fact that once there is a SG f-EMG activity, the surgeon will be more careful in tumor dissection in an attempt to safeguard the nerve. This approach could also be the reason we did not have any CN deficits in the group which displayed SG f-EMG activity. Statistical analysis did not find any significant difference in terms of LCN deficits in patients with or without SG f-EMG discharges. Since the presence of SG f-EMG activity cause a modification in the surgical procedure, it is possible that deficits were prevented in group I. This could have resulted in lack of statistical power in the analysis.

In our study, we found that group II (absence of SG f-EMG activity during surgery) was the only group which displayed postoperative LCN nerve deficits (►Table 2). All deficits presented in only two patients, both had clival chordomas. Both LCN deficits were permanent. One patient was a 59-year-old woman with chordosarcoma with significant mass effect on the pons, requiring multiple stages of EEA. She has a postoperative deficit of left CNs IX, X, and XII. The second patient was a 67-year-old woman with recurrent chordoma. She has postoperative left CN X and XII deficits. The patient had radiation therapy and previous EEA before the current procedure. No preoperative deficits were recorded in the

patients. Clival chondrosarcomas are invasive locally aggressive tumors. It is quite possible that the CNs were completely encased by tumor making dissection difficult without nerve injury. Additionally, 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 due to inadvertent sharp transection of the unidentified monitored nerve during surgery.^{29,30} 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.²⁶ Using t-EMG to localize the CNs during tumor resection may potentially help prevent nerve injuries in these types of cases.

We further analyzed the data to see if any particular variable is significantly different between the 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 postoperative morbidity, and there is a high risk for stroke which can lead to various CN deficits. The year that the surgery took place is considered because we found a learning curve effect on EEA approaches with the effectiveness of somatosensory evoked potentials monitoring.³¹ No one variable was significantly different in either group except for CN IX. With regards to CN IX, our data showed that those patients who had transclival procedures had much higher incidence of SG f-EMG activity. Surgeries performed after 2006 also had a higher incidence of having SG f-EMG activity than those who had surgeries done in earlier years. In contrast to other LCNs, there is typically little EMG activity produced in the ninth nerve by mechanical stimulation during dissection, and it is highly unreliable and thus often lost.^{10,11} The motor component of the glossopharyngeal nerve has been monitored by placing bipolar leads in the soft palate. Since the responses are volume conducted activity from the stylopharyngeus, there could be significant false-positives during f-EMG recording. As the EEA team gained more experience, more complex cases were performed and hence we monitored more cases with f-EMG for LCN after 2006 contributing to increased f-EMG activity.

This study did have limitations. Only f-EMG of LCN was monitored during the surgery and no t-EMG of LCN monitoring was performed. f-EMG is clearly an unintentional evoked EMG response and hence it is less specific. Additionally, we only monitored cases which were high risk for CN injury. In our entire series, we had 990 patients who underwent EEA procedures. 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.

Conclusion

1. F-EMG seems highly sensitive during CN and tumor manipulations for identifying CN. It appears to modify surgical approach and potentially reduce iatrogenic injury.

2. F-EMG seems to have limited value in predicting postoperative neurological deficits.
3. A better method for definitive localization of a CN may be the use of t-EMG monitoring.
4. Future studies to evaluate the utility of EMG monitoring of LCNs during EEA procedures need to be done utilizing both f-EMG and t-EMG.
5. We advocate a comprehensive approach to neurophysiological monitoring during EEAs including somatosensory evoked potentials, f-EMG, t-EMG of the CNs II to XII, brainstem auditory evoked potentials, and electroencephalogram depending on the location of the neural structures at risk and the approach being used.

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