Value of intraoperative monitoring of the trigeminal nerve in detection of a superiorly displaced facial nerve during surgery for large vestibular schwannomas

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Abstract
The aim of this study was to investigate the role of trigeminal and facial nerve monitoring in the early identification of a superiorly (anterior and superior (AS)) displaced facial nerve. This prospective study included 24 patients operated for removal of large vestibular schwannomas (VS). The latencies of the electromyographic (EMG) events recorded from the trigeminal and facial nerve innervated muscles after mapping the superior surface of the tumor were analyzed. The mean latency of the recorded compound muscle action potential (CMAP) from the masseter muscle was 3.6 ± 0.5 ms and of the peripherally transmitted responses by volume conduction from the frontalis, o. oculi, nasalis, o. oris, and mentalis muscles was 4.6 ± 0.9, 4.1 ± 0.7, 3.9 ± 0.4, 4.3 ± 0.8, and 4.5 ± 0.6 ms, respectively, after trigeminal nerve stimulation in 24 (100%) patients (pattern I response). In 6 (25%) patients, the mean latency of CMAP on the masseter was 3.3 ± 0.3 ms, and the latencies of the CMAP from the frontalis, o. oculi, nasalis, o. oris, and mentalis muscles were 6.5 ± 1.3, 5.0 ± 1.5, 7.5 ± 1.3, 7.4 ± 0.6, and 7.0 ± 1.5 ms, respectively, longer than those of the peripherally transmitted responses (p = 0.002, p = 0.001, p < 0.001, and p = 0.015, respectively) indicating simultaneous stimulation of both nerves (pattern II response). All patients with this response were later confirmed to have an AS-displaced facial nerve. Recognizing the response resulting from simultaneous stimulation of both the facial and trigeminal nerves is important to help early identification of an AS-displaced facial nerve before it is visible in the surgical field and to avoid misleading information by confusing this pattern for a pure trigeminal nerve response.

Keywords Electromyography · Facial nerve · Facial nerve displacement · Intraoperative monitoring · Trigeminal nerve · Vestibular schwannoma

Introduction
Intraoperative monitoring of the trigeminal nerve during vestibular schwannoma (VS) surgery is relatively under-stated, as it is generally less likely to be injured during tumor resection than the facial nerve [10]. Nevertheless, the motor division of the trigeminal nerve is usually monitored during surgical removal of large tumors that may grow to involve the nerve and distort regional anatomy [12, 17].

Despite the recent introduction of new techniques to monitor both the facial and trigeminal nerves, such as transcranial corticobulbar motor evoked potentials (CoMEPs) and intraoperative blink reflex, the most commonly used modalities for monitoring both nerves are still a combination of free-run and triggered electromyography (EMG) [1, 7, 8, 13, 22]. Triggered EMG is of value for the electrophysiological distinction between the facial and the trigeminal nerves in the early stages of tumor resection before anatomical differentiation is possible. Stimulation of the motor axons of the trigeminal nerve using a multichannel recording setup produces a compound muscle action potential (CMAP) from the masseter and temporalis...
muscles, together with responses that can be simultaneously recorded from one or more facial nerve monitoring channels. The latter responses are attributed to peripheral spread of activity from the contracting trigeminal nerve innervated to the facial nerve innervated muscles through volume conduction. This occurs because of the proximity of the contracting facial nerve innervated muscles to those innervated by the trigeminal nerve [23]. Similarly, stimulation of the facial nerve yields CMAPs from the facial nerve monitoring channels, with the possibility of recording simultaneous peripherally transmitted responses from the masseter and temporalis muscles by the same mechanism [17]. Despite of that, identifying which nerve is being stimulated is usually straightforward if the latencies of the recorded CMAPs are analyzed. When the trigeminal nerve is stimulated, a CMAP is recorded from the masseter and temporalis muscles having a latency less than 5 ms (3–4 ms), and the peripherally transmitted responses from the facial nerve monitoring channels will be recognized by having a latency shorter than that of facial nerve stimulation [23]. Furthermore, stimulation of the facial nerve yields a CMAP having a latency of about between 6 and 8 ms (differs according to the exact site of stimulation) recorded from the facial nerve innervated muscles, and the possible peripherally transmitted responses recorded from the trigeminal nerve monitoring channels will have a latency longer than that recorded after trigeminal nerve stimulation [3, 17, 23]. However, one exception to this rule occurs in some patients with large tumors and facial nerve displacement.

As the tumor increases in size, the course of the facial nerve may be displaced into unpredictable patterns depending on the direction of tumor growth. The displacement patterns are classified into posterior (P), towards the dorsal surface of the tumor, which is quite rare (2%); anterior and central (AC); anterior and inferior (AI); and anterior and superior (AS) patterns [9, 16]. When the facial nerve is displaced in an AS direction, it becomes anatomically closer to the trigeminal nerve, which can make the electrophysiological differentiation between both nerves even more challenging. This is especially true if the two nerves are close enough to be simultaneously stimulated when mapping the superior surface of the tumor. This situation produces a characteristic EMG response, which if recognized would avoid further electrophysiological confusion between both nerves and could be used as an early predictor of an AS course of the facial nerve. The earlier recognition of the facial nerve course in large tumors may influence the surgical strategy, extent of resection, and facial nerve outcome.

The aim of this prospective study was to characterize a triggered EMG response for the identification of an AS-displaced facial nerve close to the trigeminal nerve before it becomes visible in the surgical field and to discuss the implications of this response.

**Methods**

**Study sample**

Among 46 patients who underwent surgery for resection of VS between January 2017 and April 2019, 26 patients with tumor size of more than 30 mm (Koos stage IV) were included in this prospective study [14]. Tumor size was measured according to the maximum diameter of its extra-meatal component displayed on preoperative MRI axial view. Two patients experienced interruption of the facial nerve during surgery and were later excluded. The remaining population consisted of 24 patients whose preoperative facial function was assessed as grade I in 21 patients (87.5%) and grade II in 3 patients (12.5%) using the House and Brackmann (HB) grading system [11]. This study was approved by the institutional ethical committee, and an informed consent was obtained from all patients before being enrolled in the study.

**Intraoperative neurophysiological monitoring**

A multichannel recording protocol was used to monitor the facial nerve with sterile bipolar non-insulated 13-mm-long needle electrodes inserted into the frontalis, orbicularis oculi (o. oculi), nasalis, orbicularis oris (o. oris), and mentalis muscles [2]. A non-insulated 18-mm bipolar electrode was also inserted into the trapezius muscle to monitor the accessory nerve. In addition, a sterile paired Prass needle that is insulated except at the tip to avoid crosstalk innervation between the facial and trigeminal nerve innervated muscles (Medtronic Xomed, Jacksonville, FL, USA) was placed into the masseter muscle for trigeminal nerve monitoring [23]. Free-run and triggered EMG and CoMEPs were used to monitor the facial, trigeminal, and accessory nerves in all patients, but only triggered EMG data were analyzed in this study. Once the tumor was exposed, triggered EMG was used to map the surface of the tumor before starting resection to exclude a dorsal course of the facial nerve. Electric stimulation was performed using a monopolar flush tip probe, and a needle electrode inserted at the edge of the wound was used as a reference. The stimulator delivered constant current pulses at a rate of 7.1 pulse/s with a stimulus duration of 200 μs [3].

Tumor debulking progressed meticulously until the surgeon could reach the superior surface of the tumor. The superior surface of the tumor was then mapped using the same stimulation parameters and a current intensity between 0.2 and 0.4 mA, aiming to stimulate the trigeminal nerve as...
well as to identify a possible superior course of the facial nerve. Higher current intensities were not used to avoid intracranial fluid-conducted current spread and possible stimulation of a facial nerve that is not directly at the superior surface of the tumor. In addition, higher current intensities were found to increase the amplitude and frequency of the peripherally transmitted responses on the facial nerve monitoring channels.

The latency of the recorded CMAP from the masseter muscle as well as from each of the facial nerve monitoring channels with each response pattern was measured and analyzed in real time after stimulation of the superior surface of the tumor. Latency was defined as the time between the application of the stimulus (marked by the stimulus artifact) and the onset of the response (marked as the initial deflection from the baseline). A response recorded from any of the facial nerve monitoring channels having a latency of 7 ms or more was defined as a CMAP due to facial nerve stimulation, while a response having a latency of less than 6 ms from any of the facial nerve monitoring channels was defined as a peripherally transmitted response associated with contraction of the trigeminal nerve innervated muscles. A response recorded from any of the facial nerve monitoring channels having a latency between 6 and 6.99 ms was considered equivocal and was not used for analysis. Similarly, responses recorded from the masseter muscle having a latency less than 5 ms were defined as CMAPs due to trigeminal nerve stimulation, while responses having a latency of 5 ms or more were defined as peripherally transmitted responses associated with contraction of the facial nerve innervated muscles. Events recorded after stimulation of the superior surface of the tumor were evaluated by analyzing the latencies of the facial nerve responses in context with the latency of the responses from the masseter muscle.

Later in the course of dissection, stimulation of the facial nerve was performed near its root exit zone, as soon as the nerve was exposed; as well as at the end of dissection, to determine the threshold, amplitude, and latency of the responses to supramaximal stimulation at 2 mA from each recording muscle.

Neurophysiological monitoring was performed using Cadwell elite machine (Cadwell Laboratories Inc., Kennewick, Washington, United States).

**Anesthesia and surgical technique**

All patients were operated on in the lateral position through the retrosigmoid approach, using total intravenous anesthesia (propofol and fentanyl infusion) with no muscle relaxant except at induction.

If an AS course of the facial nerve was identified by electric stimulation, the surgeon became well-oriented about the anatomical relations and proceeded with tumor removal away from the expected location of the facial nerve. On the other hand, the absence of electrophysiological evidence of a superiorly displaced facial nerve increased comfort during the early stages of dissection by limiting the displacement possibilities between AC and Al. Piecemeal tumor removal progressed; once the course of the facial nerve was anatomically identified, dissection was continued towards the porus of the IAC, which is the site of maximal adhesion and thinning of the facial nerve over the tumor capsule. The porus and the medial 2/3 of the posterior wall of the IAC were drilled out to complete tumor resection from the fundus of the IAC. Endoscopic check of the fundus was used when in doubt of leaving residual tumor deep in the fundus. Removing the intrameatal tumor component and identifying the facial nerve in the IAC facilitated the dissection along the length of the facial nerve. The final degree of tumor removal whether total, near total, or subtotal was determined at this stage of surgery based on the degree of splaying, adhesions, and the neurophysiological responses.

**Postoperative follow-up**

Immediate postoperative assessment of facial nerve function was performed by clinical examination using the HB grading system on the second postoperative day, and then long-term evaluation followed at 9–12 months postoperative.

**Statistical analysis of the data**

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov–Smirnov was used to verify the normality of distribution of variables. Quantitative data were described using mean and standard deviation. Comparisons between groups for categorical variables were assessed using chi-square test (Fisher exact or Monte Carlo). Student’s t-test was used to compare two categories for normally distributed quantitative variables. Significance of the obtained results was judged at the 5% level.

**Results**

**Study sample**

Among 24 patients who underwent surgical resection of VS tumors, 13 were females (54.2%), and 11 were males (45.8%). The age of the patients ranged from 26 to 65 years with a mean of 46.8 ± 12.7 years. The selected patients had tumor sizes ranging from 31 up to 58 mm with a mean of 39 ± 7 mm. Tumors were right-sided in 12 patients (50%) and left-sided in 12 patients (50%). Tumors were approached...
through the retrosigmoid (RS) approach in all patients (100%).

**Intraoperative trigeminal and facial nerve monitoring**

The trigeminal nerve was stimulated at the superior surface of the tumor in 24 (100%) patients using a current intensity between 0.2 and 0.4 mA. The mean latency of the recorded CMAP from the masseter muscle was 3.6 ± 0.5 ms, while the mean latencies of the simultaneously recorded responses from the frontalis, o. oculi, nasalis, o. oris, and mentalis muscles were 4.6 ± 0.9, 4.1 ± 0.7, 3.9 ± 0.4, 4.3 ± 0.8, and 4.5 ± 0.6 ms, respectively. The latencies of the recorded responses from the various facial nerve monitoring channels were all less than 6 ms in duration and were therefore considered peripherally transmitted responses associated with contraction of the trigeminal nerve innervated muscles (Table 1, Fig. 1A). The frequency of the simultaneous peripherally transmitted responses varied among facial nerve innervated muscles and were observed on the frontalis, o. oculi, nasalis, o. oris, and mentalis channels in response to trigeminal nerve stimulation and simultaneous trigeminal and facial nerve stimulation.

**Table 1** Description and comparison between the latencies of the CMAPs and the peripherally transmitted responses by volume conduction on the masseter and facial nerve innervated muscles in response to trigeminal nerve stimulation and simultaneous trigeminal and facial nerve stimulation

| Muscle     | Responses in patients with trigeminal nerve stimulation (n=24) | Responses in patients with simultaneous trigeminal and facial nerve stimulation (n=6) |
|-----------|---------------------------------------------------------------|--------------------------------------------------------------------------------------|
|           | Number (%) | Latency       | Description     | Number (%) | Latency       | Description     |
|-----------|------------|---------------|-----------------|------------|---------------|-----------------|
|           |            | Range        | Mean ± SD       | Number (%) | Range        | Mean ± SD       |
| Masseter  | 24 (100%)  | 2.7–4.4      | 3.6 ± 0.5 CMAP  | 6 (100%)   | 2.8–3.8      | 3.3 ± 0.3 CMAP  |
| Frontalis | 12 (50%)   | 2.8–5.8      | 4.6 ± 0.9 Volume conduction | 6 (100%) | 4.5–7.5      | 6.5 ± 1.3 CMAP  |
| O. oculi  | 17 (70.8%) | 3.1–5.4      | 4.1 ± 0.7       | 6 (100%)   | 3.3–6.8      | 5.0 ± 1.5       |
| Nasalis   | 5 (20.8%)  | 3.3–4.3      | 3.9 ± 0.4       | 6 (100%)   | 6.4–9.5      | 7.5 ± 1.3       |
| O. oris   | 7 (29.2%)  | 3.1–5.9      | 4.3 ± 0.8       | 6 (100%)   | 6.6–8.5      | 7.4 ± 0.6       |
| Mentalis  | 4 (16.7%)  | 3.9–5.4      | 4.5 ± 0.6       | 6 (100%)   | 5.2–9.6      | 7.0 ± 1.5       |

*p p value, t Student’s t-test, CMAP compound muscle action potential

*Statistically significant at p ≤ 0.05

**Fig. 1** Three different patterns recorded after mapping the superior surface of the tumor at an intensity between 0.2 and 0.4 mA. The vertical marker is shown on every trace points to the latency of the recorded response. A Traces showing a CMAP recorded from the masseter due to stimulation of the trigeminal nerve associated with peripherally transmitted responses by volume conduction on the frontalis, o. oculi, and mentalis muscles (pattern I response or the trigeminal nerve stimulation response). B Traces showing a CMAPs recorded from both the masseter and facial nerve monitoring channels due to simultaneous trigeminal and facial stimulation (pattern II response or the simultaneous trigeminal and facial nerve stimulation response). C Traces showing CMAPs recorded from the facial nerve monitoring channels due to facial nerve stimulation associated with a peripherally transmitted response by volume conduction recorded on the masseter muscle (pattern III response or the facial nerve stimulation response).
12 (50%), 17 (70.8%), 5 (20.8%), 7 (29.2%), and 4 (16.7%) patients, respectively (Table 1). The recording pattern consisting of a CMAP on the massetter muscle associated with simultaneously recorded peripherally transmitted responses on various facial nerve monitoring channels was termed pattern I response or the trigeminal nerve stimulation response.

Further mapping of the superior surface of the tumor with the same current intensity in 6 (25%) patients resulted in a different recording pattern. In this pattern a response was recorded from the massetter muscle having a mean latency of 3.3 ± 0.3 ms, which was not significantly different from the previously recorded response from the same muscle in pattern I response (p = 0.214) and was therefore described as a CMAP due to trigeminal nerve stimulation. However, there were simultaneously recorded responses from the facial nerve monitoring channels having mean latencies of 6.5 ± 1.3, 5.0 ± 1.5, 7.5 ± 1.3, 7.4 ± 0.6, and 7.0 ± 1.5 ms from the frontalis, o. oculi, nasalis, o. oris, and mentalis muscles, respectively. These responses were considered CMAP resulting from facial nerve stimulation because they were significantly longer in latency on the frontalis, nasalis, o. oris, and mentalis muscles than the previously recorded peripherally transmitted responses from the same muscles in pattern I response (p = 0.002, p = 0.001, p < 0.001, and p = 0.015, respectively) (Table 1). Nevertheless, the mean latency of the response from the o. oculi in this pattern was not statistically different from the peripherally transmitted response recorded from the same muscle (p = 0.244). It is worth noting that the o. oculi muscle was observed to have the highest number of peripherally transmitted responses when the trigeminal nerve was stimulated in pattern I response.

To confirm that the facial nerve was simultaneously stimulated with the trigeminal nerve, the number of facial nerve innervated muscles having a CMAP with a latency of 7 ms or more (confirming definite facial nerve stimulation) was assessed. In each of the 6 patients, at least one muscle had a latency of 7 ms or more (Table 2: patients 1–6). The recording pattern consisting of a CMAP on the massetter muscle having a latency of less than 5 ms with simultaneous recording of a CMAP from at least one of the five facial nerve monitoring channels having a latency of 7 ms or more was termed pattern II response or the simultaneous trigeminal and facial nerve stimulation response. This response was attributed to the simultaneous stimulation of both the trigeminal and facial nerves at the superior surface of the tumor (Fig. 1B).

During surgery, the facial nerve course was identified to be AC in 10 (41.7%), AI in 6 (25%), and AS in 8 (33.3%) patients. The facial nerve in all 6 patients showing a pattern II response was anatomically confirmed later during the course of surgery to be displaced in an AS direction. However, among the 8 patients displaying an AS course of the facial nerve anatomically, 2 patients did not show a pattern II response (Table 3) but displayed a third different electrophysiological pattern. Mapping of the superior surface of the tumor in those 2 patients resulted in CMAPs having latencies of 7 ms or more on the facial nerve innervated muscles (in 4 out of 5 and 5 out of 5 facial muscles, respectively) and was not associated with a CMAP recorded from the massetter muscle having a latency of less than 5 ms. In one patient, there was no response from the massetter muscle, and in the second patient, the response on the massetter muscle had a

### Table 2

| Patient | Muscle     | Number of FN muscles ≥ 7 ms | Pattern                                |
|---------|------------|----------------------------|----------------------------------------|
| 1       | Massetter 3.83 |ることができない | Simultaneous trigeminal and facial stimulation response (pattern II response) |
| 2       | Massetter 2.80 | 4                         | Facial nerve stimulation response (pattern III response) |
| 3       | Massetter 3.35 | 3                         |                                      |
| 4       | Massetter 3.20 | 1                         |                                      |
| 5       | Massetter 3.29 | 2                         |                                      |
| 6       | Massetter 3.33 | 2                         |                                      |
| 7       | Massetter NR  | 5                         |                                      |
| 8       | Massetter 8.05 | 4                         |                                      |

### Table 3

| Pattern II response | Facial nerve course (AS) | χ² | FE | p       |
|---------------------|--------------------------|----|----|---------|
| Yes (n = 8)         | 6 (100%)                 | 16.000 * | <0.001 * |
| No (n = 16)         | 2 (11.1%)                | 16 (88.9%)  |       |

* χ² chi-square test, FE Fisher exact, p p value for comparing between the studied categories
* Statistically significant at p ≤ 0.05
latency that was longer than that of trigeminal nerve stimulation indicating peripheral transmission from the contracting facial muscles (Table 2: patients 7 and 8) (Fig. 1C).

The recording pattern consisting of CMAPs on the facial nerve innervated muscles having a latency of 7 ms or more and not associated with a simultaneously recorded CMAP from the masseter having a latency of less 5 ms was termed pattern III response or the facial nerve stimulation response. This pattern indicated only direct facial nerve stimulation at the superior surface of the tumor as the facial nerve was found anatomically to be displaced at a higher plane that separated it from the trigeminal nerve and was in closer proximity to the stimulator in those 2 patients.

Finally, when the facial nerve was stimulated at the end of surgery at the root exit zone at 2 mA, the mean latencies of the responses recorded from the frontalis, o. oculi, nasalis, and o. oris muscles were significantly shorter in the 6 patients who earlier displayed a pattern II response compared to the mean latencies from the same muscles recorded from all other patients (p = <0.001, p = 0.001, p = 0.019, and p = 0.010, respectively). In addition, responses from the mentalis muscle had a shorter latency in patients who earlier displayed a pattern II response than the rest of the patients; however, results did not reach statistical significance (p = 0.171) (Table 4). It is worth noting that the mentalis muscle displayed the least number of peripherally conducted responses when the trigeminal nerve was stimulated (Table 1). Recorded responses from the masseter muscle after proximal supramaximal stimulation of the facial nerve at the end of surgery are displayed in Table 4.

### Surgical results and relation to postoperative outcome

The degree of adhesion between the tumor capsule and the facial nerve just medial to the porus was described as weak in 4 (16.7%), intermediate in 9 (37.5%), and strong in 11 (45.8%) patients [9]. Strong adhesions were present in 75% of the patients with an AS course compared to 30% and 33% of patients with AC and AI displacements, respectively (Table 5). Gross total tumor removal was achieved in 18 (75%) patients, near-total removal (a maximum 2 mm layer of tumor capsule was left behind at the site of maximal adhesion to the facial nerve) was achieved in 4 (16.7%) patients, and a subtotal removal was performed in 2 (8.3%) patients [6]. The relation between facial nerve course, the degree of adhesion, and the degree of tumor removal are shown in Table 5. The immediate postoperative facial nerve outcome was grades I and II in 12 (50%) patients, grades III and IV in 7 (29.2%) patients, and grades V and VI in 5 (20.8%) patients. The long-term postoperative outcome was grades I and II in 17 (70.8%) patients and grades III and IV in 7 (29.2%) patients; and none of the patients had grades V and VI long-term postoperative outcome. The relation between facial nerve course and immediate and long-term postoperative outcomes is shown in Table 5.

### Discussion

Tumor size is one of the fundamental factors influencing postoperative facial nerve function during VS resection [15, 24]. The facial nerve in large and giant VS is often stretched, thinned, and splayed over the tumor surface; as a result, it becomes more vulnerable to injury [18, 20]. Moreover, the nerve may be displaced into unusual positions by the effect of tumor growth rendering its localization a difficult task [4]. In the present study, the facial nerve course was anatomically identified as AC in 10 (41.7%), AI in 6 (25%), and AS in 8 (33.3%) patients. The early identification of the AS course of the facial nerve may allow modification of the surgical strategy in favor of preservation of this critical structure.

Triggered EMG is used to map the surface of the tumor to confirm that the facial nerve is not in an area to be dissected. Once accessible in the surgical field, electric stimulation is used to assess the functional integrity of the nerve and to predict postoperative facial nerve outcome [1]. However,
to our knowledge, the use of triggered EMG for the early identification of an AS-displaced facial nerve before being visualized in the surgical field has not been exploited yet. The trigeminal nerve was stimulated at the superior surface of the tumor before the facial nerve was anatomically visualized in 24 (100%) patients. The resulting response pattern consisted of a CMAP on the masseter muscle together with simultaneously recorded peripherally transmitted responses by volume conduction on the facial nerve monitoring channels from the contracting trigeminal nerve innervated muscles (pattern I response). Moreover, further mapping of the superior surface of the tumor in 6 (25%) patients resulted in a CMAP recorded from the masseter muscle having a mean latency of 3.28 ± 0.3 ms indicating stimulation of the trigeminal nerve. In addition, a CMAP having a latency of 7 ms or more from at least one of the facial nerve innervated muscles was recorded at the same time confirming simultaneous stimulation of the facial nerve with the trigeminal nerve. This pattern was termed the simultaneous trigeminal and facial nerve stimulation response or the pattern II response and was attributed to the simultaneous stimulation of the facial and trigeminal nerves at the superior surface of the tumor due to the proximity of both nerves to the stimulating probe; a situation that would occur if the facial nerve is anatomically displaced in an AS direction close to the trigeminal nerve. All of those 6 patients were later confirmed anatomically to have an AS-displaced facial nerve once it was visible in the surgical field. On the other hand, not all patients with an AS-displaced facial nerve displayed a pattern II response. Nevertheless, it was still possible to electrophysiologically identify the AS course of the facial nerve in those patients. Mapping the superior surface of the tumor in two patients resulted in CMAPs on the facial nerve innervated muscles without a simultaneously recorded CMAP on the masseter muscle indicating that the facial nerve was stimulated at the superior surface of the tumor without simultaneous trigeminal nerve stimulation (pattern III response). The facial nerve in those two patients was found to be displaced superiorly at a higher plane that separated it from the trigeminal nerve by the effect of a giant tumor and was closer to the stimulating probe.

The early electrophysiological identification of the superior course of the facial nerve allowed removing the bulk of the tumor away from the nerve followed by progressive meticulous dissection along the plane of the facial nerve near the porus. The postoperative facial nerve outcome was not significantly different between the three facial nerve courses in the immediate or long-term period, despite the presence of strong adhesions in 75% of the patients with an AS course compared to 30% and 33% of patients with AC and AI displacements, respectively (Table 5). Thus, it is crucial to locate the AS course of the facial nerve as early as possible to plan the progression of surgery and accomplish

**Table 5** Relation between the facial nerve course and the degree of adhesion, the degree of tumor removal, and the immediate and long-term facial nerve function

|                        | AC (n=10) | AI (n=6) | AS (n=8) | Total (n=24) | χ² | MC | p   |
|------------------------|-----------|----------|----------|--------------|----|----|-----|
| **Adhesions**          |           |          |          |              |    |    |     |
| Weak                   | 3 (30%)   | 1 (16.7%)| 0 (0%)   | 4 (16.7%)    | 4.829 | 0.296 |     |
| Intermediate           | 4 (40%)   | 3 (50%)  | 2 (25%)  | 9 (37.5%)   |      |     |     |
| Strong                 | 3 (30%)   | 2 (33.3%)| 6 (75%)  | 11 (45.8%)  |      |     |     |
| **Tumor removal**      |           |          |          |              |    |    |     |
| Total                  | 8 (80%)   | 5 (83.3%)| 5 (62.5%)| 18 (75%)    | 1.991 | 0.942 |     |
| Near total             | 1 (10%)   | 1 (16.7%)| 2 (25%)  | 4 (16.7%)   |      |     |     |
| Subtotal               | 1 (10%)   | 0 (0%)   | 1 (12.5%)| 2 (8.3%)    |      |     |     |
| **Immediate postoperative outcome** |           |          |          |              |    |    |     |
| Good (I and II)        | 5 (50%)   | 4 (66.7%)| 3 (37.5%)| 12 (50%)    | 4.265 | 0.408 |     |
| Intermediate (III and IV) | 4 (40%) | 0 (0%)   | 3 (37.5%)| 7 (29.2%)   |      |     |     |
| Bad (V and VI)         | 1 (10%)   | 2 (33.3%)| 2 (25%)  | 5 (20.8%)   |      |     |     |
| **Long-term postoperative outcome** |           |          |          |              |    |    |     |
| Good (I and II)        | 8 (80%)   | 4 (66.7%)| 5 (62.5%)| 17 (70.8%)  | 0.911 | 0.739 |     |
| Intermediate (III and IV) | 2 (20%) | 2 (33.3%)| 3 (37.5%)| 7 (29.2%)   |      |     |     |
| Bad (V and VI)         | 0 (0%)    | 0 (0%)   | 0 (0%)   | 0 (0%)      |      |     |     |

χ² chi-square test, MC Monte Carlo, p value for comparing between the studied categories
tumor removal with maximum functional preservation. Esquia-Medina et al. argued that the displacement patterns of the facial nerve may impact postoperative facial nerve function [9]. They found that the AI and AC facial nerve displacements were associated with a better postoperative facial nerve function than the AS course. They attributed this to the higher incidence of strong facial nerve adhesions (85%) in patients with AS-displaced nerves in their series, compared to those with AI (31%) and AC (20%) displaced nerves. The early identification of the facial nerve course in the present work may be a reason why the patients with AS course did not have a worse outcome despite the more challenging tumor dissection in those patients.

When mapping the superior surface of the tumor, it is important for the neurophysiologist to be aware of the simultaneous trigeminal and facial nerve stimulation response (pattern II response) because if not recognized it may be misinterpreted as a response due to trigeminal nerve stimulation only. In this situation, the surgeon may be given the false impression that the facial nerve is not at the superior surface of the tumor which may jeopardize this critical structure during the early stages of dissection. It should be noted though that the electrophysiological identification of the pattern II response may require some experience because the CMAP from the facial nerve innervated muscles have variable latencies and may be easily overlooked and interpreted as peripherally transmitted responses by volume conduction.

At the end of surgery, supramaximal stimulation of the facial nerve at the root exit zone was performed. The recorded CMAPs from the facial nerve innervated muscles showed a significantly shorter response latency in patients who earlier displayed a simultaneous trigeminal and facial nerve stimulation response (pattern II response) compared to all other patients. Further analysis of the responses showed simultaneous stimulation of the trigeminal nerve in those patients. A possible explanation is that the facial nerve in case of large tumors becomes elongated, flattened, and adherent to the surroundings; therefore, at the end of surgery and after tumor removal, the AS-displaced facial nerve may still keep its superior course and its adjacency to the trigeminal nerve at least at one point along their courses. Considering that the stimulation is done using supramaximal (2 mA) current intensity which stimulates all strands and axons of the flattened facial nerve, the likelihood of transmission between both nerves at the point where they are still adjacent is possible. This will result in simultaneous contraction of the masseter and temporalis muscles and peripheral transmission of activity to the facial nerve innervated muscles contributing to the shorter latency. In other words, the recorded CMAPs from the muscles supplied by the facial nerve are not purely due to facial nerve stimulation and are likely to have peripherally transmitted contributions as well. It is therefore critical to analyze facial nerve EMG data within context of the trigeminal nerve data for more accurate analysis. Further studies are required to investigate if this problem may be one of the reasons why predictive methods for assessment of the facial nerve functional integrity show variability among different studies [5, 19, 21].

In conclusion, understanding the simultaneous trigeminal and facial nerve stimulation response (pattern II response) helps the early identification of an AS-displaced facial nerve before it is visible in the surgical field. This is important to guide the surgeon to direct the dissection away from the facial nerve. Recognizing this response is also of value to avoid electrophysiologically confusing the trigeminal and the facial nerves and to prevent providing misleading information to the surgeon. Finally, knowledge of this response may help detect if a measured CMAP to facial nerve stimulation at the end of surgery has peripherally transmitted contributions from the trigeminal nerve innervated muscles.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Yasmine A. Ashram, Youssef M. Zohdy, Tarek A. Rayan, and Mohamed M. K. Badr-El-Dine. The first draft of the manuscript was written by Yasmine A. Ashram and Mohamed M. K. Badr-El-Dine, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Availability of data and material The authors affirm that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Code availability All authors confirm that all data and materials as well as software application or custom code support their published claims and comply with field standards.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the University of Alexandria, Egypt (No. 0305049).

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for publication.

Conflict of interest The authors declare no competing interests.

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