Electrophysiologic Evaluation of the Facial Nerve and Blink Reflex Pathways in Asymptomatic Cochlear Implant Users

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Abstract

Objective. To evaluate the functional integrity of the facial nerve and blink reflex (BR) pathways in asymptomatic patients who underwent cochlear implantation (CI).

Study Design. Case series with planned data collection.

Setting. Tertiary referral center.

Subjects and Methods. Twenty-four deafened patients with unilateral CI who had no complications were enrolled. Bilateral compound muscle action potentials (CMAPs) of the facial nerve were recorded over the nasalis and occipitalis muscles, whereas BR responses were recorded over the orbicularis oculi after supraorbital nerve stimulation. All recordings were performed when the external part of the implant was in place (CIp) and after its removal (CIr), except occipitalis recordings, which were performed only after removal. The amplitude and latency of CMAP were measured to evaluate the axonal integrity of the zygomatic and posterior branches of the facial nerve. Latency, amplitude, and duration of the BR were measured to investigate the integrity of trigeminofacial connections.

Results. The amplitude and latency of CMAP over the nasalis muscle were bilaterally normal, and the difference between CIp and CIr was not statistically significant. No CMAP of the occipitalis muscle was recorded in 4 (16.7%) patients, and low-amplitude responses were recorded on the implant side of 20 (83.3%). Amplitudes of the contralateral R2 response were higher in the CIp condition versus the CIr condition ($P = .031$). There were no differences among other BR components.

Conclusion. During functioning of the CI system, excitability of the facial circuit may increase either through the facial motor nucleus or through removal of the inhibitory effect of the descending pathway.

Keywords

cochlear implantation, facial nerve, compound muscle action potential, blink reflex, trigeminofacial reflex

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BR is mediated by trigeminofacial pontomedullary circuits. Afferent and efferent pathways are formed by the trigeminal and facial nerves, respectively. The generator is in the brainstem. BR can examine the proximal segments of the facial nerve and trigeminofacial reflex pathways. Following electrical stimulation of the supraorbital nerve, 2 responses are obtained: ipsilateral R1 and bilateral R2. R1 has a shorter latency and duration with few phases, suggesting a shorter pathway in the brainstem, whereas the R2 pathway involves an increased number of interneurons. Contralateral response (R2c) is evoked by bilateral stimulation of facial nerve motoneurons. Area and amplitude of both investigations may reflect the excitability to some extent. Previous studies have investigated prelingually cochlear-implanted children and found to be associated with results of auditory and speech perception tests.

Although the labyrinthine segment of facial nerve is the most frequently stimulated area in symptomatic patients with cochlear implants, we propose that the whole circuit may exhibit abnormal excitability even in patients without any symptoms. In this study, we analyzed the effects of CI on the integrity and excitability of the facial nerve and trigeminofacial reflex pathways in asymptomatic patients, using electrophysiologic methods.

**Methods**

**Patients**

Patients who underwent unilateral CI in a tertiary referral center between January 2013 and December 2014 due to bilateral profound hearing loss were enrolled in the study. Exclusion criteria were as follows:

- any complications during or following surgery (including those affecting the facial nerve and others);
- age <8 years;
- any coexisting disorder, such as syndromes or systemic diseases (hypertension, diabetes mellitus, hyperlipidemia), including those affecting the nervous system;
- electrode impedance problems detected during the postoperative period;
- history of facial nerve trauma or paralysis;
- any inner ear malformation detected by preoperative radiologic examination;
- insufficient mental maturity to complete the tests; and
- complications regarding facial nerve.

The study was approved by the local Ethics Committee (No. 257, Istanbul Training and Research Hospital; May 24, 2013) and conducted according to the principles expressed in the Declaration of Helsinki. All patients and/or their parents were informed about the procedure and gave informed consent.

**Preoperative Analysis and Surgical Procedure**

Comorbidities of the patients were noted. Imaging studies, including temporal bone high-resolution computerized tomography and magnetic resonance imaging, were performed before surgery for all patients. Audiological criteria were bilateral profound sensorineural hearing loss without sufficient gain from the conventional hearing aids.

CI was performed under the guidance of facial nerve monitorization in all patients. A small retroauricular incision was performed. After elevation of the musculoperiosteal flap, a posteriorly positioned subperiosteal pocket was prepared for internal receiver transmitter. Bony bed was formed only for electrode array, not for internal receiver transmitter. Following mastoidectomy and posterior tympanotomy, either a round window or cochleostomy approach was chosen, depending on the exposition of the round window. An electrode array was secured in the cochleostomy site or round window by inserting a small piece of soft tissue in between. After fixation of the electrode array, impedance and electrical stapedial reflex measurements were performed.

**Clinical Analysis at the Time of Electrophysiologic Examination**

Age, sex, characteristics and duration of hearing loss, anatomy of the temporal bone, the way of electrode insertion (cochleostomy or round window approach), electrode function of the CI device, auditory maturation following CI, and the interval between the CI and the etiology of hearing loss were recorded. All patients underwent a detailed neurologic examination. Complications (including facial nerve and others) during or after surgery were specifically searched.

**Electrophysiologic Analysis**

CMAP of the facial nerve and BR investigations were performed in a soundproof room with no background noise. All electrophysiologic investigations were performed by 1 neurologist experienced in electrophysiology (T.A.) using Neurosoft Micro 2 Electromyography (Russia) and interpreted by 2 other neurologists (N.U. and A.G.) in a blinded fashion. All recordings were done twice, when the CI device was in place (active condition) and removed (removed condition), except the recording of the occipitalis muscle, which was done during only the active condition. The reason why the on and off conditions of the cochlear implant were examined separately is to evaluate whether the activity of the cochlear implant affects the BR parameters or not.

In facial nerve motor recordings, CMAPs of the zygomatic and posterior auricular branches of the facial nerve were recorded through the nasalis and occipitalis muscles. For nasalis muscle recordings, an active electrode was placed on the ipsilateral nasalis muscle, and a reference electrode was placed on the contralateral nasalis muscle in a symmetric manner. The ground electrode was placed on the forehead. For occipital muscle recordings, an active recording electrode was placed over the midpoint on the imaginary line between the external auditory meatus and external occipital protuberance (inion), while a reference electrode was located 3 cm rostral to this point on the forehead.
The ground electrode was placed on the mastoid process. The facial nerve was stimulated supra-maximally via surface electrodes placed just anterior to the tragus with 0.2-millisecond-duration, right-angled electrical impulses. Latency (millisecond), duration (millisecond), and amplitude (millivolt) of both motor responses recorded over the nasalis and occipitalis muscles were measured. Latency was defined as the period between the stimulation and the first deflection, whereas duration was defined as the period between the beginning of the first and the end of the last deflections. Amplitude, however, was recorded as a peak-to-peak interval. Analysis time, frequency filter, and amplitude sensitivity were adjusted to 10 msec/div, 3 to 20 kHz, and 500 μV, respectively. Both CMAPs were recorded bilaterally; however, CMAPs of the occipitalis muscle were recorded only in the removed condition, since the external part of the device prevents electrode placement.

BR examinations were performed bilaterally while the eyes of the subject were open or semiclosed in the supine position. An active electrode was placed on the midportion of the orbital part of the orbicularis oculi muscle, whereas a reference electrode was placed on a point 2 cm lateral to lateral canthus. A ground electrode was placed on the forehead. The supraorbital branch of the trigeminal nerve was stimulated subcutaneously with 0.1- to 0.2-millisecond, right-angled, nonnociceptive electrical impulses in a random manner to prevent habituation. The intensity of the stimulus (8-14 mA) is adjusted to a level 3 times the sensory level necessary to reveal R2 response. Five pulses with a minimum interval of 20 milliseconds were used, and bilateral responses from the orbicularis oculi muscles were recorded. The latency (millisecond), duration (millisecond), and amplitude (µV) of the R1, R2, and R2c responses were analyzed. Latency was defined as the period between the stimulation and the first deflection, whereas duration was defined as the period between the beginning of the first and the end of the last deflections. Amplitude was measured as a peak-to-peak interval. The mean amplitude of 5 responses was calculated. Analysis time, frequency filter, and amplitude sensitivity were adjusted to 10 msec/div, 3 to 20 kHz, and 200 µV, respectively. Normal latency was accepted as shorter than 13, 41, and 44 milliseconds for R1, R2, and R2c, respectively, and the normal latency difference between the 2 sides was accepted as shorter than 1.2 and 8 milliseconds for R1 and R2, respectively.

**Statistical Analysis**

Mean latency, duration, and amplitude of nasalis CMAP, R1, R2, and R2c were calculated and separately compared between implanted and nonimplanted sides during the active and removed conditions, according to the independent *t* test or Mann-Whitney *U* test for quantitative data. Parameters of occipitalis CMAPs were compared during only the removed condition. We also performed comparisons between the active and removed conditions, for which the *t* test for paired variables or the Wilcoxon test was used. Bonferroni correction was assessed by Pearson and Spearman analyses for linear and nonlinear relationships, respectively. SPSS 15.0 for Windows (IBM, Chicago, Illinois) was used for statistical analysis. A *P* value ≤.05 was considered statistically significant.

**Results**

**Clinical Findings**

A total of 24 patients with bilateral profound sensorineural hearing loss who underwent unilateral CI were included in this study. The mean age was 23.5 ± 16.1 years (range, 9-69 years), and the male:female ratio was 1:1. The mean age at which CI had been performed was 20.9 ± 17.2 years (range, 5-68 years).

All patients had normal facial nerve function (motor, sensory, and autonomic) as documented by history and physical examination. Imaging studies revealed normal inner ear anatomy in all patients. Sensorineural hearing loss was congenital in 10 (41.7%) patients but acquired in 14 (58.3%). In the acquired group, 10 (41.7%) patients had a history of childhood infectious disease, and 4 (16.7%) had a history of trauma associated with hearing loss. After careful history taking and review of previous records, all trauma cases were proved to have no facial paresis or paralysis. Four had temporal bone fracture (2 horizontal and 2 vertical) without violation of the facial nerve.

Seven patients (29.2%) underwent left-sided CI, whereas right-sided CI was performed in 17 (70.8%). For electrode insertion, cochleostomy was performed in 11 (45.8%) patients and a round window approach in 13 (54.2%). Advanced Bionics (HiRes 90K; Sylmar, California) was used in 10 patients (41.7%), MED-EL (Sonata Ti 100; Innsbruck, Austria) in 8 (33.3%), and Cochlear (CI422; Lane Cove, NSW, Australia) in 6 (25%).

The mean duration from CI to electrophysiologic examination was 26.62 ± 14.32 months (range, 8-50 months). None of the patients developed any complications related to surgery. All patients were proved to have active and functioning electrodes during the follow-up fitting protocols. Free-field audiometric thresholds were between 20 and 40 dB HL in all patients.

**Electrophysiologic Findings**

Comparisons of implanted and nonimplanted sides during the removed condition showed that latency, duration, and amplitude of the nasalis CMAP did not differ between 2 sides (Table 1). However, latencies of R1 were significantly shorter on the implanted side (*P* = .035). Regarding the latencies of R2 and R2c, no significant difference was found between the implanted and nonimplanted sides (*P* = .054 and *P* = .059, respectively). The differences of the amplitudes of R1, R2, and R2c between the implanted and nonimplanted sides were not statistically significant (*P* > .05).

In the active condition, the nasalis CMAP parameters did not differ significantly between the implanted and nonimplanted sides (*P* > .05). The amplitudes of R1 and R2c were compared during only the active and removed conditions, according to the independent *t* test or Mann-Whitney *U* test for quantitative data. Parameters of occipitalis CMAPs were compared during only the removed condition. We also performed comparisons between the active and removed conditions, for which the *t* test for paired variables or the Wilcoxon test was used. Bonferroni correction was assessed by Pearson and Spearman analyses for linear and nonlinear relationships, respectively. SPSS 15.0 for Windows (IBM, Chicago, Illinois) was used for statistical analysis. A *P* value ≤.05 was considered statistically significant.
were significantly higher on the implanted side versus the nonimplanted side \((P = .002\) for each comparison). However, the R2 amplitude difference between the 2 sides was not statistically significant \((P = .055)\). The R2:R2c ratio on the surgery side became inverse during the active condition. Latency of R2 was longer on the implanted side versus the nonimplanted side \((P = .002)\).

Comparisons of the nasalis CMAP at either side between the removed and active conditions showed similar results (Table 2). On the implanted side, the amplitudes of R1, R2, and R2c were higher in the active condition versus the removed condition, and comparisons of R1 and R2c were significant \((P = .050\) and \(P = .031\), respectively). On the implanted side, the latencies of R2 and R2c were significantly longer in the active condition \((P = .020\) and \(P = .019\), respectively), whereas that of R1 was not significantly different between the removed and active conditions \((P = .151)\). On the nonimplanted side, the only significant finding is the difference of R2c amplitudes between the removed and active conditions \((P = .034)\), which was higher in the removed condition.

On the implanted side during the removed condition, no CMAPs were recorded over the occipitalis muscle in 4 (16.7%) patients, whereas low-amplitude responses \(\text{range, } 240-370 \mu\text{V}\) were obtained in 20 (83.3%). The rate of axonal damage in the nerve innervating the occipitalis muscle was in the range of 87% to 100%. At the nonimplanted side, CMAPs were present and within normal limits in all patients during the active condition \(\text{mean amplitude, } 4.01 \text{ mV}\).

Sex, age, route of electrode insertion, etiology, and the period from surgery to electrophysiologic tests did not affect the CMAP parameters. Mean amplitudes of CMAPs over the nasalis muscle were 3.1 \pm 1.1 mV in Advanced Bionics, 4.3 \pm 1.7 mV in Cochlear, and 2.6 \pm 0.3 mV in MED-EL. CMAP amplitudes were significantly higher in the Cochlear group than the MED-EL group \((P = .020)\). Parameters related to BR did not differ among types of CI devices.

**Discussion**

The main findings of this study were as follows: (1) the CMAP amplitudes of the nasalis muscle were not different between implanted and nonimplanted sides and only showed differences according to the type of implanted device, whereas the occipitalis CMAPs were either absent or reduced in amplitude; (2) the amplitudes of BR were higher on the implanted side, which was prominent when the device was active; and (3) the latencies of BR on the implanted side were prolonged when the device was active. Smaller CMAP amplitudes indicate facial nerve damage and nerve fiber loss. Motor responses obtained from the nasalis muscle on both sides were within normal range when the external part of the device was in place or removed. These findings suggest that the peripheral part of the facial nerve, between the tragus and the nasalis muscle, was functioning normally. The motor responses of the occipitalis muscle on the implanted side could not be recorded when the external part was in place, because the external

**Table 1. Comparisons of Parameters Related to Blink Reflex and Nasalis CMAP between Implanted and Nonimplanted Sides in the Removed and Active Conditions of Cochlear Implantation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Implanted Side</th>
<th>Nonimplanted Side</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasalis CMAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency ((\mu\text{s}))</td>
<td>(2.7 \pm 0.3)</td>
<td>(2.7 \pm 0.2)</td>
<td>.766</td>
</tr>
<tr>
<td>Duration ((\mu\text{s}))</td>
<td>(8.8 \pm 1.8)</td>
<td>(8.8 \pm 1.7)</td>
<td>.526</td>
</tr>
<tr>
<td>Amplitude ((\mu\text{V}))</td>
<td>(3.3 \pm 1.1)</td>
<td>(3.0 \pm 0.8)</td>
<td>.070</td>
</tr>
<tr>
<td>Blink reflex: R1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency ((\mu\text{s}))</td>
<td>(9.5 \pm 0.4)</td>
<td>(9.7 \pm 0.5)</td>
<td>.035</td>
</tr>
<tr>
<td>Duration ((\mu\text{s}))</td>
<td>(8.8 \pm 0.9)</td>
<td>(8.6 \pm 1.0)</td>
<td>.393</td>
</tr>
<tr>
<td>Amplitude ((\mu\text{V}))</td>
<td>(529.0 \pm 217.4)</td>
<td>(441.3 \pm 201.9)</td>
<td>.057</td>
</tr>
<tr>
<td>Blink reflex: R2c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency ((\mu\text{s}))</td>
<td>(31.4 \pm 2.6)</td>
<td>(32.0 \pm 2.7)</td>
<td>.054</td>
</tr>
<tr>
<td>Duration ((\mu\text{s}))</td>
<td>(45.7 \pm 7.5)</td>
<td>(44.2 \pm 10.0)</td>
<td>.204</td>
</tr>
<tr>
<td>Amplitude ((\mu\text{V}))</td>
<td>(513.3 \pm 182.2)</td>
<td>(498.8 \pm 224.2)</td>
<td>.746</td>
</tr>
</tbody>
</table>

Abbreviation: CMAP, compound muscle action potential.

*Values presented as follows \((\text{mean} \pm \text{SD})\): latency \((\text{millisecond})\), duration \((\text{millisecond})\), and amplitude \((\text{millivolt} \text{ for CMAP, microvolt for blink reflexes})\).

*Statistically significant.
Blink reflex: R2c

The amplitude of R2 is usually higher than that of R2c. Traditionally, if R2:R2c reverses, the side with the larger R2c is theorized to have enhanced motoneuron excitability. 17,23 In patients with CI, R2:R2c became inverse during the active condition, suggesting a pronounced effect on the contralateral facial nucleus. However, electrical stimulation probably slows the axonal transmission, leading to prolongation of BR latencies during the active condition as compared with the removed condition, which may be related to overstimulation and saturation. Other possible factors that may also reflect excitability to some extent. 23 Hemifacial spasm—which is postulated to occur due to focal demyelination of the facial nerve and secondary increase in excitability in the facial nucleus—is characterized by increased amplitude of the R1 and R2 responses in the orbicularis oculi or other facial muscles. 24,25 The CI device creates an electrical field that may lead to ectopic discharges from the spiral ganglion to the facial nerve. 26,31 Electrical stimulation creates a situation mimicking hemifacial spasm. The findings in this article are consistent with the fact that facial nerve may be affected despite the presence of no symptom or sign.

Age is an important factor for the excitability of BR, and previous studies showed that the excitability and latency of BR may increase with aging. 28 The age distribution of our study population is heterogeneous. However, we observed that the excitability changes observed specifically in our study were not affected by the age interval of our study population.
may prolong latencies are age and medical conditions such as diabetes mellitus. As mentioned previously, age did not have any effect on our result, and patients with medical comorbidities were excluded from the study. However, the lack of electrophysiologic examinations before surgery was a limitation of the study.

In conclusion, CI may lead to an increase in the excitability of the facial circuit either through an increase of excitability of the facial motor nucleus or through removal of the descending inhibitory control on the nucleus even in symptom-free patients.

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Author Contributions
Deniz Tuna Edizer, conception and design, data analysis and interpretation, drafting the article, approval, accountability for all aspects of the work; Turgut Adatepe, conception and design, data acquisition, drafting and revision of the manuscript, approval, accountability for all aspects of work; Nurten Uzun, conception and design, drafting and revision of the manuscript, approval, accountability for all aspects of work; Ozgur Yigit, data analysis and interpretation, revision of the manuscript, approval, accountability for all aspects of work; Aysegul Gunduz, data analysis and interpretation, revision of the manuscript, approval, accountability for all aspects of work; Muhammet Yildiz, data acquisition, revision of the manuscript, approval, accountability for all aspects of work; Ozlem Onerci Celebi, data analysis and interpretation, revision of the manuscript, approval, accountability for all aspects of work.

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