Central functional changes after facial-spinal-accessory anastomosis in man and facial-hypoglossal anastomosis in the cat


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A left facial-spinal-accessory anastomosis was performed for peripheral facial paralysis in an 8-year-old boy. By the fourth postoperative year, the corneal reflex showed a normal latency, and left arm and face movements could be executed independently. The possibility of neural plasticity playing a role in establishing new central relationships which enable the achievement of a "normal" latency corneal reflex and independent face and arm movements is discussed.

The latency of the corneal reflex recorded as electrical response of the orbicularis oculi muscle to electrical stimulation of the ipsilateral cornea was measured in normal cats and in cats which had undergone a facial-hypoglossal anastomosis 12 to 14 months previously. The latency of the reflex was 8 to 22 msec in normal animals and 200 to 300 msec in the operated cats, while conduction times in the regenerated hypoglossal nerve fibers were found to be within normal limits. This suggests that the long latency of the corneal reflex following the cross anastomosis is due to the time required for transmission across newly-formed connections between the trigeminal terminals and the hypoglossal neurons.

KEY WORDS • nerve • anastomosis • spinal-accessory nerve • hypoglossal nerve fibers • corneal reflex

YOUNG stated that "changes affecting the central (neuronal) connections as a result of the new peripheral connections" could be among the processes completing nerve regeneration. Recently, microelectrode studies in kittens have shown changes in the pattern of monosynaptic pathways to spinal motor neurons occurring after regeneration that followed crossed anastomosis of some nerves to the hind limbs.

Spinal-accessory-facial anastomosis for the treatment of peripheral facial paralysis represents a crossed-nerve anastomosis; some of the central functional modifications occurring after this
operation were pointed out by Kennedy and Cushing. In a case of seventh nerve paralysis treated with such an operation and followed for 39 months, we have obtained additional data that also suggest the importance of central mechanisms in the ultimate regeneration that occurs following this procedure. For example, recovery of the corneal reflex which exhibited a normal latency by the end of the observation period led us to postulate the formation of functional connections between trigeminal afferents and the spinal-accessory motoneurons. The validity of such a possibility is strengthened by the anatomical recognition of second-order connections between the trigeminal complex and the neurons of both the spinal accessory and the hypoglossal nuclei.

To provide answers to some of the questions proposed by these observations, a corresponding study was carried out in animals. Recovery of the corneal reflex was investigated in cats following a hypoglossal-facial anastomosis, a procedure also used in humans for the treatment of facial paralysis.

Clinical Material and Methods

Case Report

An 8-year-old right-handed boy developed episodes of bilateral ear suppuration at the age of 2 years. During the last episode before admission a left peripheral facial paralysis was noted. He was admitted to a Children's Hospital in Santiago where a left radical mastoidectomy was performed. Three months later he was referred to our service. He had complete left facial paralysis with face asymmetry, Bell's phenomenon, and no left corneal reflex. Corneal sensation was intact. Electromyogram (EMG) of the left facial muscles showed only denervation activity, and cathodal stimuli applied behind the left ear lobe failed to elicit a visible or electrically recordable response from left facial muscles. A left facial-spinal-accessory anastomosis was performed.

Postoperative Functional Studies

Neuromuscular function and voluntary motility of the left side of the patient's face were evaluated 12, 27 and 39 months after the nerve anastomosis. The degree of facial symmetry was recorded photographically. Percutaneous cathodal stimulation of the sutured nerve trunks was carried out with a brass rod (1 x 3 mm tip surface) placed in contact with the skin overlying the nerve suture site, with the anode a large flexible copper plate applied over the opposite side of the neck. Square wave pulses of 1 msec duration were delivered through this pair of electrodes.

Electrical activity of the orbicularis oculi (OO) muscle especially in the inferior lid close to its free edge was recorded as EMG through small pairs of needle electrodes insulated except at their tips. They were inserted through the skin at points about 2 mm apart from each other and connected through capacity-coupled amplifiers to a cathode ray oscilloscope (CRO) equipped with a Grass Photo Kymograph camera.

A saline-soaked cotton wisp was used to test the corneal reflex. It was linked with a specially devised circuit which triggered the CRO beam, recording the OO electrical activity whenever the cornea was touched. Thus, the latency of the corneal reflex could be determined accurately. The cotton wisp was held for a few seconds near the temporal side of the eye before the cornea was touched so that there was no visual warning before actual mechanical stimulation. Repeated recordings proved the constancy of latency determinations for the OO response.

To record the electrical activity of voluntary arm and face movements, pairs of disc electrodes were attached to the skin overlying the superior border of both trapezii muscles (5- to 6-cm separation) and also over upper and lower eyelids or on the cheeks. These electrodes were connected through capacity-coupled amplifiers to the CRO. Records were made during the following face and shoulder movements:

*Cathode ray type 565 oscilloscope manufactured by Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97005. Grass Photo Kymograph camera manufactured by Grass Instrument Company, 101 Old Colony Avenue, Quincy, Massachusetts 02169.
Changes after facial-spinal-accessory anastomosis

1. The patient was asked to contract the left side of his face and close his left eye without raising his left arm; the same maneuver was carried out on the right side for control purposes (Fig. 1 A).

2. The patient was asked to raise his left arm without moving the left side of his face; the patient was also asked to raise his right arm without moving the right side of his face as a control (Fig. 1 B).

3. The same maneuver as in 2, but with forceful elevation of the left arm. The right side was tested similarly but the patient was instructed to contract simultaneously the right facial musculature (Fig. 1 C).

The patient's face was also observed and photographed when he smiled or cried.

**Case Study: Results**

**Reappearance of the Corneal Reflex**

The records of electrical activity of the left OO obtained upon ipsilateral mechanical corneal stimulation showed absence of a corneal reflex during the first postoperative year and reappearance of this reflex with a long latency (230 to 240 msec) during the third postoperative year (Fig. 2). During the fourth postoperative year, recordings showed a corneal reflex with a latency of only 40 msec, the value obtained from normally innervated OO (Fig. 3).

**Independence of Voluntary Face and Arm Movements**

Development of complete independence of voluntary face and arm movements was at-
C. L. Vera, M. G. Lewin, J. C. Kase and M. D. T. Calderon

Flo. 2. Bipolar needle recording (retouched) from inferior part of orbicularis muscles made 2½ years after crossed nerve suture operation during tactile corneal stimulation. Initiation of sweep indicates instant of electrical contact between cornea and cotton wisp. Upper: Operated side; time calibration = 30 msec, voltage = 500 μV. Lower: Normal side; time calibration = 20 msec, voltage = 100 μV.

Figure 3. Monopolar needle recording from inferior part of orbicularis muscles made 3½ years after crossed nerve suture operation. Stimulation as in Fig. 2. Upper: Operated side. Lower: Normal side. Time calibration = 20 msec; voltage = 500 μV.

tained gradually during the postoperative period. One year after operation, the left side of the face moved whenever the left arm was raised and it was impossible for the patient to move the left side of his face unless he raised his left arm. At 27 months after operation, the left facial muscle contractions initiated with left arm elevation could be maintained after lowering the arm. Ultimately, during the fourth postoperative year, the left arm and face could be moved voluntarily with complete independence of each other. At this time there was absence of electrical activity of the facial territory when the arm was moved and absence of electrical activity of trapezius when the face was brought into action (Fig. 1 A and B).

As reported by other observers,17 smiling or crying exposed the left facial paralysis even when all other testing demonstrated virtual recovery of facial motor function on that side. The results of all these observations are summarized in Table 1.

Animal Studies: Material and Methods

Nonoperated Animals

Young adult cats of both sexes were studied under barbiturate anesthesia. Their heads were held in position by a simple head holder. A pair of silver wires with smooth spherical tips served as stimulating electrodes. The tips were separated by 3 mm and were positioned gently to touch the cornea. Square wave pulses (0.5 msec) were applied to the cornea and the electrical activity of the ipsilateral orbicularis oculi (OO), especially the fasciculi over the lower lid,16 was recorded bipolarly with fine needles insulated except at their tips and linked to a capacity-coupled amplifier and cathode ray oscilloscope. The stimulus intensities used were supramaximal for the response studied.

Operated Animals

Sixty cats were operated on under ether anesthesia. The hypoglossal nerve was carefully dissected free from the surrounding structures in the neck38 and sectioned as distally as possible. This nerve stump was carried under the parotid gland and sutured end to end with 6-0 silk sutures through the epineurium to the distal stump of the ipsilateral facial nerve which had previously been sectioned at its point of emergence from
## Changes after facial-spinal-accessory anastomosis

### TABLE 1

Functional changes in patient after facial-spinal-accessory anastomosis*

<table>
<thead>
<tr>
<th>Feature Observed</th>
<th>Postoperative Period</th>
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<tbody>
<tr>
<td></td>
<td>12 months</td>
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<tr>
<td><strong>facial symmetry</strong></td>
<td>still asymmetric but less than preoperatively</td>
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<tr>
<td><strong>Bell's phenomenon when trying to close both eyes</strong></td>
<td>very evident on left</td>
</tr>
<tr>
<td><strong>effect of percutaneous cathodal stimulation over suture site</strong></td>
<td>visible and recordable activity of OO and other facial muscles on left</td>
</tr>
<tr>
<td><strong>needle EMG of left OO</strong></td>
<td>no fibrillation recorded on left</td>
</tr>
<tr>
<td><strong>latency of left corneal reflex</strong></td>
<td>reflex absent</td>
</tr>
<tr>
<td><strong>face &amp; shoulder muscles, voluntary movement</strong></td>
<td>impossible; elevation of left arm necessary to obtain left face motion</td>
</tr>
<tr>
<td><strong>ability to raise left arm without contracting left side of face</strong></td>
<td>impossible; contraction of muscles of left facial territory always occurred contemporaneously</td>
</tr>
<tr>
<td><strong>forced elevation of left arm smiling or crying</strong></td>
<td>inevitable wrinkling of left side of face evident left facial paralysis</td>
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* OO = orbicularis oculi muscle.

the stylomastoid foramen. This orifice was sealed with bone wax after the central stump of the facial nerve was avulsed.

Two months after the anastomosis, the animals were placed under ether anesthesia and their heads were secured in a head holder to test their corneal reflexes with the same technique as for the unoperated animals.

Percutaneous cathodal stimulation was applied to the sutured nerve trunks with a brass rod of 1 × 3-mm tip surface. The tip was pressed against the shaved skin of the neck, proximal to the nerve suture site. The anode was a copper plate applied over the opposite side of the neck. Square wave pulses of 0.5-msec duration and maximal intensity for the response studied were delivered through this pair of electrodes.

Twelve to 14 months after the anastomosis, six of the operated animals were anesthetized with ether and placed in a Baltimore stereotaxic instrument's headpiece and frame;* their spinal cords were sectioned at the C3–4 level. Procaine was applied to all pressure points and to the surgical wound. Ether anesthesia was discontinued and the cornea was stimulated electrically as described before. The OO activity subsequent to this stimulation was recorded with the same electrodes and recording technique as described above. Direct electrical stimulation of the nucleus of the twelfth nerve of these animals was carried out through concentric electrodes made of fine insulated hypodermic needles with a piece of insulated wire fitted inside them. These stimulating electrodes were

*Stereotaxic instrument made by Baltimore Instruments, Baltimore, Maryland.
C. L. Vera, M. G. Lewin, J. C. Kase and M. D. T. Calderon

Fig. 4. Bipolar recordings of orbicularis oculi response to ipsilateral electrical corneal stimuli of supramaximal intensity. Dose of intraperitoneal barbiturate anesthesia is increased in each recording. A: Light anesthesia (0.30 gr Nembutal/kg body weight). B, C, and D: Twenty percent of original dose injected before each recording. Responses were photographed after the effect of the additional anesthetic dose had become stable. Time calibration = 10 msec; voltage = 1 μV.

Fig. 5. Records obtained 3 months after hypoglossal-facial anastomosis in cats. Upper: Absence of orbicularis oculi response to corneal stimulation. Time calibration = 10 msec; voltage = 500 μV. Lower: Response to percutaneous cathodal stimulation proximal to suture site. Time calibration = 10 msec; voltage = 100 μV.

inserted stereotaxically into the medulla, and electrode placements were verified histologically.

Animal Studies: Results

Nonoperated Animals

The latency of the electrical response recorded from the OO of nonoperated animals varied from 10 to 22 msec (Fig. 4 A). This latency was constant for each animal in the same testing session but values from 8 to 25 msec were found in 120 responses measured in several different experiments. Response amplitude varied with the level of anesthesia (Fig. 4), and diminished when successive stimulating shocks were delivered at a rate of 8 to 10/sec. The OO response to single test shocks applied to the cornea every 5 to 10 seconds increased in amplitude during 10 to 15 seconds after a 10- to 15-second period of repetitive corneal stimulation (20 to 50/sec).

Operated Animals

Sixty days after facial-hypoglossal anastomosis the animals showed hemiatrophy of their tongues on the operated side. Facial movements (both sides) were observed whenever they ate or licked their bodies. The face asymmetry noted in early postoperative period was mild or absent. However, bipolar electrical stimulation of the cornea at this time failed to elicit an electrical response from the ipsilateral OO (Fig. 5 A). Electrical activity of this OO muscle could be obtained upon percutaneous cathodal stimulation of the hypoglossal nerve trunk applied well proximal to the suture site (Fig. 5 B).

Twelve months after operation, electrical corneal stimulation on the operated side produced both a visible and an electrical response in the ipsilateral OO. This response had a much longer latency (200 to 300 msec) and was of much longer duration (Fig. 6 C) than the OO response recorded from the nonoperated animals. This OO response decreased in amplitude with stimulating frequencies as low as 3/sec. Sometimes, the response could not be elicited by ipsilateral electrical stimulation with single shocks, but a series of five or six repetitive stimuli at 10 to 20 Hz did succeed in eliciting a response (Fig. 6 B). Eye closure was also elicited in these cases by projecting a puff of air to the cornea on the operated side, or by touching it with a cotton wisp before anesthetizing and preparing these animals for electrical exploration. Sectioning the twelfth nerve trunk abolished the newly established electrical response of the OO (Fig. 6 D).

Single square wave pulses of 0.5-msec duration applied directly to the twelfth nerve nucleus on the operated side through stereotaxically implanted electrodes elicited electrical activity of the ipsilateral OO (Fig. 7 A). This electrical response had a total laten-
Changes after facial-spinal-accessory anastomosis

cy of around 5 msec and the characteristics of a "direct" neuromuscular response when tested with repetitive stimulation. This response was abolished by section of the sutured twelfth nerve trunk (Fig. 7 B).

Discussion

Clinical Study

Latencies in the Corneal-Facial and Corneal-Accessory Reflexes. The long latency of the corneal reflex during the third postoperative year cannot be attributed to changes affecting its afferent trigeminal pathway. Dysfunction in the efferent path of this reflex (fibers pertaining to the eleventh nerve nucleus neurons, see below) could be a more plausible explanation. At 27 months after surgery, the stage of the regenerating spinal accessory fibers could still have exhibited a slowed conduction, and this could have accounted for the long latency of the OO response to corneal stimulation. Against such an explanation are findings in cases of severe facial nerve pathology where the corneal reflex or corresponding physiologically late components of other OO responses to corneal stimulation show much shorter latencies than the 240 msec found in our patient. The possibility that the OO response to corneal stimulation was a voluntary action in which the patient was consciously trying to avoid the touching of his cornea by attempting to move his arm and shoulder defensively was also considered. However, the latencies measured were constant and the patient remained immobile during testing. Furthermore, in animal studies where the anastomosis was performed between the hypoglossal and facial nerves, a similar long latency OO response was obtained on electrical corneal stimulation in both lightly anesthetized and unanesthetized preparations.

Another possibility is that the corneal afferents could have activated a longer central pathway than that used by the normal corneal reflex. However, during the fourth postoperative year, there was a decrease in latency of the OO response to corneal stimulation from the high values just discussed to "normal" values. This implies that the trigeminal afferent pathway from the cornea activated neurons in the eleventh nerve nucleus through pathways of similar lengths and synaptic numbers to those participating in the normal corneal reflex. The existence of such second order connec-
tions between trigeminal and eleventh nerve neurons was recognized by Ramon y Cajal. However, the details of these are not known. Conceivably, the long time (39 months) required for the appearance of the corneal-accessory reflex of normal latency could relate to plastic properties of neural pathways, that is, the development of functional neural connections incident to environmental differences or learning. Such a process occurs in more primitive nervous systems where it has been shown that in some pathways there are synapses that function only after a period of forced training.

Independent Postoperative Voluntary Arm and Face Movements. Independent voluntary movements of left arm and face became possible during the third and fourth years following facial-accessory anastomosis, and were shown to be performed with electrical silence in the surface recordings of the trapezius muscle when the face was moved and of the face muscles when the arm was elevated (Fig. 1A and B). This indicates that the left arm was not kept immobile during the left facial movement by simultaneous activity of the trapezius muscle and its antagonists (the same can be inferred for left facial muscles during elevation of the left arm). Thus, when asked to move the left side of his face, the patient had learned to activate those eleventh nerve neurons that had re-innervated the left facial musculature while keeping inactive other motor neurons concerned with left arm raising. In explanation of such learned movements, there is experimental evidence which also indicates that the plastic potential of neural pathways plays an important role. Normally, eleventh nerve motor neurons are part of the final common path of voluntary arm elevation and are activated by the shoulder area and not by the face area of the motor cortex. However, Schenn demonstrated in monkeys that had undergone a facial-spinal-accessory anastomosis that direct electrical stimulation of the shoulder area of the motor cortex produced face movement and that similar stimulation of the face area had no motor effect in these animals.

Animal Study

In the animals, as in the human, the afferent pathways of the corneal reflex (trigeminal nerve) should not be significantly altered by a crossed anastomosis between facial and hypoglossal nerve.

The results shown in Figs. 5, 6, and 7 indicate that the OO response to corneal stimulation (electrical or mechanical) was mediated by an efferent path of twelfth nerve neurons and that the time involved in traversing the efferent (hypoglossal) path of the newly established corneal reflex observed 1 year after operation takes only a fraction (5 msec) of the total latency (200 to 300 msec). Anesthesia, as a factor that might lengthen the latency of the corneal reflex, was excluded by studying animals under local anesthesia and high cervical cord section. The prolonged discharge time of the OO response on the operated side, the occasional necessity to stimulate the cornea repetitively in order to obtain it, and its long latency are compatible with an explanation that invokes the participation of central pathways involving more synapses than those of the normal corneal reflex. The known existence of second-order relations between the fifth nuclear complex and the eleventh and twelfth nerves would be compatible with this suggestion, and it is further suggested that these connections do not become functional until after the nerve anastomosis.

The failure of the newly established corneal reflex latency to return to normal and the apparent lack of development of independent face and tongue movements constitute the main differences observed between the animal after facial-hypoglossal anastomosis and the human after facial-spinal-accessory anastomosis.

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Changes after facial-spinal-accessory anastomosis

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