CRANIAL NERVE TESTING

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ANATOMY OF THE CRANIAL NERVES

The intracranial portions of cranial nerves I (olfactory) and II (optic) lie at the supratentorial level. These nerves are not studied in routine electrodiagnosis, therefore they are not covered in this handout. All the remaining cranial nerves have their nuclei in the brainstem and run through the posterior fossa.

Cranial Nerves III, IV, and VI

Cranial nerves III (oculomotor), IV (trochlear), and VI (abducens) are involved with movements of the eyes, and the oculomotor is also involved with autonomic innervation of the pupil. The nuclei of the oculomotor and trochlear nerves are located in the mesencephalon, and that of the abducens is located in the lower pons. They all go through the cavernous sinus and enter the orbit through the superior orbital fissure. The oculomotor nerve innervates the medial, superior, and inferior recti, the inferior oblique, and the levator palpebrae muscles, as well as the ciliary and pupilloconstrictor muscles. The trochlear nerve innervates the superior oblique muscle, and the abducens nerve innervates the lateral rectus. There are no known sensory fibers carried by cranial nerves III, IV, and VI. Proprioceptive information from extraocular muscles reaches the brainstem via the trigeminal afferents’ and have an important contribution to visuo-spatial localization.

Lesions of cranial nerves III, IV, and VI can occur in patients with metabolic diseases such as diabetes mellitus, and manifest clinically by diplopia. The lesion is usually located in the nerve trunk, but detailed examination may provide evidence for brainstem involvement. Damage to the parasympathetic fibers carried by the third cranial nerve cause pupillary mydriasis. Horner’s syndrome, featuring unilateral ptosis, miosis, and loss of sweating, is due to lesions involving the sympathetic system, whose fibers join the third cranial nerve at the cavernous sinus. Horner’s syndrome can be due to preganglionic lesions of the sympathetic tract in the brainstem, as in Wallenberg’s syndrome, or to postganglionic lesions of the sympathetic fibers, as in lesions of the lower cervical roots.

Cranial Nerve V

The trigeminal nerve innervates the muscles involved with mastication and receives muscle and cutaneous afferents from all the face and the skull. The motor nucleus is located in the mid pons. The motor axons emerge from the brainstem on the lateral aspect of the pons and run with the mandibular sensory branch to innervate the masseter, the temporalis, and the pterygoid muscles. The trigeminal sensory nucleus is a complex structure that is divided into many subnuclei extending from the mesencephalon to the spinal cord. The first-order afferents carrying proprioceptive sensation have their cell bodies in the mesencephalic nucleus, which receives input from muscle receptors of trigeminal, extraocular, and possibly other cranial and facial muscles. The monosynaptic connection of muscle spindle afferents from the masseter muscle with the motor nucleus of the trigeminal nerve provides the anatomical substrate for the masseter reflex. The first-order afferents carrying cutaneous sensation have their cell bodies in the Gasserian ganglion and project to the pontine and spinal nuclei of the trigeminal nerve. The
pontine nucleus is concerned with tactile sensation, and the bulbo-pontine nucleus with temperature and pain sensations. The ophthalmic and maxillary divisions of the trigeminal nerve carry sensation from the upper and middle parts of the face, respectively, whereas the mandibular division carries sensory fibers from the lower portion of the face, as well as motor fibers.

Lesions of the trigeminal nerve can occur at various levels. Selective lesions of the sensory branches are uncommon, but the Gasserian ganglion, which lies outside the blood-brainbarrier, is subject to autoimmune attack. Most common are the sensory syndromes caused by brainstem vascular lesions, such as Wallenberg’s syndrome.

**Cranial Nerve VII**

The facial nerve nucleus is located in the pons. The course of the facial nerve fibers can be artificially subdivided into four segments: intrapontine, intracranial, interosseous, and extracranial. The most central portion is the intrapontine segment, which is initially directed posteriorly to hook around the sixth nerve nucleus. The intracranial segment is the segment stretching from the emergence of the facial nerve from the brainstem at the caudal pons, in the area of the cerebellopontine angle, to the internal auditory meatus. Here the facial nerve begins the longest and most complex interosseous course of any nerve in the body. Upon exiting from the skull through the stylomastoid foramen, the extracranial facial nerve branches with some variation into five distal segments: temporalis, zygomaticus, buccalis, marginalis mandibulae, and colli. The facial nerve does not carry cutaneous sensory fibers. The so-called sensory root of the facial nerve is made up of taste afferents from the anterior two thirds of the tongue that run with the nerve intermediarius to terminate in the nucleus of the tractus solitarius together with afferents from the ninth and tenth cranial nerves.

The facial nerve may be injured in many ways. Brainstem lesions affecting the nucleus or the pontine segment will cause dysfunction similar to that of a nerve lesion. Acoustic neuromas or other tumors may cause a facial nerve lesion at the cerebello-pontine angle. Intrapetrossal nerve swelling is likely the cause of Bell’s palsy. Extracranially, the nerve can be damaged by diseases affecting the parotid gland.

**Cranial Nerve VIII**

Cranial nerve VIII is formed from two nerves, the acoustic and the vestibular. They run together but have different nuclei and different central connections and mediate different functions. Both nerves are concerned with special somatic functions and do not contain motor axons. The acoustic nerve carries sensory information from the cochlea to the medial geniculate bodies and the auditory cortex. The vestibular nerve carries sensory information from the organs of balance in the ear to the vestibular nuclei in the floor of the fourth ventricle and, from them, to other structures of the brainstem and cerebellum.

The acoustic and vestibular nerves can be damaged in the posterior fossa by cerebellopontine angle tumors and be involved in a diversity of disorders.

**Cranial Nerves IX and X, and the Cranial Root of XI**

The glossopharyngeal and vagus nerves and the cranial root of the accessory nerve innervate the laryngeal muscles. The cells of origin and termination are located in the same nuclei for all three nerves. The motor nucleus is the nucleus ambiguous, situated within the bulbar reticular formation. The neurons of the nucleus ambiguous innervate striated muscles but are in close contact with structures of the autonomic nervous system. Autonomic and somatic fibers run along the glossopharyngeal and vagus nerves to innervate the muscles of the pharynx, larynx, and most of the visceral organs. The cranial root of the accessory nerve merges with the vagus nerve after a short segment. The sensory nucleus is the nucleus of the tractus solitarius, which receives the central projections from the cells located in the ganglia of the glossopharyngeal, vagus, and facial (intermedius of Wrisberg) nerves.

Isolated lesions of the glossopharyngeal nerve are very rare. The vagus nerve is one of the longest nerves in the human body, and can be damaged in many circumstances. Focal lesions of the nerve branches to the vocal cords can occur with respiratory intubation. The distal segments of the vagus nerve are often involved in dying-back axonal peripheral neuropathies, and this can lead to gastrointestinal and cardiac dysfunction.

**The Spinal Root of the XI, and the Cranial Nerve XII**

The spinal root of the accessory nerve is made of nerves from the first five spinal segments which enter the cranial cavity through the foramen magnum. It innervates the sternocleidomastoid, trapezius, and levator scapula muscles. Although these muscles receive additional nerve supply directly from the C2-C4 roots, it has been suggested that the spinal accessory nerve provides the sole motor supply, while the innervation from the cervical roots is purely proprioceptive. The hypoglossal nerve supplies the muscles of the tongue. Its nucleus is located at the lower part of the medulla, in the floor of the fourth ventricle. The accessory and hypoglossal nerves do not carry cutaneous sensory fibers.

Lesions of the eleventh and twelfth cranial nerves are uncommon. The accessory nerve can be damaged in subjects carrying heavy objects on their shoulders. The hypoglossal nerve can be damaged in brainstem strokes. The accessory and the hy-
poglossal nerves can both be used for anastomosis with the facial nerve when it has been damaged.

**PHYSIOLOGY**

Muscles innervated by cranial nerves are activated during spontaneous, voluntary, or reflex movements. Excitatory impulses reach the motoneurons by means of monosynaptic or polysynaptic connections from the corticospinal tract, the reticular formation, the trigeminal system, or other sources. The motoneuron may reach its firing threshold with a single excitatory input or more often with a combination of inputs from different sources. Integration of the sensory afferent inputs into the commands for voluntary activation is an important aspect of the physiology of the motor system. Sensorimotor integration can be examined using the normal brainstem excitatory polysynaptic reflex known as the blink reflex.

**Spontaneous Movements**

In normal humans, relevant spontaneous movements involving cranial muscles occur with activities such as blinking and swallowing. The spontaneous blink rate is about 20 blinks per minute in a normal individual in quiet resting, but varies considerably according to mental or physical activity. Parkinsonian patients have a significantly reduced blink rate, while schizophrenic patients have an enhanced blink rate. These findings point to a direct correlation between dopaminergic systems and blinking frequency. The physiology and kinematics of blinking in animals and humans have been extensively studied by Evinger and his coworkers.

Swallowing is another natural involuntary movement that occurs repeatedly in awake humans. Swallowing requires the coordinated activity of many muscles innervated by different cranial nerves. Most of these muscles are not accessible to conventional electromyography (EMG) recording techniques, but they can be studied with combined electrophysiological and mechanical methods. An interesting observation is that the orbicularis oris and masseter muscles, which are readily accessible to EMG recordings, have an alternating pattern of activity during chewing and become synchronous during swallowing. Such change in the functional correlation between trigeminal and facial muscles might be of interest for neurophysiological studies in neurological syndromes involving chewing and swallowing disturbances.

**Electromyographic Activity at Rest and During Voluntary Contraction**

Facial and trigeminal muscles, like other muscles, have a certain degree of background activity in awake human subjects at rest. Such activity can be quantified using reliable methods. Facial muscle resting activity is increased in patients with headache and is increased on the affected side of patients with aberrant regeneration following recovery from a facial nerve injury. Abnormalities in the amount of EMG activity at rest and during voluntary contraction have been found in patients with olivopontocerebellar atrophy.

**Reflex Responses**

The only monosynaptic reflex available to electrophysiological testing in the cranial and facial muscles is the jaw jerk. It is mediated by the trigeminal nerve. The stretch receptors can be stimulated by tapping on the mandible with a reflex tendon hammer. The afferent branch of the reflex carries the inputs up to the primary afferent terminals in the trigeminal motor nucleus, where they synapse with alpha motoneurons to activate the extrafusal muscle fibers.

Blinking can be reflexly generated by a number of stimuli from different sources. Elicitation of the blink reflex has been used in neurophysiological studies for a long time. At present, electrical stimulation of the supraorbital nerve is the standard method for elicitation of the blink reflex. However, the blink reflex can also be generated by other stimuli such as loud acoustic tones, flashes of light, a tap to the glabella, a puff of air directed to the cornea, and a small corneal electrical discharge. The study of the blink reflex is one of the most informative neurophysiological tests that can be performed in cranial nerves. The relative amounts of levator palpebrae inhibition and orbicularis oculi activation, which combine to give rise to the eyelid movement in a blink, may be different for spontaneous and reflex blinking.

The perioral reflex is another trigemino-facial reflex. This can be tested clinically by tapping the lips with the finger or with a tendon hammer. EMG recordings are obtained with surface electrodes placed on the orbicularis oris.

Jaw opening is a reflex that can be elicited by many kinds of stimuli; the salient feature being a transient inhibition of sustained EMG activity of the masseter muscles. Other inhibitory and excitatory responses are also observed including a burst of activity in the digastric muscle and the suppression of tonic activity in the genioglossus muscle. The jaw opening reflex may serve to protect the tongue from an unwanted biting. The masseteric inhibitory reflex (MIR) elicited by a mechanical stretch consists of a single phase, whereas that elicited by exteroceptive stimuli consists of two distinct phases, an MIR1 and an MIR2.

**PRINCIPAL ELECTRODIAGNOSTIC TECHNIQUES**

Electrodiagnostic techniques used for the study of cranial nerves are not intrinsically different from those used for other nerves. Needle EMG can be performed in many muscles in-
nervated by cranial nerves. As in other muscles, the observation of fibrillation potentials and positive sharp waves at rest may indicate nerve damage. The electrodiagnostic medicine consultant should be aware, however, that the motor unit action potentials of the cranial nerve muscles are generally smaller in amplitude and shorter in duration than those of the limb muscles and, therefore, it may be difficult to distinguish fibrillation potentials from small motor units in muscles that are incompletely relaxed. Standard neurographic techniques for the study of motor fibers can be used only for testing the facial and the spinal accessory nerves. No cranial nerve is available for sensory nerve conduction studies. The study of reflex responses is a very useful tool for the examination of cranial nerve function.

**Needle Electromyography**

Needle EMG of the extraocular muscles is technically difficult and has the potential for ocular damage. It can be performed with the help of an eyelid securing system. Needle EMG of the levator palpebrae is of interest because of the reciprocal behavior of this muscle and the orbicularis oculi during eye opening and closing. The normal EMG pattern of the levator palpebrae in a subject with eyes open is tonic, interrupted by short silent periods corresponding to spontaneous blinks. Simultaneous recording of the levator palpebrae and the orbicularis oculi has been shown to be useful in distinguishing between subgroups of patients with blepharospasm.

Trigeminal, facial, spinal accessory, and hypoglossal nerve innervated muscles are all accessible to common needle EMG testing. The vocal cords can also be examined using indirect-transoral or direct transcutaneous methods. For indirect EMG, careful anesthesia of the fauces is needed and precaution with swallowing should be advised after the examination. Direct EMG is performed by inserting the needle electrode through the upper edge of the cricothyroid cartilage, to reach the thyroarytenoid muscle. This technique is also used for injection of botulinum toxin in patients with spasmodic dysphonia.

**Direct Stimulation of the Cranial Nerves**

Cranial nerves available for direct stimulation and muscle recording are the facial and the spinal accessory nerves (Figures 1 and 2).

**Facial Nerve**

Electrodiagnostic testing of the facial nerve is routinely performed in patients with facial palsy. Nerve excitability can be tested by applying shocks of increasing intensity and determining the intensity required to produce a muscle twitch. Although comparison of nerve excitability between sides provides useful clinical information in patients with facial palsy, surface EMG recording of the compound muscle action potential (CMAP) in the orbicularis oculi, orbicularis oris, quadratus labii, or nasalis allows more accurate and quantitative assessment. Stimuli are applied just below the ear and anterior to the mastoid process, over the stylomastoid foramina. Normal latency values in adults are 3.4 ± 0.8 ms. Selective stimulation of a given branch of the facial nerve can also be performed.

The authors believe that for the assessment of a proximal lesion as in Bell’s palsy, the latency of the direct response is rarely
useful. Even with substantial axonal degeneration, the onset latency determined by the remaining axons tend to be normal or only slightly increased. In contrast, the amplitude of the direct response provides useful information regarding prognosis by elucidating the degree of axonal loss. The amplitude of the direct response varies substantially from one subject to the next. Thus, a comparison between sides in the same individual is more meaningful than the absolute value. An amplitude reduction to one half that of the response on the normal side suggests distal degeneration. Serial determinations during the first week after paralysis may reveal progressive amplitude decrease as an increasing number of axons degenerate. Segmental evaluation of nerve conduction is possible in the facial nerve by using transcranial magnetic stimulation and recording from lower facial muscles. In this procedure, the magnetic coil applied 8 to 10 cm lateral to the vertex elicits bilateral responses at a latency of 11 to 12 ms, but if the coil is moved further laterally, a response appears only on the ipsilateral side at a latency of about 5 ms. This response is believed to result from direct stimulation of the facial nerve in the posterior fossa.\(^3\)

With shocks of very high intensity, the stimulating current may activate the masseter muscle, and a volume-conducted potential may be mistaken as the CMAP of the facial nerve. This would erroneously suggest a favorable prognosis when in fact the facial nerve has already degenerated. In these instances, visual inspection of the contracting muscle is essential to verify that the recorded potential originates from the intended muscle. From the authors’ experience, the latency of the volume-conducted response from the masseter muscle is usually less than 2 ms, far shorter than that of the facial nerve. Figure 3 shows normal CMAPs of the orbicularis oculi, and a volume conducted response from the masseter muscle. Surface stimulation of the facial nerve causes a late bilateral response in the orbicularis oculi, which can be due to activation of cutaneous fibers of the second or third branch of the trigeminal nerve or afferent activity in the facial nerve, the so-called "facio-facial reflex." Figure 4 shows a reflex response elicited by stimulation of the facial nerve, compatible with the "facio-facial reflex."

**Figure 3** Responses recorded with surface electrodes placed over the right (R) and left (L) orbicularis oculi muscles in a patient with left facial palsy 10 days from onset of the symptoms. In both parts A and B, the top trace is from stimulation at the right tragus and the bottom trace is from stimulation at the left tragus. In A, the responses are from the orbicularis muscles reflecting activation of the facial nerve. In B, with higher stimulus intensity, the responses reflect direct activation of the masseter muscles.

With shocks of very high intensity, the stimulating current may activate the masseter muscle, and a volume-conducted potential

\[200 \mu V\]
\[20 ms\]

**Figure 4** Two superimposed single trials recording from the orbicularis oculi muscle with ipsilateral facial nerve stimulation at the tragus. The first response is the CMAP, and the second response is compatible with a "facio-facial reflex."

**Spinal Accessory Nerve**

In direct stimulation studies of the spinal accessory nerve, the active electrode is placed over the upper trapezius muscle at the angle of neck and shoulder, and the reference electrode over the tendon near the acromion process. The nerve is stimulated as it descends along the posterior border of the sternocleidomastoid muscle. In some subjects, the spinal accessory nerve is easier to stimulate with the patient in the prone position. Normal latency was 1.8 to 3.0 ms in 25 normal subjects aged 10 to 60 years.\(^1^1\) Changes in amplitude provide reliable information when compared to the normal side, and an amplitude reduction of 50% or more suggests distal degeneration.

Repetitive stimulation of the spinal accessory nerve can be performed in cases with suspected disorders of the neuromuscular transmission. The recommended position for testing the neuromuscular transmission in the spinal accessory nerve is with the patient upright in a chair, the arms adducted and extended with the hand holding onto the bottom of the chair. Exercise is obtained by having the patients shrug their shoulders against their own restraint.
Hypoglossal Nerve

Hypoglossal nerve conduction can be accomplished by using surface electrodes on the top of the tongue and stimulating in the submandibular region just medial to the angle of the mandible. The mean latency was 2.2 ms in one study and 2.4 ms in another.

Reflex Responses

Reflex responses are specially useful in electrodiagnostic testing of the cranial nerves. This review will consider trigemino-trigeminal reflexes, trigemino-facial reflexes, and reflexes with afferents from the eighth nerve.

Trigemino-trigeminal Reflexes

Jaw Jerk

The jaw reflex, a myotatic reflex, is activated by sudden stretching of the muscle spindles following a sharp tap to the mandible. This reflex, relayed via the mesencephalic nucleus of the trigeminal nerve, reflects conduction through the midbrain. The mandibular division of the trigeminal nerve contains the muscle spindle afferents as well as the motor axons to the extrafusal muscle fibers, which constitute the afferent and efferent arcs of the masseter reflex, respectively. The cell bodies of the proprioceptive spindle afferents lie in the mesencephalic trigeminal nucleus. Branches from these cells make monosynaptic connection with the motor neurons of the trigeminal nerve located in the pons. The masseter reflex is ordinarily elicited by a mechanical tap on the mandible. The closure of a microswitch attached to the percussion hammer triggers the oscilloscope sweep. The reflex responses are recorded simultaneously from the right and left masseter muscles using two pairs of surface electrodes, the active placed over the muscle belly at the angle of the mandible, and the reference over the mastoid process or the ear lobe. Since reflex latencies vary with successive trials, comparison of simultaneously recorded right-sided and left-sided responses is more meaningful than absolute values, which are of the order of 6 to 8 ms in normal subjects. Reflex amplitude is also quite variable; the amplitude ratio between simultaneously recorded right-sided and left-sided responses is, however, relatively constant. Ongerboer de Visser and Goor, who use a needle recording electrode, consider the test abnormal in patients with consistent unilateral absence of the reflex, a side-to-side latency difference of more than 0.5 ms, or bilateral absence of the reflex up to the age of 70 years.

Masseteric Inhibitory Reflex

Sustained voluntary activity of the masseter muscles is transiently interrupted after stimuli of various kinds such as a tap to the chin, an electrical stimulus to the mental nerve or to peri-oral and intraoral receptors, tooth tapping, auditory stimulation, a jet of saline directed to the lower lip, or even high-intensity stimulation of the limb nerve afferents. Factors contributing to the MIR induced by muscle stretch are the refractoriness of motoneurons and the transient arrest in the proprioceptive inputs after their synchronized activation in the jaw jerk. The MIR is elicited bilaterally following unilateral electrical stimulation of the mental nerve. Electrical stimulation is usually applied to the mental nerve at its exit from the mandibular bone at the chin while subjects are asked to clenchr their teeth, producing a sustained contraction of both masseter muscles. Some subjects with bad dentures are not able to activate their masseter muscles and use the facial muscles instead. In these cases, no suppression of the EMG activity can be elicited either with a tap to the chin or with an electrical stimulus. This failure of contraction should not be mistaken for an abnormal MIR. If the MIR is to be used for electrodiagnostic purposes, the subject should be able to exert a stable background voluntary contraction and the amount of suppression should be quantified. The latter is accomplished by averaging the rectified EMG activity in a sufficient number of trials (Figure 5).

The MIR elicited by a tap to the chin begins at about 10 to 12 ms and lasts for 20 to 40 ms, although latency and duration are both dependent partly on the strength of the tap and the level of sustained activation of the masseter muscles. The MIR following electrical stimulation of the mental nerve has two components, named MIR1 and MIR2. The latency of the MIR1 is of about 10 to 14 ms and the latency of the MIR2 is of about 40
The blink reflex is an eyelid closure triggered by a stimulus. It consists of activation of the orbicularis oculi muscle and relaxation of the levator palpebrae muscle. Simple observation of the corneal reflex can be done in clinical practice, but EMG recordings furnish a more complete evaluation of the reflex response. The reflex response consists of two separate components: an early R1 and a later R2 response. Whereas R1 is relatively stable and R2 is recorded bilaterally with unilateral stimulation, R1 is a pontine reflex, while R2 is presumably relayed through a more complex route including the pons and lateral medulla.46,52,54 R1 is relatively stable with repeated trials and is therefore better suited for assessing nerve conduction through the trigeminal and facial nerves. Analysis of R2, however, is essential in determining whether a lesion involves the afferent or efferent arc of the reflex. With a lesion of the trigeminal nerve, R2 is slowed or diminished bilaterally when the affected side of the face is stimulated (afferent delay). With a lesion of the facial nerve, R2 is abnormal on the affected side regardless of the side of stimulation (efferent delay). Surface electrodes are used for stimulation of the nerve and recording of the evoked muscle action potentials.46 The active recording electrode is placed on the lower aspect of the orbicularis oculi muscle and the reference electrode on the lateral surface of the nose; the ground electrode is placed over the forehead. Electrical stimulation of the supraorbital nerve is the most commonly used, but infraorbital or mental nerve stimulation also elicits an R2 in the orbicularis oculi muscle bilaterally and, less consistently, an R1 on the side of stimulus. Shocks of the same intensity are delivered to each side to compare relative excitability of the reflexes. If R1 is unstable or not excitable, however, shocks of higher intensities or paired shocks with interstimulus intervals of 3 to 5 ms are used to facilitate the response so that the shortest latency can be determined.

The reflex latencies of R1 and R2 are measured from the stimulus artifact to the initial deflection of the evoked potential. If paired shocks are required to elicit R1, its latency is measured from the stimulus artifact of the second shock provided, of course, that the first stimulus elicits no response. With a subthreshold conditioning shock and a maximal or supramaximal test shock, the recorded response is elicited only by the second stimulus so that the latency may be accurately determined from the second shock artifact. For each subject, at least eight responses are measured, and the minimal latency is determined. Since R2 is inherently more variable than R1, its absolute latency is less reliable than the latency difference between the simultaneously elicited ipsilateral and contralateral responses.

The shock artifact is especially large when the supraorbital nerve is stimulated since the recording electrodes are located only 2 to 3 cm away from the cathode of the stimulating electrode. Therefore, R1 tends to occur at the tail of the stimulus artifact even though its latency is on the order of 10 ms. Careful repositioning of the stimulating electrode may help reduce the stimulus artifact. A low-frequency cutoff of 300 Hz may also be helpful. Some investigators use a specially designed amplifier with a short blocking time (1.0 ms) and low noise (0.5 µV RMS at bandwidth of 2,000 Hz). Stimulus artifact compensation can be effectively performed by using two stimuli of the same intensity but of reversed polarity, separated by an interval equal to their duration.44

A mechanical tap over the glabella also elicits a blink reflex. Its latency and other characteristics can be recorded if the tap is delivered with a sweep triggering hammer.21,52,74 Although the stimulus is a gentle tap, this is a cutaneous rather than a stretch reflex,46 probably relayed via the same polysynaptic reflex pathways as the electrically elicited blink reflex.

Table 1 shows the mean and the standard deviation of the R1 and R2 elicited by stimulation of the supraorbital nerve, in comparison with the latency of the CMAP and the ratio between reflex and direct responses (R/D ratio), in 83 healthy subjects, 7 to 86 years of age, and in 30 full-term neonates.46,50 An R1 was recorded in all but three infants. The R1 latency in neonates
was significantly greater than that in adults despite the considerably shorter length of the reflex arc in the former. Unlike the consistent response in adults, an R2 was difficult to elicit in infants; it was recorded in only 20 of 30 neonates, mostly on the side ipsilateral to the stimulus. There were no significant differences between sides.

In adults, the upper limit of normal was determined as the mean plus three SDs.46,47 The direct response was considered delayed if it exceeded 4.1 ms, and the R1 delayed if it exceeded 13.0 ms. Additionally, the difference in latency of the direct response between the two sides in one subject must be less than 0.6 ms and that of R1 less than 1.2 ms. The R/D ratio was considered abnormal if it fell outside the range of 2.6 to 4.6, two SDs above and below the mean in normal subjects. The upper limit of normal latency for the R2 was 40 ms on the side of stimulation and 41 ms on the contralateral side. The latency difference between the ipsilateral and the contralateral R2 evoked simultaneously by stimulation on one side should not exceed 5 ms. The latency difference between the ipsilateral R2 evoked from stimulation of the right and left sides should be less than 7 ms. With stimulation of the infraorbital and mental nerves, the upper limit was 41 ms and 50 ms, respectively, on the side of stimulus and 42 ms and 51 ms, respectively, on the contralateral side. Figure 6 shows schematically the hypothesized circuits of the blink reflex, the systems used for stimulation and recording, and the responses usually obtained in normal subjects to right side stimulation. Figure 7 shows the responses obtained in a normal subject (7A), those obtained in a patient with a lesion in the trigeminal nerve (7B, afferent pattern), and those recorded from a patient with a lesion in the facial nerve (7C, efferent pattern). In the afferent pattern, stimulation of the impaired nerve causes bilateral delay of the responses, while stimulation of the unimpaired nerve gives rise to normal responses. In the efferent pattern, responses of the orbicularis oculi of the impaired side are absent to stimulation of nerves of either side, while the contralateral responses are normal.

**Perioral Reflexes**

EMG responses can be recorded in the orbicularis oris to electrical or mechanical stimulation of the lips.54,78 The responses have an early and a late component at a latency similar to that of the R1 and R2 components of the blink reflex.

**Reflexes Conveyed by Afferents From the Eighth Nerve**

Loud and unexpected acoustic stimuli may induce a startle reaction in normal subjects. The startle reaction to loud auditory stimuli is of use for various neurophysiological reasons and will be discussed later. Also, acoustic stimuli of 85 to 100 dB SPL induce a silent period in the voluntarily activated masseter muscles, which is similar to that induced by electrical stimuli of the mental nerve.61 The vestibular nerve can be tested by using caloric stimulation and with the oculocephalic reflexes. Caloric stimulation is performed by irrigating the outer canal of each ear with either warm or cold water. The temperature gradient causes movement of the endolymph within the semicircular canals, and a reflex nystagmus that can be quantitatively measured with electronystagmography. In oculocephalic tests, head turns should give rise to smooth eye movements opposite to the head movement. Clinical caloric testing and oculocephalic re-

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**Figure 7** Blink reflex responses recorded in a normal subject (A), a patient with a unilateral lesion of the trigeminal nerve (B), and a patient with a Bell’s palsy (C).
flexes test the integrity of the labyrinth, vestibular nerves, medial longitudinal fasciculus, and oculomotor system. They are abnormal in posterior fossa lesions and cranial nerve injuries.

Excitability Recovery Curves

Paired stimulation is a technique commonly used to test the excitability of the structures integrated in a reflex system. In the blink reflex, excitability recovery curves are different for the early and late responses. 

The differences can be attributed to the larger number of synapses involved in the R2 response. Therefore, an abnormality in the blink reflex recovery curve limited to the R2 component indicates a disorder of the excitability of brainstem interneurons. Using this technique, an excitability enhancement of brainstem interneurons has been found in several neurological disorders.

The excitability recovery curve has also been examined for the masseteric silent period following paired stimulation of the mental nerve. In this case, there was a dissociation between MIR1 and MIR2, the latter being more affected than the former. Patients with dystonia have a reduced inhibition of the MIR2.

Other Techniques

Unexpected loud acoustic stimuli elicit a startle reaction. Usually, the acoustic stimulus is a tone of 90 to 105 dB SPL, delivered through earphones, although higher intensities have been used. One problem with testing the startle reaction is that habituation occurs quite fast with repeated stimuli. For this reason, the rate of stimulation should be very low, with intervals of up to 20 minutes. The brainstem circuits responsible for the startle reaction have been studied in the rat. Davis and colleagues showed that the structures implicated in startle are located in the medial bulbo pontine reticular formation, and indicated the nucleus reticularis pontis caudalis as the likely generator of the reaction. The impulses travel with the reticulospinal tract to the alpha motoneurons. The startle reaction of normal human subjects involves activity in many muscles innervated by cranial nerves as well as the muscles of the limbs and trunk. With acoustic stimuli, the response of the orbicularis oculi has the shortest latency and greatest persistence. However, Brown and colleagues have suggested that the early activity in the orbicularis oculi may be separate from the startle reaction. This would leave the sternomastoid muscle as the first muscle to be activated, in keeping with their hypothesized generation of the startle reaction in the lower brainstem, closer to the nucleus of XI than to the nucleus of VII. The issue is not resolved at the present time because in fact, the startle reaction can be generated in cats by electrical stimulation of the nucleus reticularis pontis caudalis, which lies closer to VII than to XI. In any case, persistence of activity in the sternomastoid muscle after repeated stimuli is certainly abnormal in patients with exaggerated startle reactions.

If the acoustic stimulus causing a startle is preceded by a weak signal, such as another weak auditory stimulus, a low-intensity electrical stimulus or a flash of light, there is inhibition of the startle response. This is the so-called prepulse inhibition. Prepulse inhibition has been found to be abnormal in patients with schizophrenia and in patients with Huntington’s disease. Prepulse inhibition is probably mediated by brainstem structures.

The blink reflex can also be used to study classical Pavlovian conditioning in humans. In this test, repeated presentation of a pair of time-locked stimuli leads to the generation of a conditioned response. Classical conditioning has been largely studied in rabbits and in normal humans, and the role of the cerebellum in the appropriate timing of the response has been well established. Classical conditioning is abnormal in patients with cerebellar deficits.

COMMON NEUROLOGICAL DISORDERS INVOLVING CRANIAL NERVES

Peripheral Nerve Lesions

Polyneuropathies

Cranial nerves may be involved in toxic or metabolic polyneuropathies, but the neurophysiological findings are less prominent in cranial nerves than in the nerves of the limbs. In patients with Guillain-Barré syndrome, bilateral facial nerve paralysis occurs in about 50% of patients, and involvement of bulbar cranial nerves in 10% to 30%. In these instances, the study of the blink reflex demonstrates a delay in the R1 and R2 responses. The trigeminal nerve may be involved in diseases of connective tissue, in which a trigeminal neuropathy may be the only neurological manifestation. Trigeminal involvement is relatively frequent in patients with Sjögren’s syndrome with a pure sensory neuropathy. In these patients, it is assumed that the dorsal root ganglia and the Gasserian ganglia are damaged by circulating antibodies because of their lack of protection by the blood-brain barrier. Ganglionic neuronal damage may cause involvement of all sensory modalities in the limbs, with widespread loss of deep tendon reflexes. Also, there is loss of cutaneous sensation in the face, with consistent abnormalities in trigemino-facial and trigemino-trigeminal reflexes, but the jaw jerk, mediated by neurons of the mesencephalic nucleus, remains normal.

Cranial nerves may also be involved in hereditary peripheral neuropathies. In the hereditary motor and sensory neuropathy
type I (HMSN-I), the blink reflex shows a marked delay of R1 and R2.46 This is not the case with the HMSN-II, which constitutes a clear electrophysiological difference between the two main forms of Charcot-Marie-Tooth disease.

**Trigeminal Nerve Lesions**

Despite the fact that the trigeminal nerve is the most important cranial nerve for carrying sensory inputs from the face to the central nervous system, no known technique permits study of sensory conduction in its peripheral segment. Therefore, electrodiagnostic studies rely on the assessment of reflex muscle responses. In peripheral nerve lesions affecting the first branch, there should be an afferent delay of blink reflex responses following stimulation of the affected nerve. In lesions affecting the third branch of the trigeminal nerve, a similar pattern may be observed with regard to the masseteric silent period following stimulation of the mental nerve.

Isolated trigeminal nerve lesions are rare. Lesions may be induced in the Gasserian ganglion following thermocoagulation or compression for treatment of trigeminal neuralgia. An uncommon but remarkable clinical syndrome is the numb chin syndrome, which consists of numbness restricted to the distribution of the mental nerve. This syndrome is usually associated with neoplastic processes such as breast cancer or malignant lymphoma, and may result from a metastasis involving the inferior alveolar nerve at the mandible, or the mandibular branch of the Gasserian ganglion at the base of the skull.46

**Facial Nerve Paralysis**

The facial nerve is vulnerable to various disorders in several of its segments. In the idiopathic form of facial paralysis (Bell’s palsy), the nerve injury probably occurs in the external third of the petrosal canal, just before the facial nerve exits the cranial bone. Electrodiagnostic abnormalities are observed with direct stimulation of the facial nerve, which shows reduced CMAP, and with the blink reflex, which shows absence or delay of R1 and R2 on the side of the lesion, with normal responses contralaterally, following stimulation to either side. When R1 is present, the ratio between the latency of R1 and that of the CMAP is increased, indicating that the site of the lesion is rostral to the point of direct facial nerve stimulation. After a complete transverse section of the facial nerve, excitability of the distal segment remains normal up to 4 days, but complete loss of excitability occurs by the end of the first week, when the nerve undergoes wallerian degeneration. Hence, prognosis of a facial nerve paralysis cannot safely be established until the end of the first week. A fast and complete recovery can be assumed when the amplitude of the CMAP recorded on the affected side is more than 50% of that of the unaffected side at 1 week after onset of the paralysis. When the amplitude of the CMAP is less than 15% of that of the unaffected side, a permanent motor deficit and an abnormal recovery, with probable aberrant regeneration, is the most likely. The same rule applies for patients with Bell’s palsy; while the commonest lesion is demyelination, there may be secondary axonal degeneration. Table 2 shows a prognostic classification of patients with Bell’s palsy, according to results of different tests.26

One of the most common sequelae of a facial palsy with axonal degeneration is synkinesis due to aberrant regeneration. During aberrant axon regeneration, fibers that originally innervated the orbicularis oculi muscle are misdirected to other facial muscles.49,50 Under such circumstances, blink reflex responses are present in muscles other than the orbicularis oculi. In 26 of 29 patients tested at least 4 months after total facial nerve degeneration, an aberrant blink reflex was recorded in the orbicularis oris muscle on the affected side.49 For assessing facial synkinesis after a facial nerve palsy, two pairs of recording electrodes are placed on the same side of the face, one pair over the orbicularis oculi and the other over the orbicularis oris or platysma. When the subject is asked to perform isolated movements with the lower or upper facial muscles, simultaneous activity is observed in muscles not intended to be activated. The blink reflex spreads to lower facial muscles. Other features of the postparalytic facial syndrome include an enhancement of the reflex responses, such as the orbicularis oculi response to supra-orbital nerve stimulation, and the observation of surface EMG myokymic discharges in the orbicularis oris.82

**POSTERIOR FOSSA LESIONS**

**Extra-axial Lesions**

**The Cranial Nerve Vascular Compression Syndrome**

Hemifacial spasm consists of an involuntary twitching of muscles on one side of the face. EMG recordings, usually made from the orbicularis oris, orbicularis oculi, or frontalis muscles, show short lasting bursts of activity that may progressively build up to constitute a sustained tonic discharge pattern lasting for several hundreds of milliseconds. The abnormal bursts occur simultaneously in many ipsilateral facial muscles, although synkinesis is not always present during periods when there is no abnormal activity. This feature distinguishes hemifacial spasm from postparalytic synkinesis in which the aberrant response is always present. Another anomaly that can be demonstrated neurophysiologically in patients with hemifacial spasm is ephaptic transmission.40,41 In this technique, simultaneous recordings are made from the orbicularis oculi and the orbicularis oris while an electrical stimulus is applied to a branch of the facial nerve supplying one of these muscles. In normal subjects, a CMAP is obtained only in that muscle, with no response in the other one. By contrast, patients with hemifacial spasm may have a response in the muscle whose nerve branch has not been stimulated, at a latency too short for a transynaptic reflex response. Such a response is interpreted as originating by ephap-
tic transmission in a zone poorly myelinated or damaged by vascular compression. Similar lesions have been suggested to occur in patients with trigeminal neuralgia. However, vascular compression of nerves in the posterior fossa is a common autopsy finding in asymptomatic individuals. It is therefore likely that additional factors are needed to develop the clinical syndrome. One factor may be enhanced neuronal excitability of the neurons in the corresponding nuclei. Changes in excitability of the blink reflex pathway can occur at a premotorneuronal level in some patients with hemifacial spasm.

No neurophysiological abnormalities have been demonstrated yet in trigeminal neuralgia. The blink reflex is abnormal in paratrigeminal syndromes.

**Vascular Lesions of the Brainstem**

The blink reflex can be used to evaluate brainstem lesions which may or may not be clinically manifest. In patients with Wallenberg’s syndrome, stimulation of the affected side of the face gives rise to a normal R1, but to a delayed, absent, or markedly diminished R2, bilaterally. With stimulation on the normal side of the face, all responses may be normal, although an absent contralateral R2 occurs in a small percentage of patients. Other trigemino-facial and trigemino-trigeminal reflexes can also be involved in patients with Wallenberg’s syndrome. In other brainstem syndromes, the use of various brainstem reflexes is recommended because the reflex circuits are organized at different levels.

**Demyelinating Lesions**

Conduction through a demyelinated segment in the central reflex arc can also be measured objectively by the blink reflex. In multiple sclerosis, R1 was slowed on one or both sides in 49 of 63 patients who had clinical pontine signs.

**Rostral Lesions**

The blink reflex responses can be abnormal not only with lesions affecting the reflex pathways directly, but also with lesions indirectly influencing the excitability of the polysynaptic connections. Thus R2 is absent, or markedly diminished or delayed, in comatose states regardless of the site of the responsible lesion. A significant change in the latency of R1 has also been described in acute hemispheric stroke by Fisher and colleagues who used mechanical rather than electrical stimulation.

The blink reflex excitability curve is abnormal in many disorders of the basal ganglia, such as parkinsonism, blepharospasm, or cervical dystonia. The abnormalities found in these patients are limited to the excitability recovery of the R2, while the recovery of R1 is normal. This is consistent with an enhanced ex-
citability of the interneurons in the blink reflex pathway, and not of the facial motoneurons.

REFERENCES


CRANIAL NERVE TESTING

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