Functional localization in the trigeminal root

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The composition of the trigeminal root was determined in this study by a combination of electrophysiological recording and stimulation of dissected root fibers in macaques, evaluation of deficits in man after posterior fossa root section, and microdissection in man and macaque. The roots in man and macaque were found anatomically similar. The sensory root contained three distinguishable but overlapping divisions with fibers relating to various peripheral functions and surfaces mixed within each division; no separate region contained fibers of a particular function, and no pattern of somatotopic localization could be determined within a division. The motor root contained sensory proprioceptive fibers, activated by jaw movement, and were found closely intermingled with motor fibers in all fascicles dissected. Accessory fibers (Dandy) were present in all dissections in man and macaque. They contained the same motor and sensory elements as the motor root which they joined. Human partial root sections via the posterior fossa did not exclusively diminish any single sensory modality, and an explanation is offered for the observation that generous surgical sections often result in only slight sensory loss.

Key Words • trigeminal sensory and motor roots • trigeminal accessory fibers • postoperative sensory deficit • proprioception • thermal sensation

The sudden death of Dr. Richard Lende while this careful and observant report was being printed has saddened the members of the Editorial Board of the Journal of Neurosurgery as well as his other admiring colleagues. This article is typical of his many thoughtful contributions to the Journal.

—The Editor

The proposition that fibers subserving specific functions are located in restricted portions of the trigeminal root has been controversial since the time of Dandy and Frazier. Dandy, a proponent of functional localization, contended that fibers concerned with the pain of tic douloureux were situated within a specific portion of the root. Frazier argued against functional localization and proposed that each of the three trigeminal divisions maintained within the root an individual territory containing all its sensory functions. Each of these views has its modern champions. Jannetta and Rand proposed that fibers concerned with pain and temperature were selectively sit-
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uated within the sensory root. That theory is not supported by evidence presented in this paper.

Dandy's influential views were based on observations made during and following operations. He performed partial root sections via the middle fossa and via the posterior fossa, and obtained differing results; partial section from posteriorly often resulted in relief of trigeminal neuralgia without appreciable sensory loss. That noteworthy observation led Dandy to believe that fibers concerned with the pain of trigeminal neuralgia were situated in the severed portion of the root, and he concluded that "the operation is, in effect, essentially that of a cordotomy, in that only pain fibers are sacrificed and all forms of sensation are retained."³

Dandy sometimes performed an apparent "total" sensory root transection only to find that the patient retained a surprising amount of tactile sensibility in the face. In order to explain this seeming discrepancy, he examined a series of brains and found a variable group of fibers located between the motor and sensory roots at the root entry zone. He termed these "accessory" fibers and concluded that they carried the tactile sensibility which was preserved in patients after presumed total sensory root sections. These fibers were re-examined with the dissecting microscope by Jannetta and Rand,¹¹ who maintained, as did Dandy, that these fascicles relayed tactile sensation.

A recent revival of interest in the trigeminal root led to observations that tended to refute the thesis of Dandy and Jannetta. Saunders and Sachs²¹ showed by microanatomical dissection in human specimens that the accessory rootlets were really a part of the motor root. Kerr,¹² using anatomical methods in the cat and monkey, found that the sensory root at thepons was composed of separate components for mandibular, maxillary and ophthalmic divisions, but encountered no portion that might contain separate localization of a function common to all three divisions. Emmons and Rhoton⁶ found that lesions made in selected portions of the sensory root in monkeys resulted in degeneration in both main sensory and spinal nuclei, but found no portion that appeared to project only to the spinal nucleus. Gudmundsson, et al.,⁸ in a study of cadavers, found that most of the fascicles which lay between sensory and motor roots at the pons joined the motor root distally.

In this study we used physiological methods to determine the detailed composition of the sensory and motor trigeminal roots in the monkey, and compared the anatomical results in man and monkey. We were able to correlate clinical results by evaluation of sensory deficits in patients who had partial root sections performed via the posterior fossa.

Nomenclature

The names applied to elements of the root are so various as to interfere with a lucid discussion of the root's composition. In this section we will attempt to clarify the anatomical nomenclature.

Clinicians commonly use the term "trigeminal root" to designate those bundles of fibers of the trigeminus that course between the trigeminal ganglion and the pons, but anatomists often include also under the designation "root" portions that lie within the central nervous system, such as the mesencephalic root.

The names "motor root" and "sensory root" for the two principal portions are honored by widespread current and historical usage. The terms "dorsal root" and "posterior root" when applied to the trigeminal system refer only to the sensory root. These terms express location as well as the sensory root's homology with the dorsal spinal root. The motor root has also occasionally been referred to as the "anterior root."

The "official" nomenclature of the Nomina Anatomica¹⁶ has not been invariable. Before 1961, the sensory root and motor root were designated, respectively, as "portio major" and "portio minor." The nomenclature was revised in 1961, and the more physiological terms "radix sensoria" and "radix motoria" were endorsed. However, the terms "major root" and "minor root" are still widely used.

The term "mesencephalic root" refers to a tract within the brain stem which contains fibers that originate mainly in the mesen-
cephalic nucleus of the fifth nerve and join the trigeminal nerve.

Smaller groups of fibers which emerge from the pons between motor and sensory roots have received various names. Dandy referred to these elements, qualifying by the term "accessory" such things as branches, fibers, filaments, and rootlets. Recently, a major role for these fibers was implied by a more formal title, "portio intermedia;" in our opinion, this is an unjustifiable designation, since, as shown in this paper, there appears to be no physiological justification for such a subdivision. Others have called these fibers "aberrant," "intermediate," "motor bundles." In this paper, all fibers in the root are classified as belonging to either motor or sensory roots.

Materials and Methods

Physiological Studies

Six macaque monkeys (Macaca mulatta) were used in this study. The animals were anesthetized with pentobarbital sodium (30 to 35 mg/kg administered intravenously) and maintained at a surgical level of anesthesia throughout each experiment by supplementary dosages given as required. A tracheostomy was performed and the head fixed in a stereotaxic apparatus.* A right hemispherectomy was performed through an extensive craniectomy, and allowed exposure of the trigeminal ganglion and root. Further access to the root at the pons was accomplished by dividing the tentorium and removing the overlying cerebellar tissues. The pia arachnoid was dissected free from the root with the aid of a Zeiss dissecting microscope. The cranial cavity was then filled with mineral oil that bathed the exposed ganglion and root. The root could thus be penetrated by microelectrodes under direct visual control or selected portions of the root could be dissected free and placed on small hook electrodes for recording or electrical stimulation, as shown in Fig. 1.

Neural responses to a variety of natural peripheral stimuli were recorded via steel microelectrodes or hook electrodes. Both multifiber and single fiber discharges were amplified and recorded using standard Tektronix equipment. The multifiber or multineuronal responses (simultaneous recording from several neural elements) were useful in defining peripheral field boundaries served by small filaments located within the root. Single fiber discharges which were well isolated, as determined by the constancy of individual spike amplitudes and wave forms, were used to assess the physiological functions of receptors, for instance, light touch, hair, pressure, or thermal sensitivity. Usually the central ends of dissected fibers were sectioned. Electrophysiological recording techniques and the criteria used to identify thermal and mechanoreceptive fiber types in the present study are described in detail elsewhere.13,18,19

Microelectrode recordings and dissections of the roots into fine neural fascicles were systematically performed at selected levels. Results could then be projected on a grid and representational cross sections of the root could be constructed.

Electrical stimulation of fibers was carried out at threshold values (usually about .01 mA) to assess motor functions. Both bipolar and unipolar methods of electrical stimulation were used. Fibers to be stimulat-

*Stereotaxic apparatus manufactured by Balti-
ed were held elevated by a hook and their central ends were sectioned so that the electrical stimulus proceeded only distally (see Fig. 1).

Anatomical Studies in Man and Monkey

The trigeminal roots were examined bilaterally in 36 human cadavers. The brain stem was sectioned at the mesencephalon and the hemispheres and upper stem were removed. Using the dissecting microscope at a magnification of 25×, we divided the tentorium and the petroclinoid ligament and removed the pia arachnoid in order to visualize the trigeminal complex. The anatomy of the root of each monkey was likewise examined.

Clinical Examinations

Facial sensation was tested in 10 patients in whom partial transections of the trigeminal root had been performed for relief of trigeminal neuralgia. Patients were asked to compare equivalent stimuli applied to identical fields on the normal and operated sides of the face. Subjective comparisons were made for appreciation of pin prick, light touch (using Von Frey hairs), and temperatures between 15 and 45°C. Thermal stimuli were applied with brass rods, 5 mm in diameter. No attempt was made to quantitate the subjective differences reported. Two-point appreciation was evaluated, and corneal reflexes were tested with Von Frey hairs. Additional testing with wisps of cotton and the application of direct pressure to specific areas of skin was carried out but provided little additional information. The mastication muscles were tested grossly for bulk and strength. A detailed history of the evolution of the trigeminal deficit in each patient was obtained by interview and review of clinical records.

Results

Physiological Studies

Sensory Root Recording. Electrophysiological recordings were successfully obtained in the macaque from root fibers innervating a variety of receptor types including those responsive to light tactile stimulation, movement of a single vibrissa, brushing of hairs, application of light pressure, stretching of glabrous tissue, temperature, tooth contact, touch or pressure to tongue and gums. An example of the response of a single neuron to a stimulus of slight pressure on a tooth is shown in the lower record of Fig. 2. No attempt was made to specifically isolate and record from those thinly myelinated and non-myelinated fibers known to respond to nociceptive stimulation of the skin, but successful recordings were routinely made from ther-

![Fig. 2. Sensory responses. Upper record shows multineuronal response from sensory fibers within the motor root, activated by jaw opening, silenced by jaw closure. Lower record shows response of a single neuron activated by pressure applied to a single tooth.](image-url)
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Fig. 3. Divisions in root. Monkey's sensory root shown transected above ganglion; motor root lies behind. Arrows indicate cross sections of root reconstructed from experimental data at three levels. Data were obtained from three experimental animals (TR 1, 5, and 8). Note that divisions I, II, and III maintain individual but overlapping territories throughout sensory root.

mal afferents responsive to cutaneous cooling. The latter, termed "cold" fibers, are primarily composed of thinly myelinated A-delta fibers and their responsiveness to cutaneous temperature change has been described in detail elsewhere.\textsuperscript{18,19}

Comparison of the location of each peripheral receptive field with the anatomical location of the activated fiber bundle permitted mapping of the sensory root's organization. A representative sample of a sensory root reconstruction based on electrophysiological findings is shown in Fig. 3. We found that the sensory root contained three spatially distinguishable but overlapping divisions which corresponded to the three peripheral divisions.

We did not find any region of the sensory root to be devoted to a distinctive function. Afferents specifically responsive to thermal stimulation and those activated by various forms of mechanical stimulation were found intermingled and equally widespread. We found no detectable pattern in which peripheral somatotopic relationships were preserved within a division in the root. For example, fiber bundles innervating a specific hairy field on the chin appeared thoroughly dispersed and might be encountered in the root throughout the territory for the third division. In keeping with results obtained in our study of the fifth nerve ganglion\textsuperscript{13} there was evidence for a pattern of microlocalization; that is, some small dissected bundles contained many fibers which innervated the same restricted peripheral region.

Motor Root Recording and Stimulation. A fiber bundle was considered to contain motor functions if movements were elicited when it was stimulated with a minimal current value. Threshold values for motor fibers were usually about .01 mA. Fiber bundles of the sensory root were always found to be inexcitable in response to much greater currents. Once an isolated fiber bundle was identified as a motor root component it was sectioned proximal to the electrode, isolated and restimulated. The same resultant jaw movement was invariably obtained.

Following electrical stimulation every motor root bundle was tested for the presence of afferent fiber activity by recording from the same site that was stimulated.
A striking result was that even the smallest bundles that could be separated by microdissection contained not only motor functions but also sensory functions, activated by jaw opening or stretch applied directly to the appropriate muscle groups. All bundles dissected and isolated throughout the motor root contained both motor and sensory functions concerned with jaw movement. All accessory fibers tested were found to contain similar functions and none exhibited other types of sensory activity.

The upper record of Fig. 2 illustrates the multineuronal response obtained from sensory fibers within the motor root. Each burst of impulses shown was elicited when the experimenter opened the monkey's jaw. The only other form of stimulation adequate for eliciting the response was mechanical distortion of the ipsilateral masseter or temporalis muscles.

Occasionally, sustained discharge activity was recorded from afferent fibers located within the motor root. Most often, however, the fiber remained silent until the jaw was opened. The frequency of discharge activity was always seen to initiate or increase with jaw opening and to decrease with jaw closure.

Anatomical Studies in Man and Monkey

The human trigeminal root was found upon dissection to be similar to that of the macaque monkey. In its course between ganglion and pons, the root was rotated slightly more in man than in monkey and this appeared to be because of the greater basal angle of the human skull.

The motor root in man and monkey was found to consist of two bundles of nearly equal size at the root entry zone rostral to the sensory root. These two bundles lay dorsal and ventral in relation to each other, and quickly joined to form a single motor root that curved about the sensory root to run along the medial surface of the ganglion and thence to exit with the third division.

Between the motor and sensory roots, a variable number (2 to 14) of smaller bundles entered the pons individually. These rootlets formed an inconsistent pattern but were sometimes abundant enough to appear as a crescentic band dorsal and rostral to the sensory root. Nearly all these rootlets joined the motor root as it coursed beneath the root-ganglion complex. Occasional fibers were observed to cross between sensory and motor roots or to leave the sensory root near the root entry zone to enter the pons separately.

Clinical Examinations

We evaluated the sensory deficits in 10 patients who had undergone partial sections of the trigeminal root via the posterior fossa for trigeminal neuralgia. All were operated on by Dr. A. O. Schilp of the Albany Medical College who estimated at the time of operation that 3/4 to 9/10 of the root had been sectioned. The interval since operation varied from 1 to 11 years. In all patients, the neurological deficit was stationary. None had had a recurrence of trigeminal neuralgia.

Two of the 10 patients had sustained a total sensory deficit in the skin and mucous membranes in the trigeminal distribution; motor functions were still present.

The other eight patients exhibited a wide spectrum of sensory loss. In general, these patients showed a remarkable preservation of sensory function, considering the estimated magnitude of the root section. No patient exhibited decrease or loss of any single modality without a concomitant decrease in other sensory modalities. Although touch appeared relatively well preserved to gross testing in some patients, careful examination with Von Frey hairs disclosed deficits.

In cases in which an estimated 9/10 of the root was sectioned, the sensory deficit was found primarily in the second and third divisions. One of the patients in whom the surgeon had attempted to section more rostral fibers because of trigeminal neuralgia involving the first division, did, in fact, sustain a greater sensory deficit in this division. One patient showed a sensory deficit which was more prominent nearer the nose and mouth in all three divisions.

Discussion

Anatomy of the Root

In this study the common terms, "sensory root" and "motor root" were retained.
despite our finding that the motor root contained sensory fibers. Each of the anatomical elements of the root found in man was demonstrable in the macaque monkey and it appeared that one served as an appropriate model for the other.

Anatomically separable, small bundles of fibers that emerged from the pons between motor and sensory roots and joined the motor root proper were found in all cases, and Dandy’s term “accessory fibers” was considered suitable for these. That these accessory fibers generally join the motor root was determined in the recent studies of Gudmundsson, et al., and Saunders and Sachs and was confirmed by our dissections. That they are made up of fascicles physiologically indistinguishable from those of the motor root was demonstrated only by this study.

The occasional splinters of fibers from the sensory root which were seen entering the pons separately at the root entry zone, were easily distinguished from the constant accessory fibers which formed part of the origin of the motor root. Bundles that were clearly part of the sensory root were labelled “aberrant sensory fibers” by Gudmundsson, et al., who found them in half of the roots they dissected microscopically.

Physiology of the Root

In this study the three trigeminal divisions were found to maintain separate but overlapping anatomical territories within the sensory root. Within the territory of each division in the root we encountered a generally random distribution of fibers subserving the various types of sensations tested. Presumably, the samples of fibers recorded from in these experiments were biased in favor of the larger myelinated types with the exception of those thermoceptive fibers responsive to cutaneous cooling that were successfully isolated. We did not attempt to study fibers specifically responsive to noxious forms of stimulation. Of particular importance was the finding that fibers specifically responsive to cutaneous thermal stimulation were distributed throughout the sensory root. If the common clinical observation that pain and temperature systems have similar neuroanatomical distributions holds for the trigeminal, our finding that thermal fibers are disseminated throughout the sensory root supports the view that pain fibers are similarly distributed.

The failure in the present study to demonstrate in the sensory root an anatomical segregation of fibers serving any specific sensory modality might have been predicted on the basis of previous morphological findings. Sjögquist described a population of small (0.3 μ diameter) fibers scattered throughout the sensory root. Furthermore, fiber degeneration studies of the sensory root at the pons failed to reveal any portion of the root which received fibers from all three divisions. In their search for a functional organization of the sensory root Emmons and Rhoton were unable to show fiber degeneration limited to either main sensory or spinal nuclei following lesions made in selected portions of the root.

Although the physiological evidence reported here does not support the thesis that segregation of sensory modalities exists in the trigeminal sensory root, the possibility remains that such a reorganization occurs in the sub-pial root entry zone within the pons.

Our observations gave no indication that peripheral somatotopy was preserved in the organization of sensory root fibers representing a particular division; this was consistent with our earlier findings in the trigeminal ganglion where organization appeared to be according to anatomical convenience. Although a consistent pattern of somatotopic localization could not be established in either ganglion or root, both showed evidence of a “microlocalization” or clustering of neurons innervating the same peripheral field.

Of particular interest was the observation made in the motor root that sensory fibers innervating the jaw musculature were tightly intermingled with motor fibers. To our knowledge, such fibers have not been previously demonstrated by physiological methods. However, the presence of afferent fibers within the motor root has been indicated by anatomical evidence. May and Horsley demonstrated by degeneration studies that afferent fibers serving the mesencephalic nucleus ran in the motor
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root. Allen on anatomical grounds considered that the mesencephalic root contained the "muscle sense portion of the trigeminal nerve." Thus, it has been assumed for many years that the sensory components of the fifth motor nerve represented a proprioceptive input from the muscles of mastication. The electrophysiological evidence reported in our present study clearly identifies the functional properties of afferent fibers recorded in both the motor root and the accessory fiber bundles that join the motor root. All sensory fibers encountered within the motor root were activated only by movement of jaw muscles, not by other forms of mechanical stimulation. It is improbable that the proprioceptive sensory fibers located in the motor root and its component accessory fibers play any role in the origin of the pain of trigeminal neuralgia or in its occasional recurrence following partial sections of the sensory root.

Clinical Correlation

The patients we examined after generous sections (estimated 3/4 to 9/10) of the sensory root via the posterior fossa often showed a surprising retention of sensation in all three divisions. No deficit of any single function we evaluated such as pain, thermal, or tactile sensation was encountered without accompanying deficits of other functions. These findings suggested that specific functions were not restricted to specific portions of the root.

Dandy sometimes found that posterior section of an estimated two-thirds of the root produced no significant decrease in sensation but relieved the pain of trigeminal neuralgia. In one instance (Case 27) after section of an estimated nine-tenths of the sensory root, he observed "the lightest touch with a wisp of cotton was everywhere promptly perceived. Sharp and dull objects were immediately and accurately differentiated." Similar clinical observations after sizeable root sections via the posterior fossa have been made by other neurosurgeons, including ourselves. Dandy's statement that pain fibers were situated in the posterior portion of the root was no longer emphasized after he observed that the face remained sensitive to painful stimuli following such operations. Instead, he maintained that "there are special fibers responsible for the pain of tic douloureux and that all such fibers are selectively concentrated in a well-defined part of the sensory root." Later his ideas in this regard were also modified as described in the following personal communication from Dr. Frank Otenasek, "Although Dandy originally believed that the posterior fibers of the trigeminal root were those that carried pain sensation, he found, with increasing experience, that sectioning of this portion of the root did not always relieve pain. In fact, on one occasion in which I assisted him personally, he had left one little strand of sensory root, not more than one to two millimeters in diameter, and when the patient woke up she had her old tic. The next day we took her back to the operating room and sectioned the remainder of the nerve. Following this he always did a total section and although he did not further comment upon his original ideas over the distribution of pain fibers, his ideas had, in fact, changed." Dandy also noted that facial sensation might be preserved to a greater or lesser degree after a presumed complete transection of the sensory root, and in at least one such case (Case 23) examination revealed no apparent sensory deficit after a "total division" of the sensory root. Such observations moved Dandy to search for occult branches responsible for maintenance of sensation. That role was readily assigned to the accessory fibers. However, Dandy admitted "it is difficult to understand how the small accessory fibers can often assume so much sensory control." Our analysis of the root leads us to suppose that he had performed subtotal rather than total sensory root sections in cases with retained sensation, as was also suggested by Davis and Haven and Stookey and Ransohoff. A theory similar to that held by Dandy in early years was proposed by Jannetta and Rand who suggested that "these intermediate fibers subserve light touch and that pain and temperature sensation is carried separately in the portio major." The results of our study provide no evidence in support of such a theory.

An explanation of the mechanism where-
divisions may thus be explained. The variability of degree of rotation of the sensory root entering the pons was well worked out by Gudmundsson, et al., who used this observation to explain some of the differences in the amount of sensation retained after partial root section.

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References

14. Ley A, Guitart JM: Clinical observations on


17. Otenasek FJ: Personal communication, 1971


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