Generator sites of early scalp potentials evoked from the three trigeminal branches

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Object. The aim of this study was to seek evidence about the generators of the first three components of the scalp’s early trigeminal evoked potentials (TEPs) obtained by stimulation of the supraorbital (SW1, SW2, and SW3), infraorbital (W1, W2, and W3) and mental (MW1, MW2, and MW3) nerves.

Methods. Simultaneous scalp and depth recordings were measured during surgical procedures in which thermorhizotomy and microvascular decompression were performed.

Conclusions. Direct evidence was found that the origin of MW1 lies in the mandibular nerve at the foramen ovale, whereas the origin of W1 in the maxillary nerve at the foramen rotundum and the origin of SW1 in the ophthalmic nerve at the superior orbital fissure could only be inferred. The generators of SW2, W2, and MW2 were found to be on the nerve root at a distance of 10 mm from the pons. Calculations based on conduction velocity suggested that the generators of SW3, W3, and MW3 were inside the brainstem, at distances between 16 mm and 20 mm from the root entry zone.

Recordings obtained in eight patients with discrete surgical lesions of the trigeminal pathway confirmed the sites of origin of the early components and further proved that only the fastest group of fibers is responsible for scalp responses.

KEY WORDS • generator site • trigeminal nerve • evoked potential

EARLY trigeminal evoked potentials (TEPs) can be recorded from the scalp after selective stimulation of the three trigeminal branches with electrodes inserted into the infraorbital, supraorbital, and mental foramina.7,8,11 The TEPs consist of a series of short-duration components, of which the first three are the most important because of their stability and consistency in both appearance and timing.12 When obtained after stimulation of the infraorbital nerve, these components have been named W1 (0.9 msec), W2 (1.84 msec), and W3 (2.54 msec);7,10 similarly, those obtained from the supraorbital nerve have been named SW1 (0.95 msec), SW2 (2.2 msec), and SW3 (2.89 msec)8 and those from the mental nerve have been named MW1 (1.9 msec), MW2 (2.75 msec), and MW3 (3.5 msec).11 The origin of the responses obtained by stimulation of the infraorbital nerve has been established by simultaneous scalp and direct recordings during percutaneous surgeries performed on the trigeminal nerve4 and by correlating changes in the TEPs’ morphology and latency with the presence of discrete lesions at various locations.5,9 The sensitivity and localization power of TEPs have also been shown, and these characteristics have been used in the monitoring of thermolesioning procedures for trigeminal neuralgia.6 Responses after stimulation of the infraorbital nerve are the easiest to obtain, because of their comparatively high amplitude and because the infraorbital foramen is larger than the others. However, the need for a comprehensive functional exploration of the trigeminal pathway demands that the responses from supraorbital and mental nerves should also be thoroughly studied and their origins established. This is the main aim of this study. In addition, further evidence for the precise locations of generator sites of infraorbital TEPs has been obtained, conduction times and velocities have been precisely calculated, sources of possible errors in computing conduction velocities and in estimating the electrode position relative to the nerve have been identified, and the basis for very accurate monitoring of scalp and direct responses during operations has been established.

Materials and Methods

The data presented here were collected during a 15-year period from a total of 64 patients who underwent thermorhizotomy and posterior fossa exploration for decompression of the trigeminal root. The recordings were made by the author at the Walton Centre for Neurology and Neurosurgery, Liverpool, United Kingdom, and at the Pain Relief Center of the National Institute for Cancer, Genoa, Italy. Approval of the procedures had been granted by the ethical committees of both institutions and informed consent was obtained from each patient. A portion of the data was collected retrospectively from recordings not expressly obtained for this study. Because more than one nerve (infraorbital, supraorbital, and mental) could be stimulated in one patient, the total number of recordings on which this work is based is actually higher than the number of patients. The detailed number of recordings for each procedure is given in each Results section.
Generator sites of TEPs

Patient Selection

All patients included in this study suffered from the idiopathic form of trigeminal neuralgia. It is known that in this condition approximately 50% of the TEPs evoked by stimulation of the infraorbital nerve are altered. To avoid bias of data due to such alterations, only patients with normal TEPs are reported in this study.

Stimulation Technique

The technique of stimulation of the peripheral branches has been described in detail in previous papers. The supraorbital nerve was stimulated by using two needle electrodes, 0.3 mm in diameter and 15 mm long. These electrodes were insulated with Teflon with the exception of the tip, which was uncovered for 0.5 mm. Both electrodes were inserted into the supraorbital notch, very close to each other. The infraorbital nerve was stimulated with similar electrodes, 35 mm long, and inserted into the homonymous foramen. Electrodes of the same design, but 25 mm long, were inserted into the mental foramen to stimulate the mental nerve. Electrical pulses, 0.05 msec long, were delivered by a constant-current stimulator at the rate of 5 pulses/second. Intensity was adjusted until the first component of the scalp recorded response (SW1, W1, or MW1) had just reached its maximum amplitude. The average intensities were 3.4 mA for the supraorbital nerve, 1.6 mA for the infraorbital nerve, and 2.8 mA for the mental nerve.

Recording of Evoked Potentials From the Scalp

Responses were recorded from the scalp through electroencephalograph needle electrodes placed at locations Cz (connected to the noninverting input of the amplifier) and C-7 (seventh cervical vertebra, connected to the inverting input of the amplifier). Signals were amplified with a gain of 200,000 using bandpass filters with 3-dB points at 10 Hz and 5000 Hz. The recordings were made before, during, and after the operations.

Recording of Evoked Potentials From the Trigeminal Nerve Through the Thermorhizotomy Needle

The usual thermorhizotomy needle consists of a Teflon-insulated cannula with a stylet inserted into it. Our cannula had a 3-mm bare tip. To make recordings from the needle, the original stylet was replaced by one that was insulated with Teflon except for 1 mm of the tip, which was left bare. The latter protruded 1.5 mm from the cannula. The thermorhizotomy needle was, therefore, converted into a concentric electrode, with the cannula tip providing the outer recording surface (connected to the inverting input of the amplifier) and the tip of the insulated stylet providing the inner recording surface (connected to the noninverting input of the amplifier). In this report, this electrode will be called the thermorhizotomy electrode (TRE). In all figures a negativity at the noninverting input of the amplifier will be represented as an upward deflection both for scalp and depth recordings. The position of the cannula tip was checked by examining x-ray films, and distances between the tip and the foramen ovale were measured with reference to a radiopaque ruler that was placed externally in the same plane as the cannula. Recordings were obtained at the foramen ovale and at 5, 10, and 15 mm past the foramen.

The angle between the insertion axis of the cannula and the orbitomeatal line was calculated a posteriori from lateral x-ray films. The recordings presented have been chosen so that the angle was either 60° or 90° (± 5°). Results are reported according to each grouping. A representation of the orbitomeatal line with directions of TRE insertion and landmarks on the skull is given in Fig. 1. It is worth noting that the usual main axis of the foramen ovale is angled 60° to the orbitomeatal line, but the actual direction along which the TRE could be inserted depended on various anatomical characteristics of the facial bones.

Recording of Evoked Potentials From the Retrogasserian Root

Evoked potential recordings were performed during microvascular decompression (MVD) surgeries by using a silver ball electrode (1 mm in diameter), which was held by hand over the exposed root. As a reference, a similar silver ball electrode was placed over non-nervous tissue approximately 1 cm from the nerve root and perpendicular to it. Distances were calculated by using a miniature ruler placed on one side of the root as a reference. The recordings reported in this paper were made at locations 15, 10, 5, and 0 mm from the pons.

Measurement of Distances Between Relevant Sites on the Skull

Measurements of distances between relevant sites along the trigeminal pathway were obtained on four skulls. A soldering wire with a diameter of 1 mm, providing the correct combination of plasticity and strength, was inserted into the external foramina (supraorbital, infraorbital, and mental). The wire was pushed along the presumed route of the trigeminal afferents as far as the trigeminal notch on the ridge of the roca petrosa. Marks were made on the wire at the sites of passage through the foramina and fissures. The wire was then extracted, fully straightened, and the distances between markings were measured.

Pathological Findings

It is a standard procedure in animal studies to verify the origin of evoked responses by their disappearance after destruction of the suspected site of origin. In humans it is not possible to do that intentionally; however, I have had the opportunity to examine patients in whom very localized surgical lesions were made at relevant sites along the trigeminal nerve for symptomatic pain relief. Two of these patients had a very large thermolesion of the mandibular nerve at the foramen ovale, resulting in severe sensory loss in this third of the trigeminal nerve. Four of the patients had large thermolesions of the retrogasserian root, resulting in complete numbness of half of the face. Another two had undergone surgery in which the intention was to perform MVD; because no vessel had been found impinging on the nerve, a cut extending across approximately three-fourths of the sensory-root cross section had been made at the root entry zone (REZ). These patients had been surgically treated at various institutions; they were seen by me some time afterward and, therefore, only scalp recordings were made. All three trigeminal branches
were always stimulated, according to the techniques used for intraoperative recordings.

**Statistical Analysis**

One-way analysis of variance or t-tests were used to study the data when applicable. Differences among means were defined as significant when the probability value was less than 0.01.

**Sources of Supplies and Equipment**

The stimulating electrodes (models 161215528, 161220528, and 161235528) were obtained from Seagull (Lavagna, Italy). The stimulator (model S44 with isolation unit SIU7) and the amplifier (model P511) were manufactured by Grass-Astro-Med (West Warwick, RI). The signal processor and averager used in the first years of the work was the IS-16E board with EGAA software from RC Electronics Inc. (Santa Barbara, CA); in later years the AT-MIO-16E1 board, available from National Instruments (Austin, TX) was used, which was driven by a program specially designed for intraoperative use. The cannula with the bare tip used to record TEPs was obtained from Radionics (Burlington, MA).

**Results**

**Recordings Obtained After Stimulation of the Supraorbital Nerve**

**Recordings From TREInserted at a 60° Angle to the Orbitomeatal Line.** Eight supraorbital nerves were stimulated. The scalp response is shown as the first trace in Fig. 2. The mean latency values were \( 1 \pm 0.11 \text{ msec} \) for SW1, \( 2.24 \pm 0.16 \text{ msec} \) for SW2, and \( 2.97 \pm 0.14 \text{ msec} \) for SW3. When the TRE tip was located at the foramen ovale, only a small positive peak could be recorded, with a mean latency value of \( 1.81 \pm 0.16 \text{ msec} \) (Fig. 2, second trace). Further advancement of the TRE produced a corresponding increase in the amplitude of the recorded peak and a slight, but significant, increase in latency, which reached a mean value of \( 2 \pm 0.16 \text{ msec} \) at the depth of 15 mm (Fig. 2, third trace). The mean conduction velocity calculated from these data would be 78.94 m/second, a much larger value than those previously reported.\(^4,14\) Such an overestimation was due to sources of error that will be discussed later in this paper.

Analysis of the average temporal relationships between depth and scalp recordings showed that the peak recorded at the foramen ovale took place 0.81 msec later than the SW1 component and 0.43 msec earlier than the SW2. The peak recorded at the depth of 15 mm occurred 1 msec after SW1 and 0.24 msec before SW2 (all differences are statistically significant).

**Recordings During MVD.** Nine supraorbital nerves were stimulated. The scalp components had mean values of \( 1.04 \pm 0.12 \text{ msec} \) for SW1, \( 2.21 \pm 0.16 \text{ msec} \) for SW2, and \( 3.01 \pm 0.11 \text{ msec} \) for SW3 (Fig. 3, first trace). From the root, a large initial deflection with negative–positive polarity was recorded (Fig. 3, second, third, and fourth traces); this was followed by later deflections that had a smaller and jagged appearance, resembling very closely the compound action potential that can be recorded along an exposed nerve. Morphological appearance and amplitude were practically identical at all positions along the root, with only the latency increasing slightly but significantly toward the pons. The mean latency value at 15 mm from the pons was \( 2.12 \pm 0.16 \text{ msec} \), at 10 mm it was 2.24
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Fig. 4. Traces obtained after stimulation of the infraorbital nerve. The first trace shows the scalp recorded TEP. The second and third trace show the responses recorded from the TRE at the foramen ovale and at the 15-mm depth. The peak recorded at the 15-mm depth is the largest of the two and is followed by smaller peaks. Only at this position is the tip of the TRE in close contact with the activated fibers, whereas it is at some distance from them when at the foramen ovale. The TRE has been inserted along the 60° line (see Fig. 1).

Fig. 5. Traces obtained after stimulation of the infraorbital nerve. The scalp TEP is shown in the first trace; recordings from the root obtained during MVD are in the second, third, and fourth traces. Amplitude and morphological appearance of the root potential are similar at the two locations, whereas there is a latency increase suggesting a conduction velocity of 38.14 m/second. The scalp W2 is simultaneous with the root response recorded at 10 mm (third trace), indicating that as the site of origin.

$\pm 0.17$ msec, at 5 mm $2.36 \pm 0.17$ msec, and at 0 mm from the pons it was $2.49 \pm 0.17$ msec. The mean conduction velocity calculated using a distance of 15 mm was found to be $40.08 \pm 3.51$ m/second. There was a very close correspondence between the mean latency value recorded at SW2 on the scalp and that of the root response $10$ mm from the pons. However, on average component SW3 occurred 0.52 msec later than the peak measured at 0-mm distance from the pons.

Recordings Obtained After Stimulation of the Infraorbital Nerve

Recordings From TRE Inserted at a 60˚ Angle to the Orbitomeatal Line. Fifteen infraorbital nerves were stimulated. The scalp recorded components had mean latencies of $0.9 \pm 0.05$ msec for W1, $1.92 \pm 0.10$ msec for W2, and $2.73 \pm 0.18$ msec for W3. An example is shown in the first trace of Fig. 4. With the TRE positioned at the foramen ovale, a positive–negative component could be recorded (Fig. 4, second trace). It always displayed a larger amplitude than the response recorded after stimulation of the supraorbital nerve. Its mean latency was $0.95 \pm 0.05$ msec. Pushing the TRE tip forward resulted in recording larger potentials, with constantly and significantly increasing latency, reaching a mean value of $1.27 \pm 0.06$ msec at a depth of 15 mm (Fig. 4, third trace). These data give a calculated mean conduction velocity of $46.87$ m/second. The scalp W1 response occurred an average of 0.05 msec earlier than the response recorded at the foramen ovale, whereas the W2 recording was 0.65 msec later than the response recorded at the 15-mm depth.

Recordings During MVD. Eleven infraorbital nerves were stimulated. An example of scalp and simultaneous root recordings is shown in Fig. 5. The scalp W1 recording had a mean latency of $1.02 \pm 0.10$ msec, the mean latency of the W2 was $2.23 \pm 0.15$ msec, and that of the W3 was $2.94 \pm 0.12$ msec. Recordings from the root showed a large component with negative–positive peaks followed by smaller jagged peaks. The first negative peak had a mean latency of $2.14 \pm 0.15$ msec at 15 mm from the pons; at a 10-mm distance from the pons the mean latency was $2.27 \pm 0.15$ msec, at 5 mm the mean latency was $2.4 \pm 0.15$ msec, and at the pons (0 mm) the mean latency was $2.52 \pm 0.15$ msec (differences were significant). The mean conduction velocity across the measured tract of the root can therefore be calculated at $39.93 \pm 3.18$ m/second. There was almost perfect coincidence between the latency of the first negative peak recorded at the distance of 10 mm from the pons and the scalp component W2, whereas W3 occurred on average 0.42 msec after the peak at the 0-mm position.

Recordings After Stimulation of the Mental Nerve

Recordings From TRE Inserted at a 60˚ Angle to the Orbitomeatal Line. Sixteen mental nerves were stimulated. A recording from one individual in this group is shown in Fig. 6. The scalp MW1 had a mean latency of $1.92 \pm 0.12$ msec, the MW2 had a mean latency of $2.87 \pm 0.11$ msec, and the MW3 had a mean latency of $3.59 \pm 0.11$ msec. A negative-positive-negative wave was recorded from the TRE at all locations. The largest peak was always the middle positive one, and the latencies presented here were measured to this peak. It exhibited maximum amplitude at locations between 0 and 5 mm past the foramen ovale, where it was followed by smaller peaks. Its mean latency at the foramen ovale was $1.92 \pm 0.14$ msec and at a 15-mm distance it was $2.27 \pm 0.14$ msec (significant differ-
ence), with a computed mean conduction velocity of 42.85 m/second. There was a perfect coincidence between the latency of the scalp MW1 and that of the positive peak recorded at the foramen ovale, whereas MW2 occurred at an average time of 0.6 msec after the positive peak was recorded at 15 mm from the foramen ovale.

Recordings Obtained During MVD. Thirteen mental nerves were stimulated. The scalp MW1, MW2, and MW3 had mean latencies of 1.8 ± 0.12 msec, 2.86 ± 0.12 msec, and 3.63 ± 0.17 msec, respectively (Fig. 7, first trace). A negative–positive component was recorded at all locations along the root; it was followed by a series of small jagged peaks (Fig. 7, second, third, and fourth traces). The mean latency of the positive peak recorded at 15 mm from the pons was 2.78 ± 0.13 msec; at 10 mm its latency was 2.9 ± 0.13 msec; at 5 mm it was 3.03 ± 0.13 msec; and at 0 mm it was 3.15 ± 0.13 msec (significant differences). The overall mean conduction velocity calculated across the root was 40.51 ± 2.33 m/second. The latency of MW2 occurred just 0.04 msec earlier than the latency of the positive peak recorded at 10 mm from the pons, whereas MW3 occurred 0.48 msec after the peak recorded at the 0-mm position on the root.

Results of Lesions to the Trigeminal Pathway

In the two patients who had undergone thermolesioning of the mandibular nerve at the foramen ovale, stimulation of the mental nerve evoked no response that could be recorded from the scalp (Fig. 8, first column, third trace), whereas stimulation of the infraorbital and supraorbital nerves gave rise to normal responses (Fig. 8, first column, first and second traces). The four patients who had lesions of the retrogasserian root and experienced numbness of half of the face had normal SW1, W1, and MW1 components, according to the peripheral branch stimulated, but no later components were visible (Fig. 8, second column). Stimulation of the supraorbital, infraorbital, and mental nerves in the two patients who had undergone lesioning at the REZ during MVD evoked normal responses up to the SW2, W2, and MW2 components, whereas the SW3, W3, and MW3 components were markedly reduced in amplitude or absent (Fig. 8, third column).

Measurement of Distances on the Skull

In measuring the skulls, we found that it was 18 to 22 mm from the foramen ovale to the trigeminal notch; 23 to 28 mm from the foramen rotundum to the trigeminal notch; 35 to 39 mm from the medial portion of the superior orbital fissure to the trigeminal notch; 75 to 80 mm from the infraorbital foramen to the trigeminal notch; 85 to 90 mm from the supraorbital foramen to the trigeminal notch; and 140 to 150 mm from the mental foramen to the trigeminal notch. On the skulls examined, the distance between the trigeminal notch and the supposed site of entrance of the trigeminal root into the pons could be approximated as ranging from 15 to 20 mm, which is in agreement with the measurements of the overall root length by other authors,3 who found values between 18 and 26 mm.

Recordings Obtained After Stimulation of the Supraorbital, Infraorbital, and Mental Nerves From TRE Inserted at a 90° Angle to the Orbitomeatal Line

These recordings were obtained after stimulation of a total of 39 nerves. The data are reported here very briefly.
because they gave flawed results, for reasons that will be analyzed in the Discussion section. Moving the TRE from the foramen ovale to the 15-mm depth produced an amplitude increase, but an almost negligible latency increase (0.07 msec) in the response when the supraorbital nerve was stimulated. In the case of stimulation of the infraorbital and mental nerves, the mean increase in latency was 0.12 msec and 0.26 msec, respectively. The resulting conduction velocities would range from 214.2 to 59.58 m/second.

Discussion

Evidence gathered in this paper to demonstrate generator sites of TEPs comes mainly from simultaneous scalp and nerve or root recordings. During MVD the recording electrode could be positioned over the desired part of the root under visual inspection, so there could be no doubt as to the site of origin of the electrical activity that was recorded. The recorded scalp component SW2, W2, or MW2, according to the nerve stimulated, was almost perfectly simultaneous with the root response recorded at the site situated 10 mm from the pons. It is a logical conclusion, therefore, that all these scalp components arise from the root shortly before its entrance into the pons. It is not clear why the stationary field responsible for the scalp components should be generated at that site; but one may speculate that this is a result of a change in conducting properties of the REZ, whose distal limit extends at some distance from the pons. The finding of a very precise site of origin for the SW2, W2, and MW2 components, which is common to all stimulated branches, is very convenient because this provides a stable point of reference for the temporal relationship of the other components. The recordings obtained during MVD also provided the means for a very reliable measurement of the conduction velocity across the root, because both sites of recording were accessible under visual control, and the distance between the two points could be directly measured. The mean conduction velocities calculated after stimulation of the different branches ranged from 39.93 to 40.08 m/second, with no significant difference among them. Therefore, we could safely state that the fastest fibers from the different branches travel along the root at the same speed of approximately 40 m/second. The SW3, W3, and MW3 components occur 0.42 to 0.52 msec later than the components measured at the pons (distance 0 mm). If it is assumed that the conduction velocities calculated earlier are maintained for a short distance into the brainstem, this would indicate that the sites of origin of these scalp-recorded components are at distances of approximately 16.8 to 20.8 mm centripetal to the site of root entry. On examination of a topometric atlas, the distance between the principal sensory trigeminal nucleus and the site of root entry into the pons can be calculated as being 12.4 mm. Slightly longer distances are involved in the path to the other sensory nuclei. We already know that the SW3, W3, and MW3 components are generated before the first synapse, because their recovery cycle is the same as the peripheral components. It is thus conceivable that each of them is generated at a site of change in direction or in the surrounding conductive medium just before entering one or more of the nuclei. Data acquired during the MVD procedure also provide some indirect clues to the origin
of the scalp SW1, W1, and MW1 components. Assuming that the root conduction velocity of 40 m/second is constant through the more peripheral portions of the pathway, the distance between the generators of SW1, W1, and MW1 and the site 10 mm from the pons can be easily calculated from the time intervals SW1 to SW2, W1 to W2, and MW1 to MW2. The results of the calculation, performed by pooling data from all the patients, indicate an approximate distance of 48 mm for the supraorbital nerve, 44 mm for the infraorbital nerve, and 40 mm for the mental nerve stimulation. Because the average total length of the root is 22 mm, and the origin of the SW2, W2, and MW2 is located at approximately one-half the length of the root, our values indicate that the origin of the SW1, W1, and MW1 components is peripheral to the gasserian ganglion.

The use of the TRE provided additional and sometimes more direct clues to the location of the generator sites of SW1, W1, and MW1. Whether the angle of insertion was 60° or 90° to the orbitomeatal line, the recording tip was in close contact with the fibers activated by stimulation of the mental nerve at the foramen ovale and for a few millimeters thereafter. The simultaneous occurrence of the scalp component MW1 and the response recorded at the foramen ovale by the TRE is clear proof that the origin of MW1 lies at the mandibular nerve at the foramen. No such straightforward evidence is available about the origin of W1 and SW1. When the TRE was at the foramen ovale, its tip recorded activity after stimulations of the infraorbital nerve (Fig. 4, second trace) and the supraorbital nerve (Fig. 2, second trace), the latter displaying much less amplitude and longer latency than the former. At the foramen ovale, the tip of the TRE was a few millimeters from the maxillary nerve and farther away from the ophthalmic nerve. As discussed in a previous publication, in the case of impulses being conveyed by the maxillary nerve after stimulation of the infraorbital nerve, it is quite conceivable that the recording surfaces of the TRE would “see” the activation of the very first tract of the afferent fibers inside the skull, just after their passage through the foramen rotundum. The activity thus recorded took place an average of 0.05 msec after the peak of the scalp W1 (angle of insertion was 60°). This suggests that the site of origin of W1 would be at the foramen rotundum or just on the distal side of it. The stimulation of the supraorbital nerve evoked a response recorded from the tip of the TRE that had a latency twice as long as the one from the infraorbital nerve. This result was apparently paradoxical, because the route lengths from the sites of stimulation to the gasserian ganglion are similar for the two nerves. A large difference in conduction velocities can be excluded because measurements obtained on the root provided similar values for all three trigeminal branches. The only possible explanation for such a late recording lies in the spatial relationships between the fibers of the first branch and the tip of the TRE. The fibers run from front to back along a line approximately parallel to the orbitomeatal, steeply angled to the direction of the TRE (whether inserted at 90° or 60°). It is likely that the relative orientation of the recording electrode and activated fibers limited the “field of vision” of the electrode to the short tract of the fibers situated just in front of it. Thus, with the electrode at the foramen ovale, the activity of the ophthalmic nerve at the superior orbital fissure could not be recorded, and the site originating the response would be definitely inside the skull (it may be inferred, by the latency of the response and the direction of the electrode, that the originating site would be the fibers of the first division approximately at the clivus level). No helpful clues, therefore, can be derived from the TRE recordings about the origin of SW1, which has to be hypothesized on the basis of the distance from the site of origin of SW2 and conduction velocities. The range of distance from the superior orbital fissure to the entrance of the root into the pons can be estimated at 50 to 59 mm (extrapolated by data reported in Measurements of Distances on the Skull). Because the site of origin of SW2 is situated 10 mm from the entrance into the pons, its distance from the orbital fissure can be estimated to range between 40 mm and 49 mm. The calculated root conduction velocity suggests that the site of origin of SW1 would be situated 48 mm distal to the origin of SW2. The two figures are coincident; therefore, one can reasonably estimate that the site of origin of SW1 is at the ophthalmic nerve as it runs across the superior orbital fissure. When the TRE was advanced from the foramen ovale toward the clivus, it recorded responses at different latencies according to the nerve stimulated and the direction of advancement (60° or 90° to the orbitomeatal line). The latency of the response recorded from the TRE was linearly related to the depth of its tip only if the direction of advancement was parallel to the fibers activated. That happened only when the angle was 60° and the mental nerve was stimulated. Deviations from linearity were dependent on the angle formed between the direction of electrode advancement and the fibers activated. They were slight in the case of stimulation of the infraorbital nerve and electrode insertion along the 60° line, but were very large in the case of stimulation of the supraorbital nerve and electrode insertion along the 90° line. Deviations from linearity explain the very different and often paradoxical values of conduction velocities obtained by dividing the distance of electrode advancement by the time interval between responses at the various depths. The two most reliable estimates of conduction velocities obtained from the TRE were those taken along the 60° line after stimulation of the mental and infraorbital nerves, with respective values of 42.85 m/second and 46.87 m/second, which were broadly in agreement with the root conduction velocity calculated during MVD.

The aforementioned conclusions about the generator sites of the early components are confirmed by findings in patients with discrete lesions. Thermolesioning at the foramen ovale clearly destroyed the generator site of MW1, whereas the afferent channels from the other branches were left intact. The retrogasserian thermorhizotomies left the peripheral function of the nerve unaltered, thus allowing the normal generation of SW1, W1, and MW1, but seriously impairing any additional centripetal conduction. Cutting the root at its entry zone into the pons did not affect the SW2, W2, and MW2 components. This information indicates a generator site for these components between the gasserian ganglion and the REZ, whereas the origin of SW3, W3, and MW3 has to be placed beyond the REZ, inside the brainstem. The disappearance of components according to the site of lesion is also proof that they are caused by activation of discrete
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sites by one single group of fibers and not a result of volleys at different conduction velocities.

Conclusions

The data presented here provide definite evidence that the components SW1, W1, and MW1 have their origins, respectively, in the ophthalmic, maxillary, and mandibular nerves at those nerves’ points of entry into the skull (superior orbital fissure, foramen rotundum, and foramen ovale). Conversely, components SW2, W2, and MW2 all originate in the same site on the retrogasserian root, 10 mm before its entrance into the pons. Components SW3, W3, and MW3 originate in the trigeminal sensory nuclei. The detection of well-defined generators will make the use of early scalp TEPs even more reliable, both in detecting pathological lesions and in surgical monitoring. The data presented in this paper indicate that, in recordings in which the TRE is used during thermorhizotomy operations, as in a technique recently proposed, the direction in which the TRE is advanced has a significant effect on the latencies recorded, and must be taken into account.

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References


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