(K) 305

Citation 319

Unique Identifier
90126522

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Origin of scalp far-field N18 of SSEPs in response to **median nerve** stimulation.

Source
Electroencephalography & Clinical Neurophysiology. 77(1):39-51, 1990 Jan-Feb.

Abstract
To identify the origin of scalp-recorded far-field negativity of short-latency **somatosensory evoked** potentials to **median nerve** stimulation (designated N18), direct records were made from the thalamus and ventricular system during 4 stereotaxic and 3 posterior fossa operations. In the thalamus a negative potential with almost the same latency as the scalp N18 was restricted to the Vim nucleus, but there was a large positive potential in the VC nucleus and medial lemniscus. Vim negativity increased in amplitude when high frequency stimulation was given to the **median nerve**, indicative of a facilitation effect. In contrast, the amplitude of scalp N18 decreased at high frequency stimulus. Direct recordings made through the medulla oblongata to the mid-brain showed a negative potential with gradually increasing latency. Above the upper pons, there was stationary negativity with no latency shift. The similarity between this negative potential and N18 is shown by their having the same latency and same response to the amplitude reduction and latency prolongation produced by high frequency stimulus. Our data suggest that scalp N18 comes from brain-stem activity between the upper pons and the mid-brain rather than from the thalamus.

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Electroencephalography and clinical Neurophysiology, 1990, 77: 39–51
Elsevier Scientific Publishers Ireland, Ltd.

EVOPOT 89024

Origin of scalp far-field N18 of SSEPs in response to median nerve stimulation

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(Accepted for publication: 28 April 1989)

Summary To identify the origin of scalp-recorded far-field negativity of short-latency somatosensory evoked potentials to median nerve stimulation (designated N18), direct records were made from the thalamus and ventricular system during 4 stereotaxic and 3 posterior fossa operations.

In the thalamus a negative potential with almost the same latency as the scalp N18 was restricted to the Vim nucleus, but there was a large positive potential in the VC nucleus and medial lemniscus. Vim negativity increased in amplitude when high frequency stimulation was given to the median nerve, indicative of a facilitation effect. In contrast, the amplitude of scalp N18 decreased at high frequency stimulus.

Direct recordings made through the medulla oblongata to the mid-brain showed a negative potential with gradually increasing latency. Above the upper pons, there was stationary negativity with no latency shift. The similarity between this negative potential and N18 is shown by their having the same latency and same response to the amplitude reduction and latency prolongation produced by high frequency stimulus.

Our data suggest that scalp N18 comes from brain-stem activity between the upper pons and the mid-brain rather than from the thalamus.

Key words: Somatosensory evoked potentials; Negative far-field potential; Direct recording

The early phase of short-latency somatosensory evoked potentials (SSEPs) elicited by median nerve stimulation generally consists of 3 positive and 1 negative components that precede the cortical potentials. Their respective peak latencies are about 9 msec (P9), 11 msec (P11), 13–14 msec (P14), and 16–18 msec (N18) after median nerve stimulation. Since Cracco (1972a) first recorded subcortical potentials from the scalp, there have been many reports on the origin of SSEPs and their clinical uses. The recent consensus is that the 3 positive components are generated in the brachial plexus (P9), the dorsal column (P11), and the cervico-medullary junction (P14) (Cracco and Cracco 1976; Anziska and Cracco 1980; Desmedt and Cheron 1980, 1981; Lueders et al. 1983; Hashimoto 1984; Suzuki and Mayanagi 1984; Mauguière et al. 1983a,b; Mauguière and Ibañez 1985; Urasaki et al. 1948a,b, 1985a,b, 1988a,b).

The first scalp negative wave in SSEPs has been considered a type of sensory cortical activity because its largest amplitude is in the parietal area contralateral to the side of stimulation. This negative potential, however, is broadly distributed over the scalp, and the latency of the frontal negativity is shorter than that of the parieto-occipital negativity (Cracco 1972b; Kritchevsky and Wiederholt 1978). Using a non-cephalic reference, Desmedt and Cheron (1981) clearly showed that N18 is

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distributed over the entire scalp; whereas, N20 is restricted to the area of the hand sensory cortex. This far-field N18 has been speculated to originate either from (Desmedt and Cheron 1981; Tsuji et al. 1984; Yasue et al. 1985) or below (Maguière et al. 1983b; Hashimoto 1984; Urasaki et al. 1985a,b) the thalamus.

Several researchers have made direct records in humans of SSEPs from the thalamus, medial lemniscus, brain-stem and ventricular system near the sensory pathway in order to establish the origin of scalp N18 (Hashimoto 1984; Suzuki and Mayanagi 1984; Tsuji et al. 1984; Yasue et al. 1985; Albe-Fessard et al. 1986; Taira et al. 1986; Katayama and Tsubokawa 1987). But, to establish the generating source of scalp N18, additional data on the distribution and spatial gradients of directly recorded SSEPs are needed. The characteristics of SSEPs at intracranial and scalp sites determined by changing the frequency of stimulus to the median nerve may be useful in correlating directly recorded SSEPs with scalp SSEPs (Albe-Fessard et al. 1986).

We recorded SSEPs in humans using an array of electrodes implanted in the Vim and VC nuclei of the thalamus, the medial lemniscus, the fourth ventricle, the aqueduct, the third ventricle, the lateral ventricle and the subcortex. We correlated our directly recorded SSEPs with scalp SSEPs and analyzed their distribution and spatial gradients, and the wave form changes produced by high frequency stimulation of the median nerve. The data obtained provide information about the origin of scalp SSEPs, especially the N18 component.

Subjects and methods

Records were made during surgery for 3 posterior fossa lesions and 4 stereotaxic investigations. Informed consent was obtained both from the patients and their families. Three of the 7 patients had posterior fossa lesions; Arnold-Chiari malformation (case 1), ependymoma (case 2) and choroid plexus papilloma (case 3) in the fourth ventricle. Voa thalamotomy was performed on one who had choreo-ballismus (case 4), and Vim thalamotomy on three who showed the tremors of Parkinson's disease (cases 5–7). None of the patients showed impairment of deep sensation in their upper limbs either before or after surgery. Recording from the fourth ventricle to the aqueduct were done in the three with posterior fossa lesions after sufficient decompression of the posterior fossa or removal of the tumor, just before cloning the dura mater, under general anesthesia (cases 1–3). Records from the third and lateral ventricles and frontal subcortex were made from 4 patients during stereotaxic surgery, case 4 being done under general anesthesia and 5, 6 and 7 under lcoal anesthesia with 1% procaine HCl. Thalamic SSEPs were also recorded in the latter 3 cases under local anesthesia.

Positive contrast ventriculography was used to make the lateral and third ventricles visible.

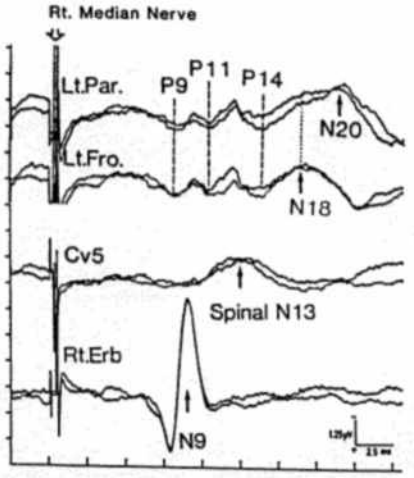

Fig. 1. Normal short-latency somatosensory evoked potentials (SSEPs) for right median nerve stimulation in non-cephalic reference recording. Negativity of scalp electrodes upward. Par., contralateral parietal point; Fro., contralateral frontal point; Cv5, spinous process of the fifth cervical vertebra; Erb, ipsilateral Erb's point. This figure demonstrates the relation between each component. The peaks of scalp far-field P9 and N18 appear slightly earlier than those of Erb's N9 and cortical N20; whereas, the peak of scalp far-field P14 has a slightly longer latency than spinal N13. Calibration: 1.25 μV, 2.5 msec.

Parameters for the Vim nucleus were 6 mm anterior to the posterior commissure and 15 mm lateral to the midline of the third ventricle and on the intercommissural line between the anterior and posterior commissures. The recording electrodes for the ventricular system consisted of 8 platinum ring electrodes, each with an outer diameter of 2 mm, set at intervals of 0.5 or 1 cm. Thalamic SSEPs were recorded with a tungsten steel needle 30 cm long, 250 μm in diameter with 100 μm bared tip. The recording electrodes on the midclavicular point (Erb's point), neck and scalp were silver-silver chloride disks 0.7 cm in diameter placed over the ipsilateral Erb's point, the fifth cervical spinous process, and on the contralateral frontal scalp (F3 or F4) for all the patients. Contralateral parietal scalp (C3 or C4) or ipsilateral frontal and parietal scalp electrodes were also placed in some cases. The shoulder contralateral to stimulation (non-cephalic, NC) or bilateral ear lobes (A1 + A2) served as the reference for direct and scalp recording.

The standard method used to stimulate the median nerve consisted of square wave pulses of 0.2 msec duration delivered at 6/sec to the wrist via a saddle type bipolar electrode with the cathode 3 cm proximal to the anode. Stimulus intensity was adjusted to produce a thumb twitch in the patients under general anesthesia, or to just above the sensory threshold when local anesthesia was used, because high frequency stimulation at such an intensity did not produce intolerable or disagreeable sensations of pain.

Modifications in the SSEP waves with changes

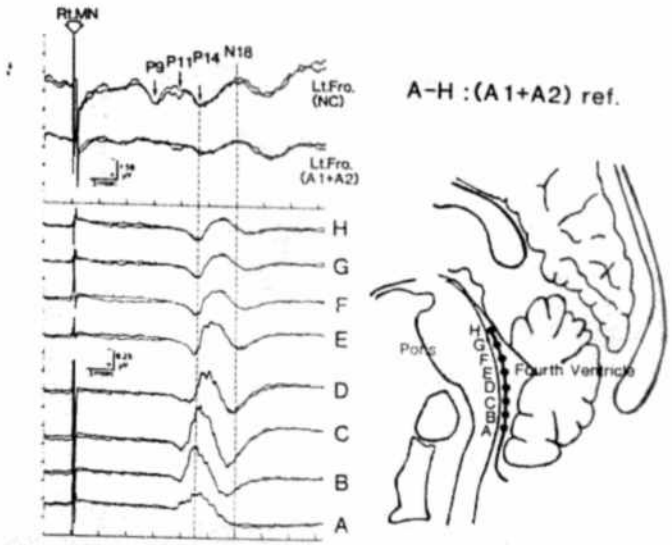

Fig. 2. Intraoperative records of scalp and intracranial SSEPs from a 33-year-old male patient with Arnold-Chiari malformation (case 1). The recording sites of SSEPs are mapped on the sagittal MRI view and are indicated alphabetically. Direct records were made simultaneously with an 8-electrode array with an A1 + A2 reference. The distance between electrodes was 5 mm. The peak of the negative potential on the cuneate nucleus (C) showed the same latency as that of scalp far-field P14; far-field positivity with a stationary peak was formed above the cuneate nucleus.

in the stimulation frequency (6, 12, 18, 21, 24 and 27 Hz) were studied in 4 patients (cases 3, 4, 5 and 7). The evoked activity was amplified with a band-pass filter of 5–3000 Hz (−3 dB); 400–1000 trials being averaged by the Nicolet Pathfinder II system. The analysis epoch was between 30 and 35 msec with a 10% prestimulus time (512 points). Responses were replicated at least once, all data being stored on floppy disks and plotted separately. The negativity of the direct and scalp electrodes registered upward in all the records. The electrode positions were confirmed by an intraoperative plain skull X-ray or by ventriculography and were compared with the patient's preoperative CT, MRI scan or the human brain atlas of Schaltenbrand and Baily (1959).

Results

Fig. 1 shows typical SSEP waves following median nerve stimulation in a normal subject. The scalp far-field potentials P9, P11, P14 and N18 were identified by their relations to the latency of Erb's N9, spinal N13 and scalp N20. Our normative data and those of others show that the peaks of P9 and N18 appear slightly earlier than those of Erb's N9 and cortical N20; whereas, the latency of P14 is almost the same as, or slightly longer than, that of spinal N13 (Urasaki et al. 1984a, 1988a; Jacobson and Tew 1988). These correlations remained unchanged intraoperatively: therefore, they should be of use in determining each scalp far-field potential.

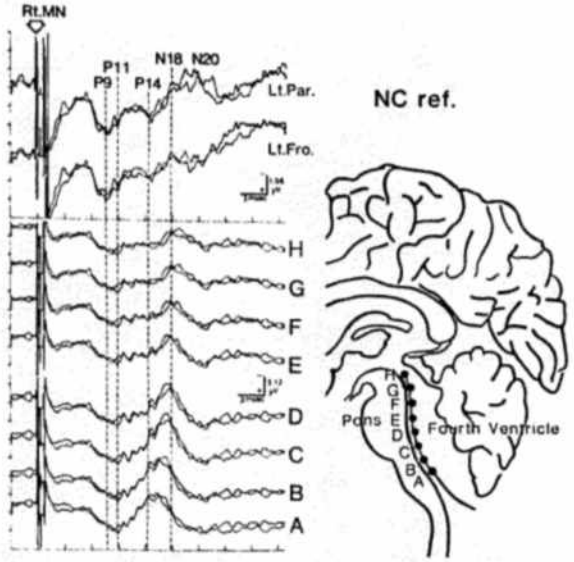

Fig. 3. Intraoperative records of scalp and intracranial SSEPs from a 10-year-old female patient with fourth ventricular ependymoma (case 2). The recording sites of SSEPs are mapped on the sagittal MRI view. Scalp and intracranial SSEPs were recorded with a non-cephalic reference. The distance between electrodes was 5 mm. Far-field P9 and P11 were identified at the scalp and all intracranial electrodes with no latency shift. Negative potential at the cuneate nucleus (A) showed the same latency as scalp P14; far-field positivity with a stationary peak was formed above the cuneate nucleus. Stationary negativity with no latency shift was also identified above electrode E (mid-pontine level), and this negative peak coincided in latency with that of scalp N18.

The intraoperative record for case 1 is shown in Fig. 2. When compared to non-cephalic reference records, the A1 + A2 reference record showed canceling out of scalp P9 and P11, and small amplitudes for scalp P14 and N18, even though these latter 2 components were clearly identifiable. Simultaneous direct recording from the medulla oblongata and the mid-pontine area with the A1 + A2 reference also showed canceling of P9 and P11. The wave form of the response recorded from the vicinity of the cuneate nucleus (sites B and C, the latter probably being just on the cuneate nucleus) had an initial small positivity, followed by a broad negativity with the same peak latency as scalp P14; this was followed by a slow positivity. Several smaller peaks rode on the negative peak which became progressively longer rostrally (D–H). We interpreted the far-field positivity as being a stationary peak formed above the site of the cuneate nucleus that showed the same latency as scalp P14. In this case, however, there was no stationary negativity which coincided with scalp N18.

Intraoperative records for case 2 with a non-cephalic reference are shown in Fig. 3. A far-field P9 of small amplitude and a clear P11 were identified at the scalp and all the intracranial electrodes (A–H) with no latency shift. As in case 1, the negative response at the cuneate nucleus (A) changed to far-field P14 above the rostral electrodes and was clearly identifiable from E to H. Although the peak of negativity became longer rostrally, a stationary peak negativity also formed above the mid-pontine area (F–H), which coincided in latency with the scalp N18.

Similar recording sites as for case 3 with the A1 + A2 reference are shown in Fig. 4. Simultaneous recording from the scalp and intracranial

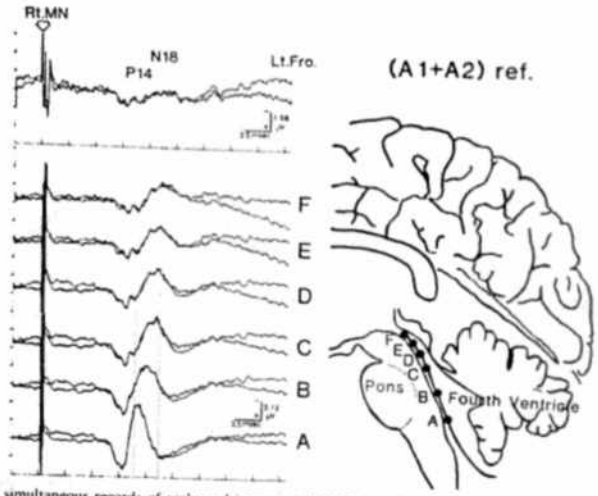

Fig. 4. Intraoperative simultaneous records of scalp and intracranial SSEPs in a 27-year-old female patient with fourth ventricular choroid plexus papilloma (case 3). Recording sites of SSEPs are mapped on the sagittal MRI view. The reference was A1 + A2. The distance between electrodes A–B and B–C was 10 mm. The distance between electrodes C–D, D–E and E–F was 5 mm. Negativity at the cuneate nucleus (A) changed to far-field positivity which coincided in latency with the peak of scalp P14. Negativity with a stationary peak was formed above electrode C (border between the upper third and lower two-thirds of the pons) which coincided in latency with the peak of scalp far-field N18.

electrodes revealed stationary far-field P14 in rostral sites of the cuneate nucleus where there was a large negative peak. As in case 2, there was a stationary negative potential with almost the same latency as scalp N18 above electrode C on the border between the upper third and lower two-thirds of the pons. Another small negative notch after the stationary negative peak was seen at electrode F.

SSEPs obtained from the third and lateral ventricles, and the frontal subcortex are shown in Fig. 5 for case 4 and in Fig. 6 for case 5. Far-field P14 and N18 with stationary peak latencies were identified in both the A1 + A2 reference (Fig. 5) and the NC reference (Fig. 6). P9 and P11 were present at all the intracranial electrodes with no latency shift (Fig. 5).

Scalp SSEPs and direct records for case 6, which were obtained from Vim, VC and the medial lemniscus, confirmed by the brain atlas of Schaltenbrand and Baily (1959), are shown in Fig. 7. The electrodes from the target point (0 mm) to 5 mm above it (−5 mm) were presumed to be located in the Vim nucleus. In this area there was a major negative peak, with minor small notches, that showed almost the same latency as scalp N18. Records from the VC and medial lemniscus, however, showed a large positive potential with several small notches. Therefore, a large spatial gradient for the potentials probably exists in the thalamus and major thalamic negativity is restricted to the Vim nucleus. In the medial lemnicus there were several positive peaks, the one for the initial positivity being almost coincident with the peak of scalp P14.

Direct records around the Vim for case 7 are

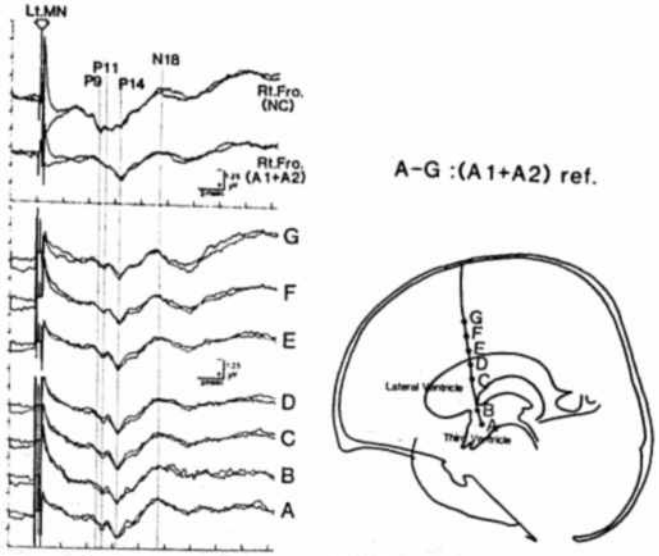

Fig. 5. Intraoperative records of scalp and intracranial SSEPs in a 9-year-old female patient with choreo-ballismus (case 4). Recording sites of SSEPs are mapped on the lateral view of the X-ray of the ventricular system and indicated alphabetically. The reference was A1 + A2. The distance between electrodes was 10 mm except for B–C (20 mm). P9, P11, P14 and N18 were recorded by both the scalp and intracranial electrodes with no latency shift.

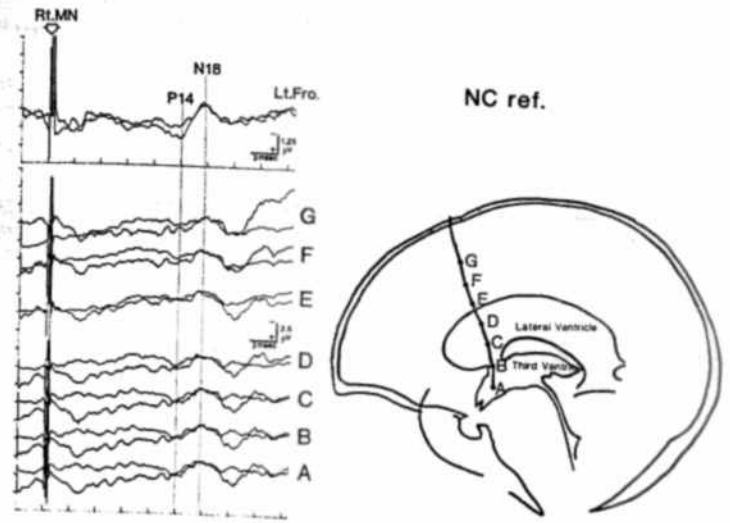

Fig. 6. Intraoperative records of scalp and intracranial SSEPs from a 64-year-old male with Parkinson's disease (case 5). Recording sites of SSEPs are mapped on the lateral X-ray of the ventricular system. A non-cephalic reference was used. The distance between electrodes was 10 mm. P14 and N18 were recorded by both the scalp and intracranial electrodes with no latency shift.

given in Fig. 8. The amplitude of Vim thalamic negativity was maximal at the target point, but decreased when the electrode was elsewhere. These findings suggest that Vim thalamic negativity is restricted to the region in the Vim nucleus.

The pre- and postoperative SSEP wave forms for case 6 (electrocoagulation of Vim) are shown in Fig. 9. Scalp N18 is readily identifiable, and the fact that its amplitude did not change after surgery indicates that Vim thalamotomy had no marked effect on it. Similar results were found in the pre- and postoperative records of cases 5 and 7.

Wave modification of SSEPs with change in stimulation frequency is shown in Figs. 10 (case 7), 11 (case 4) and 12 (case 3). When there was high frequency stimulation, scalp N18 showed a reduced amplitude and prolonged latency (Figs. 10–12). Interestingly, the Vim thalamic negativity had different patterns of change from scalp N18. Its amplitude was increased by some high frequency stimuli; 21, 24 and 27 Hz in case 7 (Fig. 10) and 12 and 18 Hz in case 6 (not illustrated). This amplitude increase in Vim suggests that high frequency stimulation has a facilitating effect. In contrast, the evoked potentials recorded in the frontal subcortex, third ventricle (Fig. 11, case 4), and aqueduct (sites D, E and F in Figs. 4 and 12, case 3) showed characteristics similar to those of scalp N18, amplitude decrease and latency prolongation when there was high frequency stimulation. The evoked activities recorded in the regions below the border between the upper third and lower two-thirds of the pons (sites B and C in Figs. 4 and 12, case 3) and the cuneate nucleus (site A in Figs. 4 and 12), however, showed only amplitude reduction. Therefore, evoked activity with char-

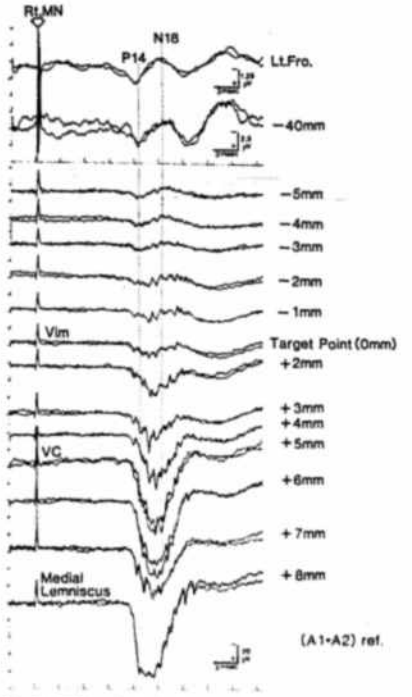

Fig. 7. SSEPs obtained during a Vim thalamotomy on a 64-year-old male with Parkinson's disease (case 6). SSEPs in Vim, VC and the medial lemniscus are shown. The reference was A1 + A2. A large spatial gradient of evoked potentials is present.

acteristics similar to those of scalp N18 was recorded in the region above the upper pons, but not in the thalamus.

Discussion

Thalamic activity has been considered the possible generator of the far-field component of SSEPs produced by median nerve stimulation. Scalp P14 (Cracco and Cracco 1976; Kritchevsky and

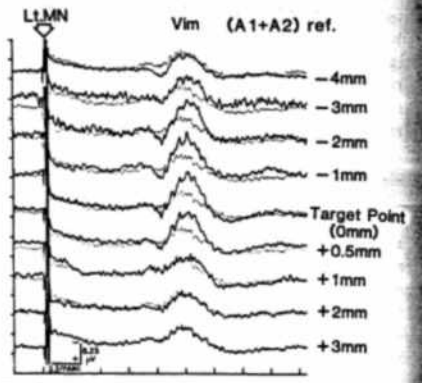

Fig. 8. SSEPs recorded around the Vim during a Vim thalamotomy on a 72-year-old male with Parkinson's disease (case 7). The reference was A1 + A2. The SSEP obtained from the electrode located +3 mm inferior to the target point was superimposed on that for each electrode site. Note that the amplitude of Vim negativity apparently decreased when the electrode was located away from the target point.

Wiederholt 1978; Desmedt and Cheron 1981; Albe-Fessard et al. 1986; Jacobson and Tew 1988) and N18 (Desmedt and Cheron 1981; Tsuji et al. 1984; Yasue et al. 1985) are the candidates for this thalamic potential. From thalamic SSEPs recorded during a stereotaxic operation, Fukushima et al.

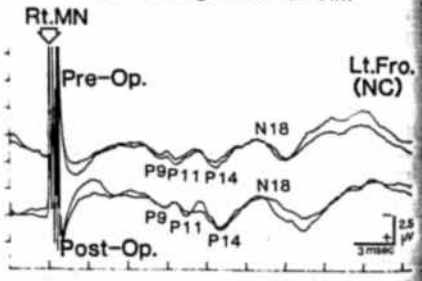

Fig. 9. Pre- and postoperative SSEPs of case 6 (Fig. 7), the patient who underwent the Vim thalamotomy, demonstrating no remarkable change in his wave forms. A non-cephalic reference was used.

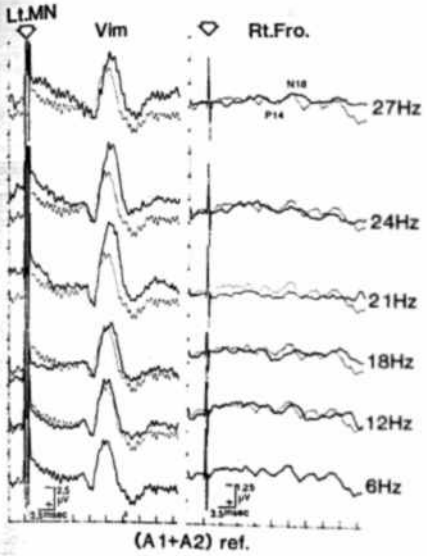

Fig. 10. Effect of increased stimulation frequency to the median nerve on evoked thalamic activity (left), and evoked scalp responses (right) recorded simultaneously. The wave form for evoked activity at 6 Hz stimulation was superimposed on each response obtained by high frequency stimulation. The scalp N18 showed amplitude reduction, whereas the amplitude of Vim negativity increased under high frequency stimulation.

(1976) showed that the latency of the large positivity in the VC nucleus is shorter by about 1–2 msec than that of cortical negativity and that a triphasic potential is recorded from the Vim nucleus.

Because the first positive component in thalamic SSEPs has a latency almost identical to scalp P14 (Fig. 7), some researchers consider that scalp P14 is generated by the thalamus (Kritchevsky and Wiederholt 1978; Albe-Fessard et al. 1986). Desmedt and Cheron (1981) calculated the theoretical conduction velocity and speculated that the onset of scalp P14 represents activity in the caudal lemniscal fiber and that its peak might represent the arrival of the volley in the thalamus. Furthermore, they differentiated far-field N18 from cortical N20 and suggested that the former originates in the thalamus or in thalamo-cortical radiations (Desmedt and Cheron 1981). In the Vim nucleus, there is a negative potential with almost the same latency as scalp N18 (Fig. 7). This Vim negativity also has been suggested to be the origin of scalp N18 (Tsuji et al. 1984; Yasue et al. 1985).

Our present findings from direct surface recording taken from the brain-stem show that the peak latencies of scalp P14 on SSEPs coincide with the peak of negative potential recorded directly from the cuneate nucleus (Figs. 2–4) and that far-field positivity clearly forms above the cuneate nucleus (Figs. 2–6). These results suggest that the origin of scalp P14 is close to the cuneate nucleus. Although several reports have indicated a relation between the cuneate nucleus potential and scalp P14 (Suzuki and Mayanagi 1984; Urasaki et al. 1984b, 1985a; Yasue et al. 1985; Møller et al. 1986; Jacobson and Tew 1988), we are unaware of any that have clearly demonstrated far-field activity above the cuneate nucleus by the use of simultaneous records from multiple electrodes on the surface of the human brain-stem.

Several recent clinical studies support our findings in that they demonstrate that lesions or dysfunction of the cervico-medullary junction may result in the loss or latency delay of scalp P14 (Anziska and Cracco 1980, 1981; Maugière and Courjon 1981; Mauguière et al. 1983a,b; Mauguière and Ibañez 1985; Urasaki et al. 1988a,b), and that thalamic lesions do not affect scalp P14 (Mauguière et al. 1983b). Lueders et al. (1983) reported that the evoked potentials recorded directly from the fourth ventricle showed a longer latency than scalp P14. Their observations are in good agreement with ours. The negativity on the cuneate nucleus closely resembles the configuration of the N wave in the cat reported by Anderson et al. (1964), who emphasized that this wave is a synaptically induced depolarization of the cuneate cells produced by an ascending volley in the dorsal column.

Elsewhere, we have demonstrated that the latency of scalp P14 is changed significantly by high frequency stimulation, which suggests that P14 is generated by activity interposed by synaptic events (Urasaki et al. 1985a,b, 1988a). Very similar results have been reported by Pratt et al.

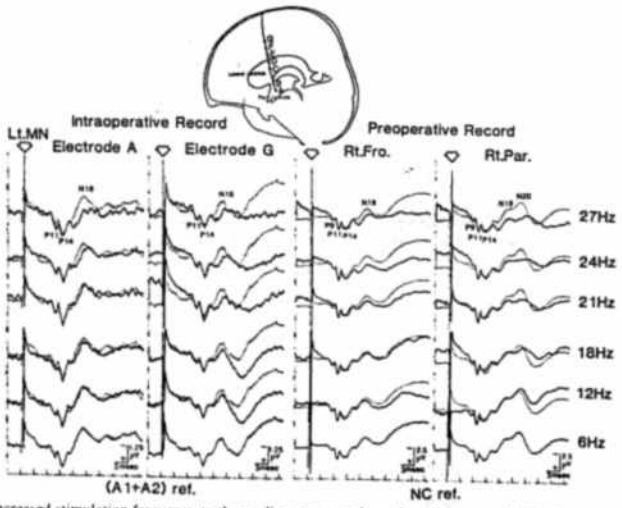

Fig. 11. Effect of increased stimulation frequency to the median nerve on the scalp and intracranial SSEPs for case 4. The wave form of the evoked activity at 6 Hz stimulation was superimposed on each response obtained by high frequency stimulation. Scalp SSEPs with a non-cephalic reference were recorded before surgery and during barbiturate therapy to control severe choreo-ballistic movements. SSEPs in the frontal subcortex (electrode A) and in the third ventricle (electrode G) showed amplitude reduction and latency prolongation of intracranial N18 similar to those of scalp-recorded N18 under high frequency stimulation. Other intracranial electrodes (B–F) showed similar changes (not illustrated).

(1980) and Meyer-Hardting et al. (1983). We also found that scalp P14 may still be present with low voltage even after cardiac arrest (unpublished). Moller et al. (1986) suggested that the P14 peak is generated at the termination of the dorsal column fibers, not in the cuneate nucleus itself, based on their depth recording from the cuneate nucleus and antidromic stimulation of the dorsal column fibers in the monkey. Different results also have been obtained by Jacobson and Tew (1988), who reported that SSEPs recorded at the junction of the cervical cord and medulla occurred earlier than scalp-recorded P14. They concluded that scalp P14 is generated within the medial lemniscus in the rostral brain-stem or by the thalamus. Scalp P14 is known to sometimes show bilobed peaks, and a component that precedes scalp P14 has been referred to as scalp P13 (Desmedt and Cheron 1980; Yamada et al. 1980; Jacobson and Tew 1988). Therefore, scalp P14 might have two components of different natures, such as primary afferent and second-order neuron near the cuneate nucleus.

Our study reported here has shown (1) that thalamic negativity is restricted to the Vim nucleus, and its amplitude is markedly decreased at electrodes away from the center of the Vim nucleus (Figs. 7 and 8); (2) that Vim negativity is facilitated by high frequency stimulation of the median nerve, whereas the amplitude of scalp N18 is decreased (Fig. 10); (3) that electrocoagulation of Vim has no effect on the amplitude of scalp N18 (Fig. 9); and (4) that the stationary negativity coincident with the latency of scalp N18 is formed above the upper pons (Figs. 3–6) and has the same characteristics as scalp N18, as shown by the amplitude reduction when there was high frequency stimulation (Figs. 11 and 12). All these findings

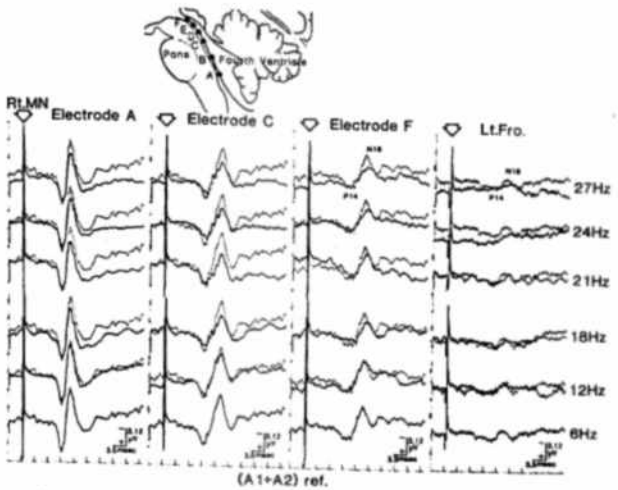

Fig. 12. Effect of increased stimulation frequency to the median nerve on scalp and intracranial SSEPs recorded simultaneously. The wave form of evoked activity at 6 Hz stimulation was superimposed on each response obtained by high frequency stimulation. Intracranial N18 recorded in the aqueduct (electrode F) showed amplitude reduction and latency prolongation caused by high frequency stimulation similar to those of scalp N18. (The same characteristics were obtained in the responses recorded by electrodes D and E.) SSEPs obtained below the upper pons showed amplitude reduction, but not latency prolongation.

provide strong evidence that scalp N18 originates somewhere below the thalamus, probably beginning in the upper pontine area.

Different responses for scalp N18 and Vim negativity produced by high frequency stimulation have been demonstrated here for the first time. The facilitating effect on Vim negativity probably reflects locally generated postsynaptic activity (Arezzo et al. 1979; Katayama and Tsubokawa 1987). But Albe-Fessard et al. (1986) also noted different SSEP behavior for the thalamus and scalp when the intensity and frequency of the median nerve stimulation was changed. Mauguière et al. (1983b) and Urasaki et al. (1985a,b) reported that thalamic lesions do not affect the amplitude of scalp N18. Arezzo et al. (1979) reported difficulty in identifying thalamic potentials above the thalamus, and a closed field formation also has been suggested (Klee and Rall 1977; Ladds et al. 1988).

In contrast, the prolonged latency of N18 in thalamic lesions has been demonstrated in several reports (Mauguière et al. 1983b; Tsuji et al. 1984; Urasaki et al. 1985a,b). The latency delay of N18 in these lesions may be produced because the effects of such lesions extend to structures below the thalamus such as brain-stem nuclei (Urasaki et al. 1985a,b). Urasaki et al. (1985a,b) showed that N18 sometimes splits into 2 peaks when there is a brain-stem lesion and explained the mechanism of this change as follows: component N18 is generated, with a time lag, by cumulative nervous activities and conduction disturbance along the pathway in the pons together with partial dysfunction of these generation sites might divide N18 into two or more components. Mauguière et al. (1983b) and Hashimoto (1984) suggested that activities related to collateral branches in the brain-stem contribute to N18. Our present findings are compatible with their speculations.

Multiple generators of scalp-recorded N18, however, must also be considered. More than one peak for N18 suggests such a possibility (Mauguière et al. 1983b; Taira et al. 1986; Katayama and Tsubokawa 1987). In the study reported here, we have focused on the main negative peak of scalp-recorded N18, but it is possible that at least 2 negative peaks might exist on the ascending slope of N18 (Figs. 3–7). Several small positive or negative activities were also found in the Vim, VC, medial lemniscus and the more caudal brain-stem regions (Figs. 2–7), some of these peaks being located between scalp-recorded P14 and N18. The thalamo-cortical radiation is considered by some as one generating source of the notches on the ascending slope of N18 (Albe-Fessard et al. 1986; Katayama and Tsubokawa 1987). Although our study has clearly demonstrated a close relation between the peak of N18 and brain-stem activities, an additional contribution to the ascending or descending slopes of N18 might be made from the thalamic nuclei, e.g., Vim, VC or other nuclei (Urasaki et al. 1985b).

Recent studies of the mechanism of far-field potentials have shown that stationary peaks are generated by changes in the conductivity and geometry of the surrounding media or the direction of the propagated volley in a nerve trunk (Nakanishi 1982; Nakanishi et al. 1986; Kimura et al. 1984; Cunningham et al. 1986; Stegeman et al. 1987). Far-field negative potentials have also been suggested to be generated by such mechanisms as conductivity change in the media and reversal of the direction of propagation (Stegeman et al. 1987), and independent attenuation of the sink and source (Cunningham et al. 1986). Kimura et al. (1984) speculated that branching of the nerve axon may also be an important factor for producing a stationary peak. These theories might account for collateral branch generation of N18 because the conduction slowing and direction of change of the propagated volley, as well as independent attenuation of the sink and source, might all occur in collateral branches in the brain-stem.

We thank Dr. Nai-Shin Chu (Professor, Department of Neurology, Chang Gung Memorial Hospital, Taiwan) for his critical reading of the manuscript.

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