Origin of somatosensory evoked responses recorded from the cervical skin surface

KOKI SHIMOJI, M.D., HIROYUKI SHIMIZU, M.D., AND YOICHI MARUYAMA, M.D.

Laboratory of Clinical Neurophysiology, Department of Anesthesiology, Niigata University School of Medicine, Niigata, Japan

Somatosensory evoked response from the cervical skin surface over the spine (the cervical SER) was recorded, and compared with the cord dorsum potential (CDP) simultaneously recorded from the posterior epidural space at the same segment. The cervical SER evoked by segmental nerve stimulation consisted of an initially positive spike (P1), the peak latency being the same as that of the P1 of the CDP, followed by a smaller negative wave with two peaks. The latency of the second peak of the negative wave (N1) coincided with that of the N1 of the CDP. Subsequent to this negative wave, a slow positive wave (P2) with peak latency similar to that of the P2 of the CDP, could be noticed in some subjects. The cervical SER could not be evoked even by strong stimulation of the cauda equina. Thus, the cervical SER might reflect a segmental phenomenon rather than the conducted potential along the cord, and originate from the spinal root and cord in the same way as the segmentally evoked CDP.

KEY WORDS • cord dorsum potential • posterior epidural space • cervical somatosensory evoked response • positive spike • negative wave • positive wave

Some small changes in potentials have been recorded from surface electrodes over the spine in man. However, there has been no convincing evidence that these potentials originate from the spinal cord. In the cat, comparison of skin recordings with direct recordings from the cord surface was reported; it was shown that response configurations were similar from both recording techniques at lumbar levels, but had different wave forms at both thoracic and cervical levels. On the other hand, the cord dorsum potential (CDP) can be recorded from the posterior epidural space (PES) in man, and its wave form has been found to be basically similar to that recorded directly in animals.

We have tested the origins of the somatosensory evoked response recorded from the cervical skin surface (the cervical SER) by comparison with CDP simultaneously recorded from the PES, and found that the cervical SER probably originates from the spinal cord and roots. This might suggest the applicability of surface recordings for the study of spinal cord disease.

Clinical Material and Method

In the first series of observations, the simultaneous recordings of both the cervical SER from surface and CDP from the PES were made during surgery in seven patients who were undergoing spinal operations, under neuroleptanesthesia (60% nitrous oxide, 0.005 mg/kg fentanyl, and 0.25 mg/kg droperidol), and under complete muscle relaxation (0.1 mg/kg pancuronium). No
Evoked responses over spine

![Diagram of evoked responses over spine]

FIG. 1. Simultaneous recordings of cord dorsum potential (CDP) from the posterior epidural space (PES) (E) and the evoked response from the surface (S) in response to ulnar nerve (left records) and cauda equina (right records) stimulations. Note that peak latencies of the initial positive potential, the second components of the subsequent negative wave demonstrated as a small notch and slow positive wave are consistent with those of the P₁, N₁, and P₂ waves of the CDP, respectively. An arrow indicates the second component of the negative wave. Cauda equina stimulation evokes a “conductive” potential that is recordable from the PES but not from the skin surface (right records). The vertical lines represent the start of stimulus pulse. Three averaged responses (N = 150) are superimposed. Upward deflection denotes positivity in this and the following records. The recording was made from a neurologically normal 16-year-old girl.

Neurological deficits were found at the cervical level. Two pairs of epidural electrodes were placed bipolarly at C6-7 (for recording) and L3-4 (for stimulation) to monitor the spinal cord potential during the spinal manipulations. This procedure is routinely used during spinal fusion in our hospital. The conducted potentials along the spinal cord can be constantly obtained from thoracic or cervical PES by placing the stimulating electrodes in the PES at the level of the cauda equina rather than along a peripheral nerve such as the posterior tibial nerve. Our previous data have shown that the conducted response recorded from the cervical PES was very small and not always recordable in response to the tibial nerve. On the other hand, the conducted response by the stimulation of the cauda equina was large and highly reproducible in all subjects.

The methods of placing the electrodes in the PES were based on the technique of continuous epidural anesthesia, and have been described previously. The surface electrodes (silver disc) were placed over the cervical spine at the C6-7 level with a reference electrode at the suprasternal notch (Fig. 1). The evoked response was amplified with a biophysical amplifier (Nihonkohden RB-5) having a frequency response of more than 3 KHz that led to a computer (Nihonkohden 201) for averaging.* The time constant used was 0.3 seconds for all responses. The background potential changes were also monitored on the pen-writing system. The stimulus was a

*Biophysical amplifier (RB-5) and computer (210) manufactured by Nihon Kohden Kogyo Co., Nishiochiai 1-31-4, Shinjuku, Tokyo 161, Japan.
K. Shimoji, H. Shimizu and Y. Maruyama

Fig. 2. Upper: Effect of double stimuli on the CDP (upper trace) and the surface record (lower trace) at 1-, 5-, and 10-msec intervals. C = control, the single shock. Note that the second peak (arrows) of the negative wave and subsequent positive wave can be demonstrated in all records with constant latency but with a variable amplitude. Dots on each record indicate the stimulus pulses. Lower: Comparison of the relative refractory period of both the initial positive potential of the surface lead (open triangles) and the P1 of CDP (closed triangles) with that of the N1 wave (circle), measured in four subjects. Ordinate: 100 X amplitude of test response/amplitude of conditioning response; abscissa: interval between two stimuli.
Evoked responses over spine

square-wave pulse of 0.5 msec duration at five times threshold of the initial spike potential of CDP, applied closely to the ulnar nerve at the wrist or elbow. The evoked responses were small and easily obscured by the electrocardiogram (EKG) artifacts, and as a result signal averaging was made at isoelectric intervals between T and P waves of the EKG in both skin-surface recordings and epidural recordings. The sampling rate was 5 to 20 points/msec and 100 to 300 responses were summed.

In the second series of observations, we recorded the response from the surface in 15 normal subjects aged 21 to 40 years in the wakeful state. Recording methods were the same as those in the first series, except for the epidural recordings, which were discarded.

Results

The segmental nerve stimulation invariably produced the initially positive spike (P1) followed by negative (N1)-positive (P2) waves, sometimes accompanied by the second component of the P2 in CDP recorded from the PES (Fig. 1). The cervical SER consisted of a predominately positive spike, the peak latency being the same as that of P1 of CDP (Fig. 1 left). Approximate conduction velocity was similar in all subjects (57.0 ± 0.2 m/sec, mean ± SE), calculated from the peak latency of the initial positive potential and distance between the sites of stimulation and recordings. This positive spike (duration 1.8 to 3.2 msec) was followed by a smaller negative wave with a longer duration (5.2 to 8.0 msec). The time courses of these positive and negative potentials were approximately the same as those of the P1 and N1 of CDP, respectively. The negative wave had two peaks, and latency of the second peak coincided with that of the N1 of CDP (Fig. 1, arrow). After this negative wave, a slow positive wave with a peak latency similar to that of the P2, could be demonstrated in four subjects (Figs. 1 and 2). To test whether the cervical SER involved an afferent volley conducted through the spinal cord, we applied the stimuli to the cauda equina at the L3-4 level, from the PES. The conductive cord potentials were recorded from the PES but not from the surface, even with strong stimulation. This indicates that the cervical SER reflects the segmental phenomenon rather than the conductive one through the cord.

The paired stimulation applied to the ulnar nerve revealed that the initial positive spike of the cervical SER as well as the P1 of CDP had a short refractory period, not exceeding 3 to 5 msec (Fig. 2). Thus, it might be concluded that the initial positive potential of the cervical SER is presynaptic in nature, and represents the incoming volleys conducted through the roots as the P1 of CDP. Although it was difficult to demonstrate clearly the refractoriness of the subsequent negative and slow positive waves due to their small size and variability, the configurations of these potentials were always noticeable, and their latencies remained consistent with those of the N1 and P2 of CDP (Fig. 2 upper). Therefore, these negative and slow positive waves might also share the same origins with the N1, interpreted to be the interneuronal activity, and P2 waves, believed to be caused by primary afferent depolarization respectively.

Although we observed a slight individual variation in the wave form of the cervical SER in the wakeful state, the fundamental pattern was the same in all subjects as that demonstrated during anesthesia. Both the initially positive spike and subsequent negative wave were recorded from all subjects, while the slow positive wave was recordable in 11 cases, and hardly demonstrated in four subjects who were relatively muscular.

Discussion

Matthews, et al. have recorded the cervical SER in normal subjects with the reference electrode at the midfrontal region and noticed a predominantly negative wave with three peaks, but did not characterize the origins of the wave. Preliminary experiments, however, showed that with a reference electrode at the ear lobe the evoked response was contaminated by the cortical activity, which made it difficult to analyze the origins of the response. We have recorded the cervical SER with the reference electrode placed in the suprasternal region where the cortical contamination was minimal, since a previous study has shown that the amplitude of the CDP is largest in the anteroposterior axis on the horizontal plane.

We could not elucidate the reason why the conducted potential was not recorded in all subjects tested from the cervical skin surface,
even by strong epidural stimulation of the cauda equina. Only a slow background shift was observed, the origin of which was not certain (Fig. 1). Both Cracco’s group\(^8,^{12}\) and Happel, \textit{et al.}\(^7,\) have demonstrated the small potential change along the spine, which they called a “conducted” potential along the spinal cord. Indeed, the “conducted” potential, which is definitely different from the segmental one, has been recorded directly from the cord\(^4,^{8,10}\) and in the remote PES\(^16,^{17}\) just as in the present study. However, with our methods, the “conducted” potential was not recorded from the skin surface.

Our most important findings, we believe, are that each component of the cervical SER evoked segmentally coincides with that in the CDP recorded epidurally, and that a conducted response along the spinal cord is hardly recordable from the skin surface. Thus, it might be feasible to make a specific diagnosis of spinal structures through observation of each component of the segmentally evoked potentials related to the P\(_1\) and N\(_1\) with the simple surface recording.

References