USE OF EVOKED POTENTIALS AS A WARNING OR AS AN ASSESSMENT OF DAMAGE TO THE SPINAL CORD

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SUMMARY

A technique for monitoring the neurological integrity of the spinal cord is being investigated as a possible clinical tool for warning of potential danger to the cord during spinal surgery and as a diagnostic tool for incomplete spinal cord injuries. Evoked potentials initiated by stimulation of peripheral nerves or direct stimulation of the cord are recorded from the spinal cord rostral to the injury site or the potential site of injury. Signals are recorded with electrodes placed in the epidural space and averaged during repetitive stimulation to improve the signal to noise ratio.

Animal experiments are currently being conducted to identify the specific contribution to the waveform of the evoked potential of impulses conducted along the dorsal and lateral tracts of the spinal cord. This information will be important in assessing the extent and location of damage to the cord. Spinal cord monitoring is also being done in the operating room during selected spinal surgeries to build up a bank of data on normal and injured spinal cords. Recent results of both of these studies are discussed.

INTRODUCTION

A rare but possible complication of spinal surgery is damage to the spinal cord. Studies have shown that neurological complications following surgical correction of scoliosis occurs in 0.7% of cases performed.[1] The risk is even greater in surgical cases to correct congenital deformities and kyphosis. In cases where neurological damage has occurred, it has been shown that removal of the instrumentation within three hours of the surgery often reverses the neurological changes. The potential benefits of an instrumentation system to measure the neurological function of the spinal cord intraoperatively seem clear.

For some time, the only available test to monitor cord function was the "wake-up" test popularized by Stagnara.[2] In this test, the patient is awakened during surgery by lightening the anesthesia until the patient responds to a command to move his upper or lower extremities. Corrective action can be taken if he is unable to do so.

An alternative technique, which has the advantage of monitoring spinal cord function throughout the surgical procedure, involves recording electrical activity within the central nervous system which is evoked by electrical stimulation of the spinal cord or peripheral nerves. In this approach, referred to as spinal cord monitoring, electrical stimuli causes impulses to be conducted up the ascending sensory tracts of the cord. These impulses can be recorded from the cord above the level of the surgical procedure (spinal evoked potentials or SEPs) or from the scalp (cortical evoked potentials). Changes in these evoked potentials may be an indication of damage to the cord.

Two methods of monitoring have been under investigation at Rancho Los Amigos Hospital during the past four years. In one method, a peripheral nerve is stimulated and the evoked potential is recorded from a metal pin placed into one of the spinous processes of the spinal column. This technique (referred to in the remainder of the paper as bone recording) has the advantage of being relatively noninvasive with little or no risk to the patient. The second method uses electrodes placed on small diameter, flexible tubing which is placed into the epidural space around the spinal cord. One epidural electrode is placed below the surgical site and is used to stimulate the spinal cord, while another epidural electrode is placed above the surgical site to record the resulting evoked potential. In this paper, this method will be referred to as epidural recording. Epidural recording was introduced by Imai in 1956,[3] and has been used extensively in Japan for the past ten years.[4] Bone recording has been used only for the last four years.[5]

In addition to its use to prevent spinal cord damage during surgery, spinal cord monitoring may also be valuable as a prognostic tool in cases of incomplete spinal cord injury. Early prognosis of spinal cord lesions is difficult because of spinal shock induced by trauma to the cord. Comparing the spinal evoked potential in these patients with those recorded from normals may provide an early indication of the extent of the lesion which could be useful in determining appropriate surgical and therapeutic treatment plans.

The objectives of this study can be summarized as follows:

1. To compare epidural and bone recording from the standpoint of the quality of the recorded signal and its sensitivity to factors such as stimulation waveform parameters, anesthesia and blood pressure.
2. To determine whether changes to the SEP are associated with damage to the spinal cord and whether the damage is reversible or permanent.
3. To identify various components of the SEP with specific ascending tracts of the spinal cord. (This information may be useful in using spinal cord monitoring as a prognostic tool).

METHODS AND PROCEDURE

The basic spinal cord monitoring system shown schematically in Figure 1 was employed for stimulation, signal acquisition, signal processing, storage, and display of the SEP. The stimulator supplied the stimulation electrodes with constant-current, capacity-coupled monophasic pulses of 50 or 200 μsec duration at an amplitude and rate that can be varied. At the recording site, an AC coupled preamplifier picked up the evoked potential from the recording electrodes. Both single-ended and differential recording was employed. In each case, a large reference electrode was placed lateral to the recording site. The bandwidth of the preamplifier and successive stages of amplification was generally 5 Hz to 3 KHz.

A trigger signal, initiated with each stimulus pulse, synchronized acquisition of the individual SEPs by an averaging computer (Nicolet 1170). Random noise in the frequency bandwidth of the SEP that could not be filtered out was removed through a digital averaging routine in the Nicolet 1170, in which a

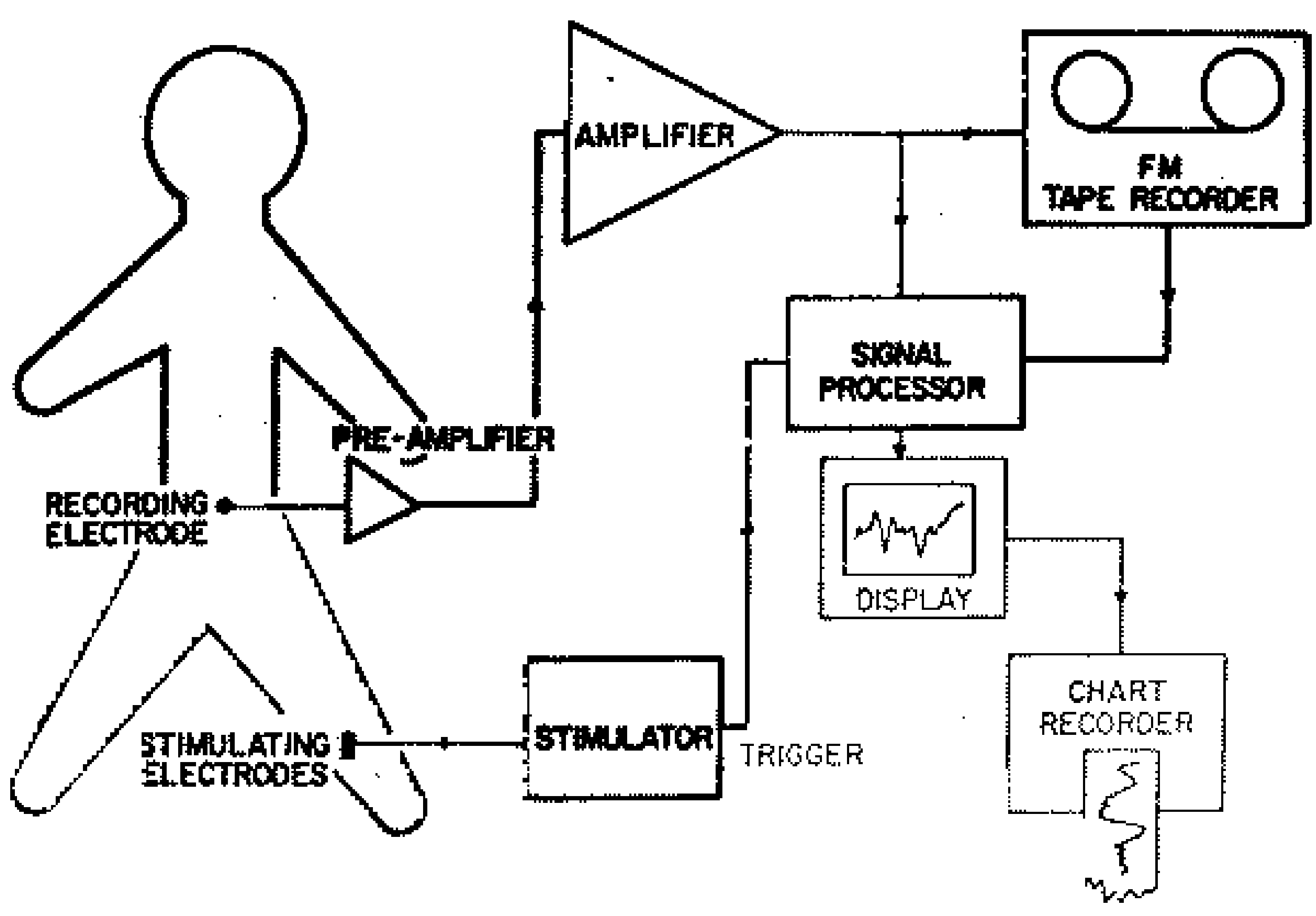


Figure 1: Schematic Diagram of Spinal Cord Monitoring System.

prescribed number of individual evoked potentials are summated to improve the signal to noise ratio. The resulting SEP was displayed and hard copied for visual examination and reading. In some cases, the individual SEPs and the synchronization pulses were stored on magnetic tape (Bell and Howell 7-track FM tape recorder, CPR 4010) for off-line signal analysis.

Studies on cats and humans have been done. Results of three sets of experiments on cats will be described in this paper. In the first experiment, the basic form and properties of the SEP recorded from bone and the epidural space are explored. Changes in the SEP resulting from distraction of the spinal cord are investigated in the second experiment. Finally, selective cutting of tracts of the spinal cord and the resulting changes in the SEP are determined in the third experiment. Clinical results of monitoring surgical patients using both bone and epidural recording are also presented.

RESULTS

Animal Studies

SEPs recorded from bone and the epidural space of cats are shown in Figure 2. In both cases, bipolar recording at T10/T11 was used. For bone recording, the sciatic nerve was stimulated with 200 μsec duration pulses at an amplitude of five times motor threshold. Pulse rate was 9 pps. For epidural recording, the spinal cord was stimulated with 50 μsec pulses at an amplitude of 15 times motor threshold. Pulse rate was also 9 pps. Fifty SEPs were averaged to obtain the records shown.

Both SEPs consist fundamentally of three positive (P1, P2, P3) and two negative (N1, N2) deflections. Each increases in latency and decreased in amplitude as the recording site is moved further up the spinal cord. The SEP obtained from bone increased rapidly in amplitude as stimulus amplitude was increased from one to two times threshold and showed no further increase beyond six times threshold. In epidural recording, the amplitude of the SEP increased up to fifteen times threshold, and plateaued between 15 and 20 times threshold. Stimulus frequencies up to 50 pps did not significantly alter the components of the epidural SEP, whereas the later components of the bone SEP decreased in amplitude at pulse rates above 10 pps.

In the distraction studies, the SEP was recorded from the spinous process of T9 to observe changes in the signal due to spinal distraction at the L1/L2 level. The sciatic nerve was stimulated, and the parameters (10 pps and 6 times SEP threshold) established in the first part of the study were used. In all six cats, the T9 recording obtained with no distraction (1 mm between the laminae of L1/L2) was kept as reference throughout the distraction study. In general, the amplitude of the P1, N1, P2, N2 components decreased with increased cord distraction. A sudden fall-off in SEP amplitude and

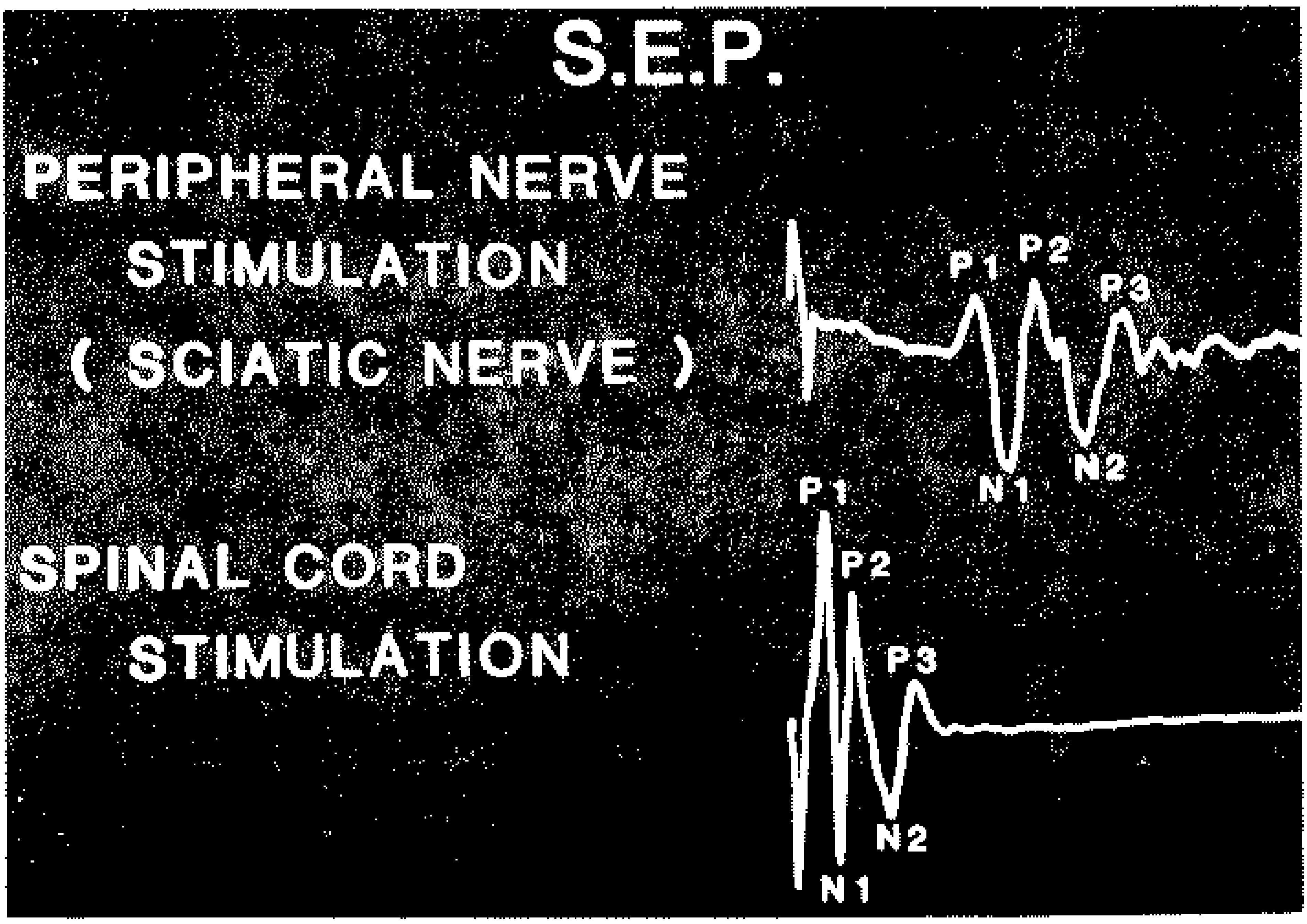


Figure 2: SEP recorded in a cat during stimulation of the sciatic nerve and the spinal cord.

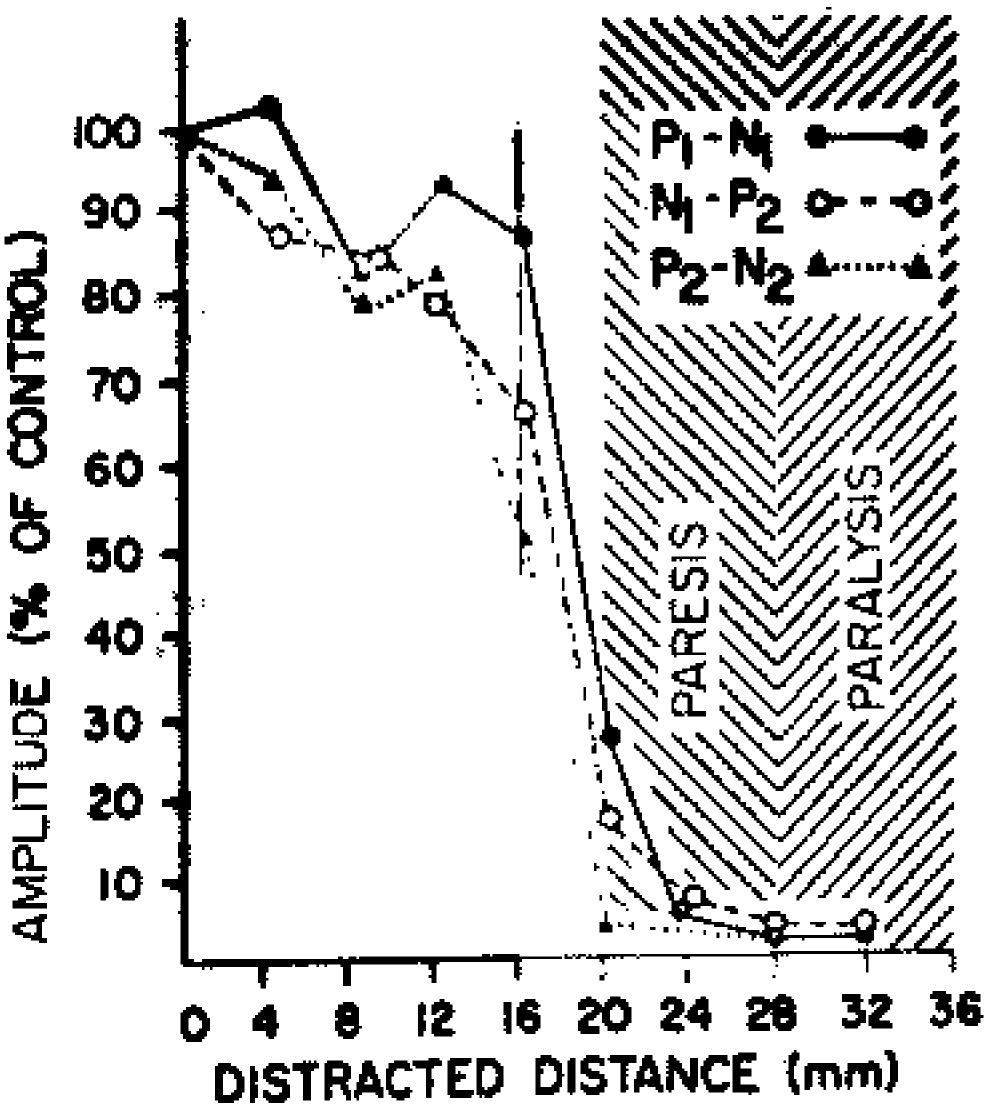


Figure 3: Spinal evoked potential components (as percentage of the predistraction control values) are plotted as a function of distracted cord distance. Abnormal cord function is indicated by the vertical bars.

corresponding neurologic deficit as detected by the wake-up test occurred at 16 mm of distraction in three cats and at 20 mm in the other three. Beyond 20 mm of distraction, all SEP components were obliterated. The amplitudes of the P1-N1, N1-P2, P2-N2 peaks are plotted in Figure 3 as a function of distracted distance. On the average, P1-N1 had decreased to 87% of non-distracted value, N1-P2 to 66%, and P2-N2 to 50% at a distracted distance of 16 mm. At 20 mm of distraction, the amplitudes had fallen to 26%, 17%, and 4% respectively, and the wake-up test indicated paralysis. Even with motor paralysis and disappearance of skin sensation at 20 mm of distraction, deep pain sensation seemed to remain up to 32 mm of distraction in two of the animals.

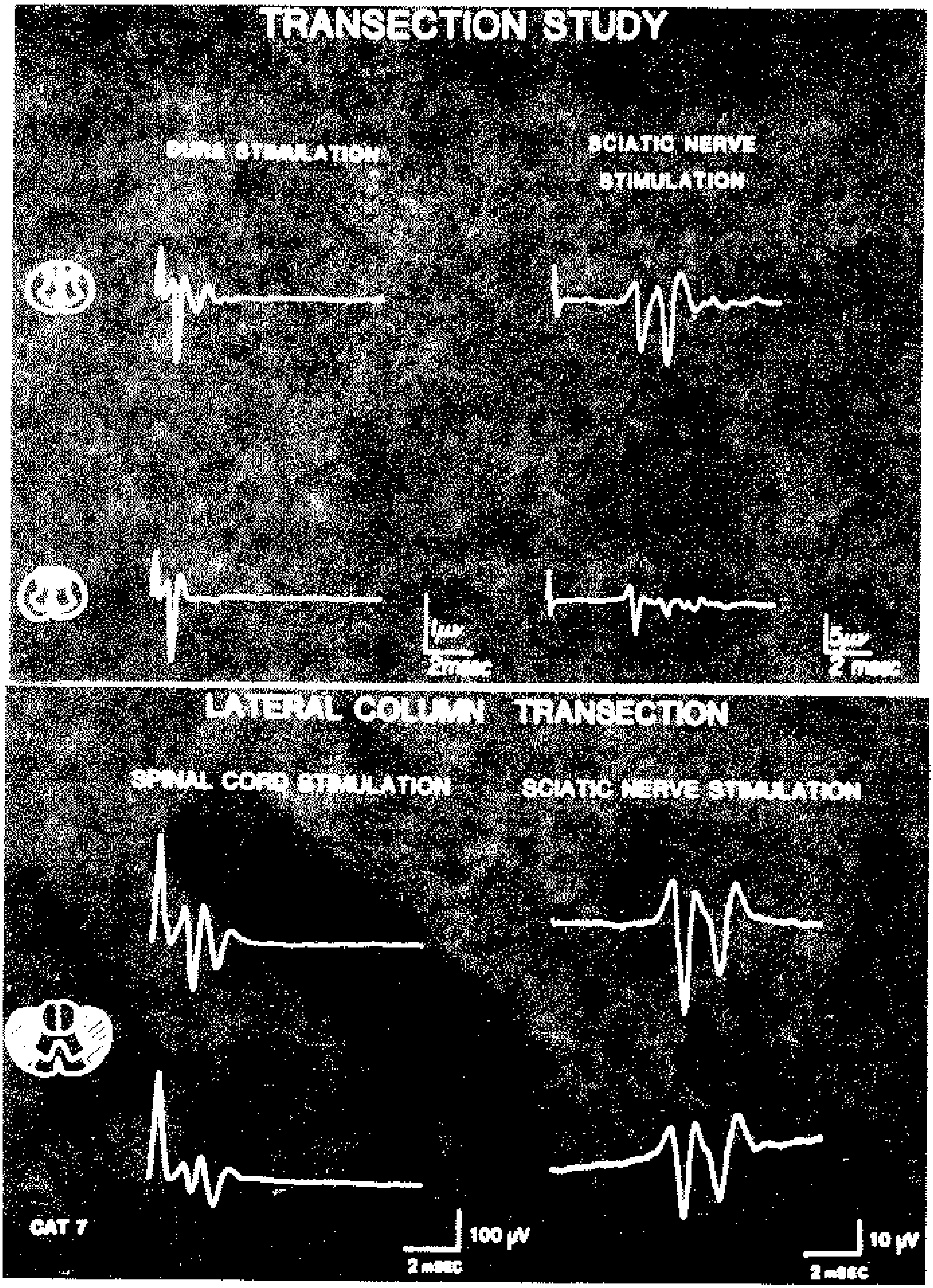
The effect of elapsed time on SEP cord function recovery during release from 20, 24, 28 and 32 mm of distraction was observed over a period of 30 minutes. After release of the 20 mm distraction, the P1-N1 amplitude recovered to 40% of the control value and the injury changed from complete to incomplete. Release of the 24 mm distraction showed the same recovery trend in time, but after 28 and 32 mm of distraction there was no recovery in either SEP or neurologic function upon release.

Transection of the posterior column of the spinal cord produced changes mainly in the late components of SEPs recorded from bone and the epidural space (Figure 4a). When the sciatic nerve is stimulated, the later components disappeared almost entirely and the earlier component also decreased. With stimulation of the spinal cord, the later component N2 disappeared almost completely with only slight amplitude reduction in the earlier component N1. Upon lateral column transection, the SEP evoked by stimulation of the sciatic nerve showed a small decrease in the early component while the spinal cord SEP showed a 60% decrease of N1 with small changes in N2 (Figure 4b). With both posterior and lateral columns transected a small deflection was seen in both SEPs. These deflections were absent upon complete transection.

Human Monitoring

From May 1979 to August 1980, bone recording was used to monitor 47 spinal surgery cases. The results are summarized below:

1. There are well-defined areas in the thoraco-lumbar region where SEPs can be recorded. The percentage of acceptable signals (noise-free and consistent) is better than 80% from the T12-T9 and L5-L4 regions, but has been less than 20% in the T8-T2 and L3-L1 regions. Both the peroneal and tibial nerves were stimulated with similar results.



(a)

(b)

Figure 4: Effect on the SEP of selective cutting of the dorsal column only (a) and transverse columns only (b).

2. In the T1-C2 region (ulnar or median nerve stimulated) the percentage of acceptable signals is 65%. This percentage is lower than it should be because of early failures when the technique was initially tried.
3. Monitoring during anterior surgical approaches has been unsuccessful.

As of April 1981, only three patients have been monitored at Rancho with epidural electrodes. An evoked potential obtained from one patient undergoing correction of an 80 degree scoliotic curve is shown in Figure 5. This recording was made by stimulating the spinal cord at 8 ma through one epidural electrode placed at L1/L2 and recording with another bipolar electrode placed in the epidural space at C6/C7. Evoked potentials acquired with epidural electrodes are relatively noise-free and remarkably stable. Only 32 averages were required to obtain the signal shown with an acquisition time of less than two seconds. Twenty-four recordings were made over a period of two hours prior to distraction. The standard deviation of the primary peak-to-peak amplitudes P1-N1, N1-P2 and P2-N2 were 5%, 4%, and 8% respectively. Latencies were even more consistent with standard deviations of 3% or less. After distraction, there was a slight decrease in the mean values of the primary

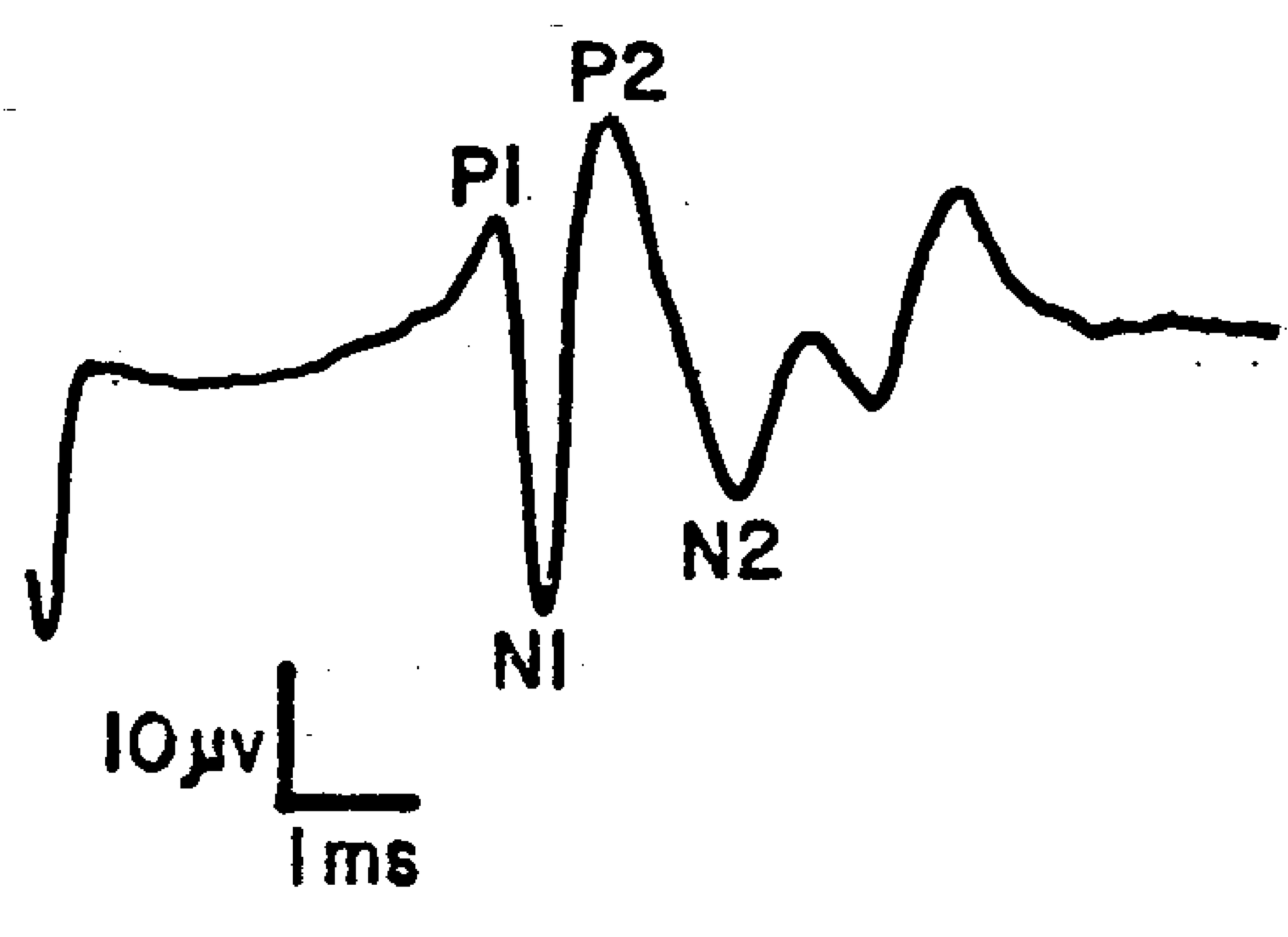


Figure 5: SEP recorded with epidural electrodes in patient undergoing spinal surgery. Stimulating electrode at L1/L2, recording electrode at C6/C7.

peak-to-peak amplitudes (-11%, -15% and -18%), perhaps due to slight shifts in the position of the stimulating and recording electrodes relative to the cord. There was, however no significant change in the latencies. The patient recovered from surgery with no complications.

CONCLUSION

The feasibility of using spinal cord monitoring as an early warning of potential damage to the spinal cord has been demonstrated. The SEP has been shown to be stable for as long as two hours and is sensitive to cord trauma. changes in amplitude and latency of peak components of the SEP are an indication of forces acting on the cord or its vascular supply which can result in permanent damage if corrective action is not taken to remove the forces. At this time, the poor quality of bone recordings obtained from the high thoracic region in humans precludes the use of this method as a practical instrumentation technique. Epidural recording, however, is very promising. Little can yet be said about the potential of spinal cord monitoring as an aid to prognosis of incomplete spinal cord injuries, but the studies of selective cutting of tracts of the spinal cord indicate that it may be feasible.

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