Double train stimulation of thoracic pedicle screw, nerve root and spinal cord

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ABSTRACT

Objective
Neuromonitoring with pedicle screw stimulation (PSS) is used during scoliosis surgery to prevent the pedicle screw encroaching upon spinal nerve roots and spinal cord. EMG responses from truncal and lower limb muscles were compared after direct stimulation of thoracic nerve roots and spinal cord and after PSS in a single patient study. Double train stimulus paradigm was used combining single and train stimuli in the same recording epoch.
Methods
Following placement of pedicle screw at 7th thoracic segment, PSS was performed, using double train stimulus consisting of single and train pulse with 50 ms interstimulus interval, stimulus intensity increasing from 0 to 20 mA in 1 mA steps, and EMG recorded in intercostal and abdominal (i.e. truncal) muscles, and in lower limb muscles. Laminotomy was performed exposing 6th and 7th thoracic nerve roots and the spinal cord, enabling direct stimulation with the same parameters.
Results
Direct stimulation of Th 6 and Th 7 spinal nerve roots triggered EMG responses in truncal muscles only, after single and train stimulus, up to stimulus intensity of 20 mA, and with the 1 mA threshold. Direct stimulation of spinal cord triggered EMG responses in both truncal and in lower limb muscles with thresholds 3 mA and 11 mA, respectively, in truncal muscles after single and train stimuli, and in lower limb muscles after train stimuli only. In PSS the pattern of muscle activation was the same as in direct stimulation of the spinal cord, and at 4 mA threshold for truncal muscles and 8 mA for lower limb muscles.
Conclusion
Recordings suggest that in thoracic PSS isolated truncal muscle responses reflect the stimulation of nerve roots, whereas combination of truncal and lower limb muscle responses imply stimulation of the spinal cord, with nerve roots possibly stimulated through the spread of current. A double train stimulus paradigm aids in differentiation between segmental nerve root and spinal cord stimulation in PSS.

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INTRODUCTION

Intraoperative neuromonitoring techniques have been developed for monitoring placement of pedicle screws. Pedicle screw stimulation (PSS) helps to check on the possible proximity of pedicle screws to spinal neural structures. When the screw is placed in the pedicle it is enclosed in high resistance bone, acting like an insulation, which makes stimulation of spinal nerve roots and spinal cord only possible with high intensity electrical currents. But when the screw is placed out of the pedicle, it is in low resistance soft tissues, and possibly close to nerve roots and spinal cord which could thus be stimulated with electrical currents of low intensity.

Stimulation of either nerve roots or spinal cord triggers EMG responses. In case of thoracic spine EMG responses may come from stimulation of either nerve roots or spinal cord. When nerve roots are activated EMG response will be in intercostal or abdominal (i.e., truncal) muscles. But when spinal cord is stimulated EMG responses are evoked in lower limbs. Whereas single stimuli activate nerve root axons, train stimuli are needed to activate lower motor neurons via corticospinal axons, similar to transcranial MEPs.

METHODS AND MATERIALS

45-year-old female patient was operated for thoracic scoliosis. Neuromonitoring was performed using EMG, pedicle screw testing, median and tibial nerve SSEP, transcranial MEP, and H-reflex.

EMG recording were performed from intercostal and abdominal (i.e., truncal) muscles, quadriceps and tibial anterior (i.e., lower limb) muscles. PSS was performed through the ball tipped probe as cathode, with monopolar needle electrode over the spinous process cranially to the surgical opening acting as anode. Stimulus was rectangular, 0.2 ms duration, with the maximum 20 mA. A double train stimulation paradigm was used, consisting of single and train stimulus, with the 50 ms interval. The train consisted of 4 stimuli with 3 ms interstimulus interval. Double trains were delivered in repetitive fashion with 2 Hz stimulation frequency, increasing intensity in a stepwise manner in 0.1 mA step till maximum intensity.

Placement of pedicle screws was guided with jigs and during drilling of the Th7 right pedicle a CSF leakage was noted. A guiding jig was checked, and drilling direction was changed. Pedicle screw was placed (Figure 1) and tested with PSS. After that, a laminotomy was performed to facilitate correction of scoliosis, exposing Th7 and Th6 nerve roots and spinal cord between them. Then both exposed spinal nerve roots and spinal cord were stimulated directly, using the same stimulation protocol as in PSS.

RESULTS

Direct stimulation of either Th7 or Th6 nerve roots with stimulus intensities of up to 20 mA produced EMG responses only in intercostal and abdominal muscles and not in lower limb muscles. Threshold was 1 mA. EMG responses to direct stimulation of Th7 and Th6 roots are shown in upper two series of waveforms in Figure 1.

Direct stimulation of spinal cord in between Th6 and Th7 roots triggered EMG responses in truncal muscles and in lower limb muscles, in former after single and train stimulus, and in latter only after train stimulus. Truncal muscle response threshold was 4 mA and lower limb muscle response threshold was 10 mA. EMG responses to direct stimulation of spinal cord between Th7 and Th6 roots are shown in lower series of waveforms in Figure 1.

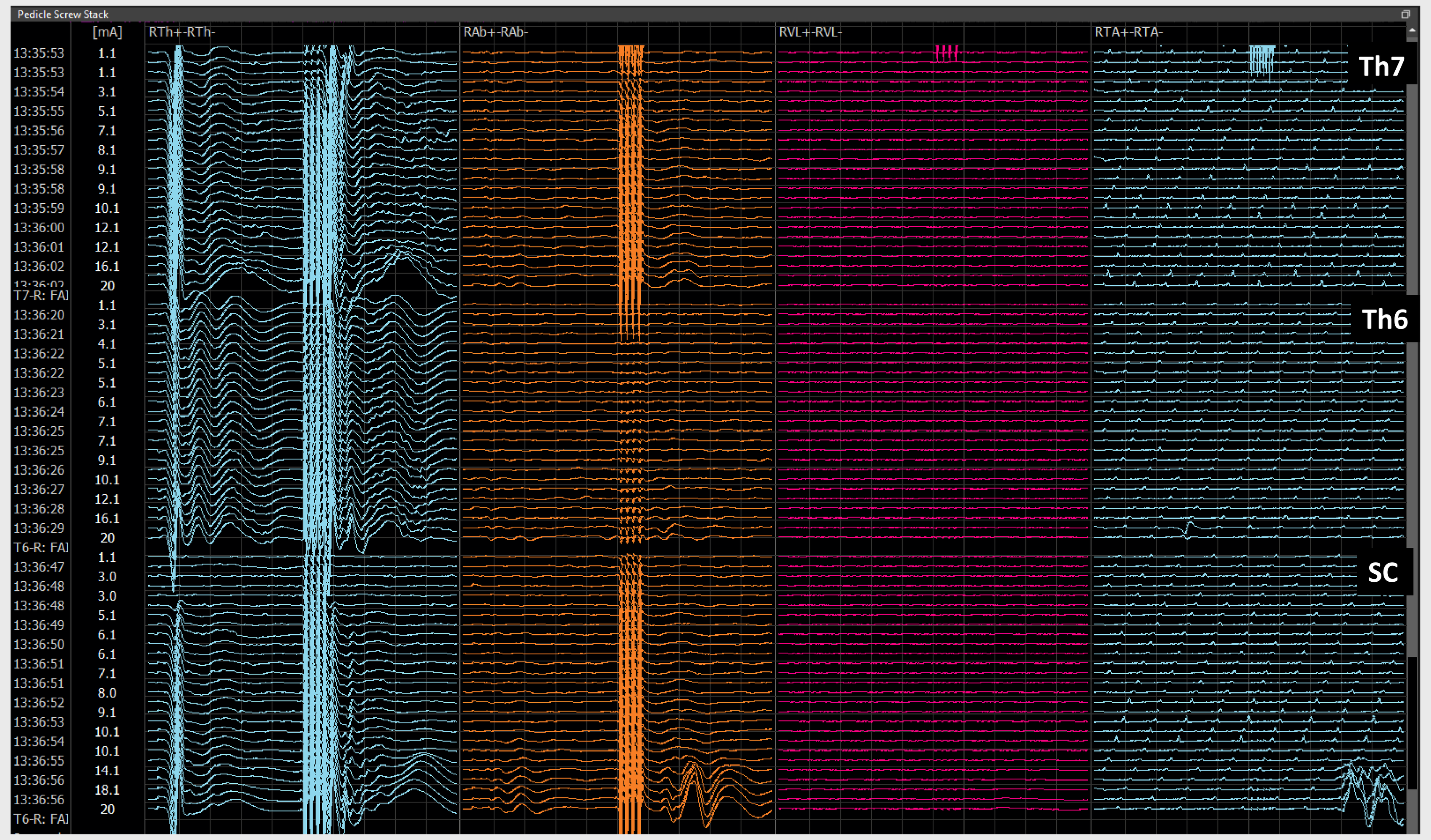

Figure 1. EMG responses to direct stimulation of Th7 and Th6 (upper two series of waveforms) and to direct stimulation of spinal cord in between the roots (lower series of waveforms). Truncal muscles threshold was 1 mA to stimulation of nerve roots and 4 mA to stimulation of spinal cord. Lower limb muscles were activated only after train stimulus and threshold was 10 mA.

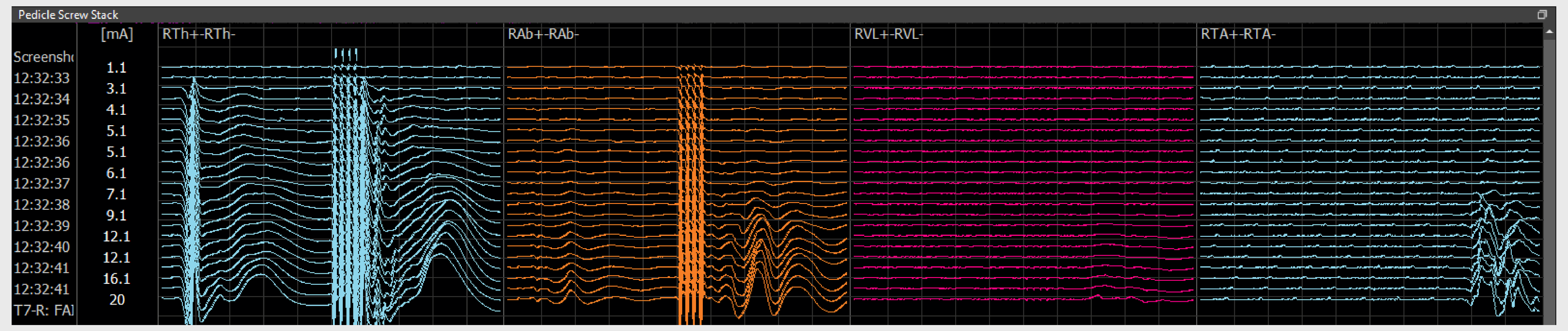

Figure 2. EMG responses to PSS. Pattern of muscle responses is similar to direct stimulation of spinal cord (Figure 1) with truncal muscle threshold 3 mA and lower limb muscles threshold 7 mA.

RESULTS

PSS at Th7 triggered EMG responses in truncal muscles and in lower limb muscles, in former after single and train stimulus, and in latter only after train stimulus. The pattern of recorded EMG responses was the same as in direct stimulation of spinal cord. Truncal muscle response threshold was 3 mA, and lower limb muscle response threshold was 7 mA. EMG responses to PSS are shown in Figure 2.

Postoperative CT scan showed that the right side Th7 pedicle screw was deviated medially and encroached upon the spinal canal.

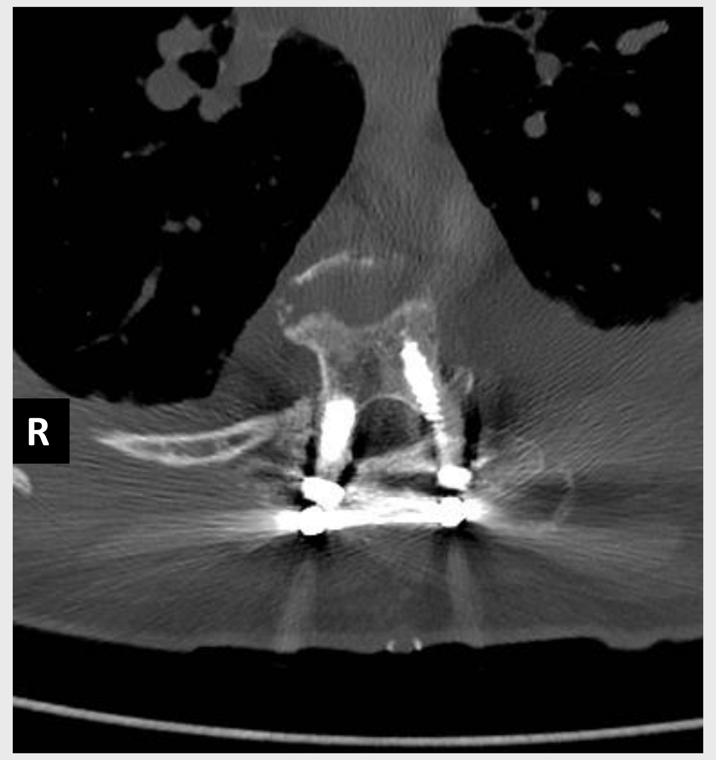

Figure 3. CT scan shows that the right-side screw at Th7 was deviated medially and encroached upon the spinal canal.

DISCUSSION

Combination of single and train stimulus in the double train stimulation paradigm helps in recognition of nerve root and spinal cord effects of pedicular electrical stimulation, either through pedicle screw as in PSS or through the instruments used in placement of the pedicle screw (e.g., awl, tap, ball tipped probe). Double train stimulation produces easily (graphically) recognizable pattern of muscle recordings with responses to both single and train stimulus in intercostals and abdominals and responses to train stimulus only in lower limb muscles (Figures 1 and 2). It also saves operating time as the measurements are performed in single recording epoch rather than separately for nerve roots (single stimulus) and spinal cord (train stimulus).

It seems from our recordings that in nerve root stimulation electrical currents don't spread to spinal cord, whereas in case of spinal cord stimulation the currents tend to spread to nerve roots, giving the impression of simultaneous stimulation of both nerve roots and spinal cord (although the primary point of stimulation is spinal cord). Early appearance of EMG response in truncal muscles might stop the procedure of stimulating before appearance of lower limb responses and give the wrong impression of pedicle screw breaching inferior pedicular wall or encroaching on neural foramen, when in fact it is breaching the medial pedicular wall and thus encroaching upon the spinal canal.

Crucial to identification of possible breach of pedicle wall, however, is to establish normative criteria.

CONCLUSIONS

Double train paradigm with single and train stimuli aids in usefulness of PSS in thoracic spine. It seems that when stimulating the spinal cord there is a substantial leakage of current to the nerve root which may mislead the neurophysiologist to erroneous conclusion as to what is the primary point of stimulation. PSS deserves further studies on correlation between position of the screw, stimulation threshold, and pattern of EMG responses in truncal and lower limb muscles.

REFERENCES

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