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SSEP analysis in surgery of idiopathic scoliosis: the influence of spine deformity and surgical approach

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Abstract The study was conducted to assess the possible impact of spine deformity in patients with idiopathic scoliosis (IS) on tibial nerve somatosensory evoked potentials (t-SSEPs) and the influence of spine correction upon postoperative SSEP recordings. In 61 consecutive patients undergoing 64 spinal instrumentations, 129 pre- and postoperative SSEPs were analyzed. The degree of spine deformity was assessed by the pre-operative Cobb angle of the major scoliotic curve. In a control group, reference values of t-SSEP latencies were established with respect to body height. In a cohort study, IS patients were compared with healthy controls with respect to t-SSEP latency, amplitude, configuration and interside difference. The results of the analysis showed that preoperative-body-height-corrected t-SSEP latencies were prolonged in 61% of patients, with a pathological interside difference in 23.4% of them. The impairment of t-SSEPs was not related to the extent of spine deformity as assessed by the

Cobb angle. Even without occurrence of postoperative neurological deficits, postoperative t-SSEPs showed significantly increased latencies without changes in t-SSEP configuration. The prolongation of t-SSEP latencies was related to the surgical procedure (combined ventro-dorsal approach), but not to the extent of spine correction, level of instrumentation, or number of fused segments. The analysis of preoperative t-SSEPs was of no predictive value for intra- or postoperative neurological complications. t-SSEPs are significantly affected in IS patients, although these patients show no obvious clinical neurological deficits. The extent of t-SSEP impairment is not related to the severity of scoliosis. Even in clinically uneventful surgery, the postoperative t-SSEPs can be deteriorated depending on the surgical approach. This indicates a subclinical impact of spine surgery upon spinal cord function.

Keywords Tibial SSEP · Idiopathic scoliosis · Spine surgery

Introduction

Recordings of somatosensory evoked potentials (SSEPs) have shown to be of diagnostic value in traumatic and non-traumatic disorders of the spinal cord. Therefore, impaired spinal cord function due to diseases of the spinal cord itself (myelitis, tumor) or of the vertebral column with impairment of spinal cord function (fracture, cervical

myelopathy) can be assessed by tibial SSEP analysis [6, 7].

SSEP recordings can also be performed as an intra-operative electrophysiological monitoring of spinal cord function, to assess the integrity and function of the monitored spinal fiber tracts during operations of the spine and spinal cord [8, 9, 12, 16, 17]. The effectiveness of these recordings in reducing the incidence of postoperative neurological deficits has been shown in several studies [13, 14].

Idiopathic scoliosis (IS) patients are defined as those presenting a lateral curvature of the spine without any neurological history or signs [20]. In contrast, patients suffering from symptomatic scoliosis, especially degenerative scoliosis, usually present neurological deficits or impairment of spinal cord function [20]. In these patients, the results of SSEP assessment are believed to indicate the degree of impairment of those spinal tract fibers tested [15]. How far and due to what pathophysiological mechanism tibial SSEPs in IS patients are pathologically altered remain matters of discussion. There is also no consensus over whether, the changes in SSEPs are related to the extent of spinal deformity, and if so, to what extent [1, 3, 4, 18, 21]. Finally, the need for routinely performed preoperative SSEPs in IS has not been established and the influence of spine surgery upon SSEPs and reproducibility of postoperative SSEP recordings have yet not been evaluated.

The aim of this study is, firstly, to evaluate alterations of tibial SSEPs in patients with IS, paying specific attention to the extent of spine deformity; secondly, to study the influence of spine surgery upon postoperative SSEPs; and thirdly, to assess the predictive value of SSEPs for postoperative neurological complications.

Materials and methods

Patients

Pre- and postoperative SSEP recordings of 61 consecutive patients with IS who underwent 64 spinal instrumentations between 1996 and 1999 were prospectively analyzed. Fifty-two female and nine male patients (mean height $161\text{ cm} \pm 10.9\text{ cm}$ SD) were included, and 129 tibial nerve SSEPs (t-SSEPs) were evaluated. IS patients were mainly juvenile and adolescent (mean age $20.4\text{ years} \pm 15.6\text{ years}$ SD) with no history or evidence of a neurological deficit on full neurological examination.

The present study was approved by the local Ethical Committee.

Radiological work-up

All patients underwent a preoperative radiological work-up with X-ray and magnetic resonance imaging (MRI) of the whole spine to rule out any intraspinal lesions. In none of the patients was an intraspinal or intramedullary lesion other than the spinal deformity detected.

SSEP recordings

Preoperative electrophysiological evaluation was performed 1–3 days preoperatively. The postoperative control examination was performed during the same hospitalization, 7–10 days after the surgery, before discharge. Tibial SSEPs were elicited by electrical stimulation using a conventional EMG machine (Dantec Keypoint; software 2.0), using surface electrodes (proximally placed cathodes, the anode placed 2 cm distally) at the ankle. The tibial nerves were stimulated with a square-wave stimulation for 0.2 ms at a frequency of 3 Hz. The stimulus intensity (up to a maximum of 40 mA) was adjusted to produce a clear muscle contraction. For recording, scalp electrodes were applied at Cz' and Fz, using the international 10/20 electrode system. The electrode impedance was maintained at below 5 kOhm. The amplifier was set at 5 μV per division, and the frequency bandpass was set at 50–2000 Hz. Two sets of 500 replications were averaged to improve the signal-to-noise ratio for latency and amplitude measurements. All measurements were carried out at ambient temperature.

For calculation of SSEP recording, latencies (onset, P1, N1, P2, and N2), as well as interpeak latencies (onset to P1, P1 to N1, N1 to P2, and P2 to N2), were determined. The size of amplitudes was calculated by baseline to peak P1 and peak to peak for the remaining markers. Figure 1 shows the position of the markers.

Additionally, pre- and postoperative SSEP configuration was visually categorized as normal or abnormal. A waveform was considered normal when it resembled a double-peak 'w-form' with a clear onset (Fig. 1). The SSEP was regarded as abnormal when the w-form was lost and the shape of the evoked potential was only bi- or monophasic.

To avoid any possible bias in the analysis of recordings that could arise from "looking for" specific results, and to reduce inter-rater variability, all markers were set by a single person, who was blinded to the patients history, operative procedures, and statistical analysis.

Fig. 1A-D Pre- and postoperative tibial somatosensory evoked potentials (t-SSEPs).

A,B A representative example of a normal t-SSEP of the left leg with a typical w-waveform with no difference between the pre- and postoperative study. Each set represents 500 replications of a recorded t-SSEP of the left leg. **C,D** A representative example of a t-SSEP with a left-right interside difference that did not change from the pre- to the postoperative study. Each set represents 500 replications of a recorded t-SSEP

Control data

Twenty healthy adults (11 men and 9 women) with a mean age of 31.0 ± 7.5 years (range: 17.4–52.2 years) were examined as controls and for calculation of the influence of body height upon SSEP recordings. Their mean height was 174.9 ± 11.6 cm (range: 156–192 cm). Stimulation and recording techniques were the same as described above.

Statistics

Statistical evaluations were performed using the SAS software package. For all statistical tests and correlations, $P < 0.01$ was considered as significant, and only natural values of electrophysiological recordings were calculated. For statistical evaluation, repeated measurements of the analysis of variance was used to compare pre- to postoperative data. Student's *t*-test was used to calculate differences between SSEPs that were regarded by the clinician as normal or pathological. Paired *t*-tests were used to calculate significances of interside differences. Qualitative variables were analyzed using the Chi-square and Fisher's exact test.

Results

Healthy subjects

Tibial SSEP latencies

Absolute t-SSEP latencies in healthy subjects showed a marked variance due to the wide range of body height. The range of t-SSEP latencies stretched about 10 ms (for example the t-SSEP onset ranged from 30.0 ms to 40.0 ms). The means and standard deviations of latencies are presented in Table 1. The t-SSEP latencies of onset, P1 and N1 showed a significant correlation ($P < 0.001$) to body height (Spearman correlation coefficient: onset $r = 0.889$; P1 latency

$r = 0.924$; N1 $r = 0.843$). Therefore, to allow a comparison of t-SSEP latencies of subjects with different body height, the formula $y = 0.199x + 3.9037$ was applied to achieve body-height corrected values. Latencies within $\pm 2SD$ were accepted as normal. In contrast to SSEP latencies, there was no correlation between interpeak latencies and body height.

Tibial SSEP amplitudes

Amplitudes in the healthy subjects were highly variable. The mean, SD, and range values of the amplitudes are presented in Table 1. No correlation between amplitude and body height was found.

Interside differences of latencies and amplitudes

Statistical analysis of the t-SSEP recordings revealed left-to-right differences for latencies of all peaks, though they measured less than 2 ms for the first three t-SSEP markers (onset: 0.63 ± 0.76 ms; P1 latency: 0.82 ± 0.58 ms; N1 latency: 1.50 ± 1.13 ms; Table 1). Therefore, interside differences of t-SSEPs were regarded as normal when the P1 latency was less than 2 ms (= differences within $\pm 2SD$) and the t-SSEP had a clearly expressed w-form. Due to the high variability of amplitudes, no significant interside difference of amplitudes were found in normal subjects.

Tibial SSEP configuration

All 20 volunteers, with a total of 40 tibial t-SSEP recordings, had normal bilateral w-waveform shaped evoked po-

Table 1 Tibial somatosensory evoked potential (t-SSEP) latencies, interpeak latencies, and amplitudes of healthy subjects ($n=20$) for calculation of control data (in milliseconds)

	Right tibial nerve		Left tibial nerve		Side difference	
	Mean $\pm$ 1SD	Range	Mean $\pm$ 1SD	Range	Mean $\pm$ 1SD	Range
Peak latencies						
Onset	33.91 ± 2.69	30.8–40.0	33.85 ± 2.73	30.4–39.8	0.63 ± 0.76	0.0–3.2
P1	38.38 ± 2.52	34.0–42.6	39.04 ± 2.43	34.5–43.0	0.82 ± 0.58	0.0–2.0
N1	46.65 ± 3.21	41.0–51.6	47.68 ± 3.18	41.2–55.0	1.50 ± 1.13	0.0–4.0
P2	57.22 ± 3.13	52.2–62.8	58.41 ± 3.13	53.8–64.2	1.87 ± 1.03	0.2–3.4
N2	69.69 ± 4.25	62.6–76.8	72.23 ± 3.53	66.4–77.8	3.36 ± 3.36	0.0–12.0
Interpeak latencies						
Onset–P1	4.47 ± 1.14	2.6–6.6	5.19 ± 1.05	2.8–6.8	0.87 ± 0.66	0.2–2.8
P1–N1	8.27 ± 1.31	5.6–11.0	8.64 ± 1.04	6.6–12.4	1.00 ± 0.86	0.2–4.0
N1–P2	10.57 ± 2.01	5.6–16.6	10.73 ± 1.98	7.4–14.2	1.37 ± 0.97	0.0–3.0
P2–N2	12.47 ± 3.18	7.8–20.2	13.96 ± 3.06	9.8–19.4	2.47 ± 2.77	0.0–12.0
Peak to peak amplitudes						
Onset–P1	1.61 ± 1.12	0.15–4.08	1.77 ± 0.93	0.29–3.67	0.65 ± 0.86	0.02–3.81
P1–N1	3.30 ± 1.99	0.24–7.55	3.39 ± 1.85	0.68–6.94	0.93 ± 1.17	0.06–4.60
N1–P2	2.64 ± 1.70	0.04–6.14	2.90 ± 1.78	0.29–7.66	0.63 ± 0.37	0.08–1.43
P2–N2	2.60 ± 1.50	0.28–5.90	3.24 ± 1.70	0.81–7.55	1.05 ± 0.87	0.03–3.03

Fig. 2 P1 latencies in patients with idiopathic scoliosis plotted against body height and overlaid on the range of values in healthy subjects (with 2SD above and below the positive correlation of body height). The dotted P1 line represents a standard normative value of 43.5 ms for the P1 latency, without taking into account body height

tentials. In all t-SSEPs, the markers of onset, P1, N1, P2, and N2 were clearly identifiable (Fig. 1).

differences of P1 latency were found in 23.4% of IS patients.

Patients

Preoperative t-SSEP latencies and amplitudes

In 61% of IS patients, preoperative t-SSEP latencies with correction for body height were prolonged. Although all t-SSEP markers were calculated, in the following sections only P1 values are listed. Figure 2 represents the distribution among IS patients of P1 latencies within and outside the normal limits (mean $\pm$ 2SD) corrected for body height. If t-SSEP latencies had been analyzed without correction for body height, the upper limit for normal P1 latency (mean + 2SD = 38.4 ms + 2.52 ms) would have been 43.5 ms, and only 21.9% of t-SSEP latencies would therefore have been defined as pathological. For determination of the body-height-corrected latency, the preoperative body height was used. Taking into account that the stretched spinal column will increase the body height by 3–5 cm, this would not be enough to have influenced the percentage of prolonged t-SSEP latencies (Fig. 2) in IS patients. On the basis of these values, analysis of the t-SSEP amplitudes revealed no significant differences between IS patients and healthy subjects ($P > 0.05$, data not shown).

Preoperative interside differences

Mean preoperative interside differences in IS patients were significantly ($P < 0.01$) increased (1.58 ± 1.28 ms) as compared to controls (0.82 ± 0.58 ms). Pathological interside

Influence of spine deformity

To assess the influence of the degree of scoliosis on the t-SSEP latency, the preoperative Cobb angle of the major scoliotic curve was correlated with the onset and P1 latencies. Mean Cobb angle in IS was $57.8^\circ \pm 12.6^\circ$ (range 33° – 85°). There was no significant correlation ($P > 0.05$) between the absolute onset and P1 latency, the extent of the Cobb angle, and body height (Spearman correlation coefficient: $r = 0.2364$). Therefore, statistical analysis failed to show a correlation between the increase in t-SSEP latency (absolute and corrected) and the severity of spinal deformity. Similarly, t-SSEP amplitude was not correlated to severity of spinal deformity. There was no correlation between interside difference and Cobb angle ($P > 0.05$).

Pre- to postoperative t-SSEP

Differences between pre- and postoperative peak and interpeak latencies and amplitudes were compared, in order to evaluate the influence of spine surgery upon the reproducibility of t-SSEPs. Although postoperative latencies of onset, P1, and N1 were significantly increased (onset +1.31 ms, $P < 0.001$; P1 +1.12 ms, $P < 0.001$; N1 +1.75 ms, $P < 0.001$), there was a high postoperative reproducibility of t-SSEPs in patients with an unchanged postoperative neurological condition.

Postoperative amplitudes were smaller compared with the preoperative values; however, only the reduc-

Table 2 Summary of surgical approach, level, and extension of 64 spinal instrumentations in idiopathic scoliosis patients. Surgeries with extension from thoracal/lumbar region to the sacrum are summarized as 'up to sacrum'

Approach (N=64)	
Dorsal	n=42
Ventral	n=20
Combined	n=12
Level of surgery (N=64)	
Thoracal	n=20
Thoracolumbar	n=35
Lumbar	n=5
Up to sacrum	n=4
No. of fused segments	
Mean value	7.2 segments

tion of the onset-P1 amplitude was significant (-0.6 V, $P<0.0001$).

Tibial SSEP configuration

Fifty-seven of 61 patients showed a normal bilateral w-waveform pre- and postoperatively. In two patients, a preoperative biphasic t-SSEP changed postoperatively to a normal waveform. In one patient the preoperative monophasic t-SSEP configuration remained postoperatively unchanged. Only in one patient did the configuration deteriorate postoperatively, from normal to a monophasic-shaped t-SSEP. However, none of the postoperatively changed t-SSEP configurations was associated with postoperative neurological deficits.

Influence of operative techniques

To evaluate the impact of surgery upon t-SSEPs, the surgical approach (ventral, dorsal, or combined ventro-dorsal), level of spinal instrumentation, and number of fused segments were related to any t-SSEP changes after surgery (Table 2). Analysis of variance showed a significant difference ($P<0.0195$) with respect to the influence of the surgical approach upon postoperative P1 latency. With the combined ventro-dorsal approach, the mean P1 latency increased by 1.38 ms as compared to 0.28 ms with a dorsal approach. There was no significant correlation between the number of fused segments, the level of spinal instrumentation, and postoperative t-SSEP changes.

Predictive value of tibial SSEPs

Patients with preoperative severely affected t-SSEPs showed no increased probability of neurological complication compared with patients with normal t-SSEPs. Even in patients with prolongation of t-SSEP latencies and accompanying deteriorated t-SSEP configuration, no postoperative neurological complications arose.

Perioperative complications occurred in 3 of 64 spinal fusions. There was no relation between the SSEPs and the complications observed in the patients. One patient with a dorsal T4–T12 fusion presented a minor sensory deficit in one limb postoperatively, which resolved completely within 6 months. However, there was no change in the postoperative SSEPs. In another patient, a secondary paralysis occurred 6 h postoperatively due to epidural analgesia following an uneventful ventral release and dorsal T4–L1 fusion. The paralysis improved continuously, with only a discrete paresis of the leg noted 3 months postoperatively. The postoperative SSEPs were within normal limits in this case, probably due to the delayed onset of neurological deficit. There was one postoperative death, on the 4th day following ventral release and T5–T11 fusion, due to acute respiratory distress syndrome with fatal cardiopulmonary failure.

Discussion

Tibial nerve SSEPs are used for diagnostic purposes to assess dorsal column function in traumatic and non-traumatic disorders of the spinal cord [6, 10]. SSEPs are also performed intraoperatively to detect a deterioration of spinal cord function during spine surgery [14]. However, the significance of pre- and postoperative SSEPs in patients suffering from idiopathic scoliosis is less clear.

In general, t-SSEP latencies are related to total body height and leg length, which account for most interindividual variations [11]. We confirm that it is also important in scoliosis patients to use body-height-corrected SSEP latencies to allow comparisons between SSEP latencies of IS patients with different body height. Due to the scoliotic deformity based on changes of regional spinal length development (affection of vertebral growth plates) it is difficult to assess the absolute body height of the respective patients. The statistical analysis ruled out the possibility that the high rate of pathological t-SSEP latencies (61%) was purely due to the applied calculation of body height correction. The extent of spine deformity as assessed by the Cobb angle, which influences the calculation of body height, was not related to any increment in SSEP latencies. Furthermore, the t-SSEP latency outliers of IS patients were present at all ranges of body height, and many of them were even beyond the 2.5–3SD upper limits. In addition to SSEP latencies, analysis of interside differences of the first three SSEP markers also provides a useful parameter for interpreting SSEP recordings in scoliosis patients [2, 5]. The high proportion of pathological interside differences (23.4%) in this study is in line with earlier findings even in patients with less severe scoliosis [3]. The configuration of the t-SSEP response was usually w-waveform shaped, and less than 3% of patients showed a different configuration, which is in the range of findings in healthy subjects and is in accordance with an earlier study [4].

The extent of pathological t-SSEPs presented is much higher than described in some previous studies [1, 19]. One study reported only three abnormal preoperative SSEPs out of 48 in IS patients, and concluded that routine preoperative evaluation is not necessary. However, in that study, no correction for body height was performed [19]. The present results are consistent with a previous study, in which 58% of preoperative body-height-corrected t-SSEPs were regarded as pathological [18].

Although IS patients do not present obvious neurological deficits, the high rate of pathological SSEP recordings favors the theory that IS may have a neurological cause [3, 18]. The combined finding of increased t-SSEP latencies and interside differences, the latter being changes that are not influenced by body height, support the assumption of some neurological affection in IS. Consequently, a variety of functional changes within the spinal cord due to IS or affection of other nervous structures have been postulated [1, 3, 13, 14]. The prolongation of latencies in IS has been thought to be caused by deformities of the spinal cord due to the scoliosis. However, the present study is not able to demonstrate any correlation between the severity of the scoliosis and the delay in SSEPs. Furthermore, in contrast to a recent paper, we could not find any significant link between structural changes assessed by MRI and abnormal SSEPs in IS [4]. As cortical SSEPs have been recorded without additional neurophysiological explorations, no specific information about the location and pathophysiological mechanisms of SSEP deterioration can be concluded from this study.

Although preoperative t-SSEPs in IS show SSEPs from normal up to severely affected, the finding of pathological t-SSEP recordings failed to be of predictive value for the outcome of surgery. Neither patients with severely in-

creased SSEP latencies nor those with a pathological SSEP configuration showed a higher risk for postoperative neurological deficit.

However, the postoperative re-examination of t-SSEPs revealed a significant influence of spine surgery upon SSEP latencies not only in neurologically impaired patients, but in those without deterioration of the neurological condition as well. These patients showed an increment of postoperative latencies, while the SSEP configuration remained unchanged. The extent of postoperative SSEP changes was related to the surgical approach, with significantly prolonged latencies after a ventral-dorsal surgical approach. This indicates that the surgical approach can influence spinal cord function even in patients who show no clinical neurological deterioration after spine surgery.

Conclusion

We conclude that, in scoliosis patients, a routine pre-operative SSEP examination gives additional diagnostic information about a possible spinal cord impairment even in IS patients without any neurological deficit. Although preoperative t-SSEPs are not of predictive value for the outcome of surgery, postoperative t-SSEP re-examinations enable assessment of changes related to the surgical approach even in uneventful surgery.

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