The “tethered cord syndrome” (TCS) is a progressive neurological dysfunction presumably due to longitudinal traction of the lower spinal cord. The tethering has been attributed to a variety of pathological entities, and the morphological changes are now well established by neuroimaging. Although the clinical signs and symptoms can be classified as a mainly orthopaedic syndrome or as a mainly neurological syndrome, differences in the mode of onset, clinical manifestations and outcome exist between paediatric and adult patients. In the opinion of most authors, it is the degree of traction on the conus that determines the age when symptoms set in. It is therefore possible that discrete tethering without severe stretching may remain subclinical in childhood. Precipitating factors, mainly traumatic injuries, produce damage to the lumbosacral cord by upsetting the balance between abnormal tension and optimal cellular function. The adult form of TCS presents a picture of low back pain, progressive wasting and muscular atrophy of the legs, which may be long-standing and stable over a lengthy period or progressive, associated or not with upper motor neuron involvement. A functional investigation of the spinal cord may be provided by somatosensory and motor evoked potentials which assess the conduction along the central pathways. Moreover, it is now widely accepted that lumbosacral somatosensory evoked potentials (SEPs) may also provide information on the post-synaptic activity of the dorsal horn interneurons in response to non-noxious inputs.

Separate components with a characteristic field distribution have been observed in the human evoked electrospinogram (EESG) following stimulation of mixed nerves in the leg. In monopolar surface recordings, posterior tibial nerve stimulation provides evidence of spinal malformations was provided by magnetic resonance imaging. The functional assessment of the spinal cord was performed by analysing both spinal and cortical somatosensory evoked potentials. The evoked electrospinogram was recorded from the thoracic and lumbosacral spinous processes. The N22 lumbosacral potential was selectively affected, being rostrocaudally displaced and reduced in amplitude or even absent in patients with neurological signs indicating a segmental lower cord lesion. Inter-peak somatosensory evoked potentials latency was normal in all cases, suggesting that ascending axonal potentials in the dorsal column fibres may be synchronized. Segmental potentials of the lumbosacral response, originating from the post-synaptic activity of dorsal horn interneurons, are selectively affected in this syndrome resulting from the rostrocaudal displacement of the spinal cord due to tethering. Our findings in the clinical field are consistent with previous experimental evidence indicating a different sensitivity of the gray vs. white matter to progressive stretching.

Spinal Somatosensory Evoked Potentials in Patients with Tethered Cord Syndrome

Alberto Polo, Giampietro Zanette, Paolo Manganotti, Laura Bertolasi, Domenico De Grandis and Nicolo' Rizzuto

Abstract: We studied the electrophysiological changes occurring in six patients with tethered cord syndrome. Evidence of spinal malformations was provided by magnetic resonance imaging. The functional assessment of the spinal cord was performed by analysing both spinal and cortical somatosensory evoked potentials. The evoked electrospinogram was recorded from the thoracic and lumbosacral spinous processes. The N22 lumbosacral potential was selectively affected, being rostrocaudally displaced and reduced in amplitude or even absent in patients with neurological signs indicating a segmental lower cord lesion. Inter-peak somatosensory evoked potentials latency was normal in all cases, suggesting that ascending axonal potentials in the dorsal column fibres may be synchronized. Segmental potentials of the lumbosacral response, originating from the post-synaptic activity of dorsal horn interneurons, are selectively affected in this syndrome resulting from the rostrocaudal displacement of the spinal cord due to tethering. Our findings in the clinical field are consistent with previous experimental evidence indicating a different sensitivity of the gray vs. white matter to progressive stretching.

Résumé: Potentiels évoqués somesthesiques spinaux chez les patients atteints du syndrome du filum terminale.

Nous avons étudié les changements électrophysiologiques présents chez six patients atteints du syndrome du filum terminale. Les malformations médullaires étaient détectées par imagerie par résonance magnétique. L'évaluation fonctionnelle de la moelle épinière était effectuée par l'analyse des potentiels évoqués somesthesiques spinaux et corticaux (PES). L'électrospinogramme évoqué était enregistré au niveau des apophyses épineuses thoraciques et lombosacrées. Le potentiel lumbosacré N22 était sélectivement atteint: il était déplacé en position rostrocaudale et son amplitude était réduite et il était absent chez les patients qui avaient des signes neurologiques indiquant une lésion segmentaire basse de la moelle épinière. La latence interpics des PES était normale chez tous les cas suggérant que les potentiels axonaux ascendants des fibres du faisceau postérieur sont synchronisés. Les potentiels segmentaires de la réponse lombosacrée originant de l'activité post-synaptique des neurones intercalaires de la corne postérieure de la moelle sont atteints sélectivement dans ce syndrome dû au déplacement rostrocaudal de la moelle épinière par fixation caudale. Nos observations cliniques sont en accord avec les données expérimentales indiquant une sensibilité différente de la substance grise et de la substance blanche à l'étirement progressif.


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evoked a first positive far-field potential (P15) generated by the afferent volley in the proximal portion of the lumbosacral plexus. Following this potential, two different negative peaks arise from the thoracolumbar regions. The first stationary peak (N22) represents the post-synaptic neural activity in laminae IV and V of the dorsal horn during activation of large-diameter afferent fibres.22

The possibility of finding a clear dissociation between normal cauda equina and scalp responses and an abnormal N22 spinal potential was first suggested by investigators who found a spinal N22 not serial with the ascending somatosensory volley.17 Evoked potential studies have been conducted in patients with early-onset TCS, which is by far the most common and severe form. A literature survey revealed approximately 50 anecdotal accounts of TCS with symptom onset in adulthood, but most studies lack precise clinico-pathological correlations.10

In this work, we evaluated somatosensory evoked potentials (SEPs) in 6 patients with adult TCS confirmed by radiological investigations. Our aim was to study the effect of spinal cord displacement due to stretching not only on the conduction along the ascending and descending cord pathways, but also on the waveform and field distribution of the EESG. The electrophysiological findings were correlated with the clinical picture.

**METHODS**

**Patients**

In the present study, the patients were subgrouped into two categories as proposed by Pang et al.: A) those who were normal as children but developed symptoms in adulthood, and B) those with static neurological deformities diagnosed in childhood but who remained well until the onset of new, progressive neurological deficits in adulthood.

A) Two females, patients 1 and 2 in Table 1, were referred to our institute complaining of chronic low back pain as the main symptom, mostly aggravated by prolonged sitting and standing. One of them also complained of a progressive weakness of the legs during walking. In both cases clear-cut circumstances (fall on the buttocks, leg-stretching exercises) led to the onset of symptoms. Spinal MRI showed an enlarged lumbosacral sac with a low-lying conus stretched against the posterior wall of the canal.

B) Three females and one male (patients 3 to 6 in Table 1) showed a long-standing discrete deformity of the foot (pes cavus), segmental or diffuse hypotrophy of the leg muscles. All patients presented with a several-year history of intermittent or chronic low back pain. Surgical intervention, pregnancy and spinal trauma were indicated as clear-cut circumstances undoubtedly worsening the course of the disease. MRI showed spinal malformations associated with a tethered cord (Figure 1). In all patients (groups A and B) vibratory sensation and joint position sense were intact.

The general physical examination yielded negative findings.

**METHOD**

Lower-limb SEPs were recorded following electrical stimulation consisting of square-wave pulses at a rate of 4/sec applied to the posterior tibial nerve at the ankle; stimulus intensity was adjusted so that each stimulus just produced a visible plantar flexion of the big toe. Spinal SEPs were obtained with a linear

<table>
<thead>
<tr>
<th>PT</th>
<th>AGE</th>
<th>HEIGHT</th>
<th>SEX</th>
<th>SYMPTOMS</th>
<th>SIGNS</th>
<th>MRI</th>
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<tbody>
<tr>
<td>1)</td>
<td>42</td>
<td>162</td>
<td>F</td>
<td>low back pain, neurogenic claudicatio</td>
<td>absent</td>
<td>low lying conus thickened filum</td>
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<td>2)</td>
<td>46</td>
<td>164</td>
<td>F</td>
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<td>3)</td>
<td>62</td>
<td>166</td>
<td>F</td>
<td>low back pain, weakness of the feet, dorsiflexion</td>
<td>pes cavus</td>
<td>sacral meningocele intradural lipoma</td>
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<td>4)</td>
<td>54</td>
<td>160</td>
<td>M</td>
<td>low back pain, sphincter disturbances, left leg weakness</td>
<td>diffuse left leg hypotrophy</td>
<td>fatty tissue within the lower part of filum terminale</td>
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<tr>
<td>5)</td>
<td>33</td>
<td>168</td>
<td>F</td>
<td>low back pain, weakness of foot, dorsiflexion, sphincter disturbances, slight spastic gait</td>
<td>pes cavus, hyporeflexia</td>
<td>anterior leg hypotrophy</td>
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<tr>
<td>6)</td>
<td>64</td>
<td>158</td>
<td>F</td>
<td>low back pain, lighting sensations on the left buttoc, weakness of the legs, sphincter disturbances</td>
<td>absent Achilles tendon reflexes</td>
<td>sacral meningocele with lipoma adherent to S1 root</td>
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Table 2. SEP latency and amplitude in 23 healthy subjects (mean age 43).

<table>
<thead>
<tr>
<th>Peak latency (ms)</th>
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<th>SD</th>
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<tr>
<td>PI5</td>
<td>14.8</td>
<td>1.22</td>
</tr>
<tr>
<td>NI8</td>
<td>18.1</td>
<td>1.30</td>
</tr>
<tr>
<td>N22</td>
<td>21.6</td>
<td>1.32</td>
</tr>
<tr>
<td>P37</td>
<td>36.2</td>
<td>1.48</td>
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<tr>
<th>Interpeak latency (ms)</th>
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<th>SD</th>
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<tr>
<td>PI5-N37</td>
<td>21.5</td>
<td>1.04</td>
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<th>N22 amplitude distribution (µV)</th>
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<th>Minimum value</th>
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<td>T8</td>
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<tr>
<td>T10</td>
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<td>L4</td>
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<tr>
<th>N22 amplitude ratio</th>
<th>Mean</th>
<th>Minimum value</th>
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</thead>
<tbody>
<tr>
<td>T10/L4</td>
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<tr>
<td>T12/L4</td>
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<td></td>
</tr>
<tr>
<td>L2/L4</td>
<td>2.67</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Tethered cord in a 54-year-old woman with low back pain and spinal claudication (patient 4). MRI shows enlargement of the sacral canal, a low-lying conus medullaris, a thickened terminal filament stretched against the posterior wall of the lumbo-sacral canal. Mid-sagittal section, spin-echo (SE) sequence TR: 500 TE: 15.

Figure 2: Evoked electrospinogram (EESG) in a normal subject. Recordings are obtained from the dorsal midline following stimulation of the posterior tibial nerve at the ankle. Electrode positions are the corresponding spinous process (on the left): the common reference is the iliac crest ipsilateral to the stimulus. The EESG peaks are labelled according to their positive (P) or negative (N) polarities at the "active" electrode and labelled with nominal latencies reflecting the mean latency for each peak in our control group. The stationary plexus potential is indicated as PI5. The solid line connects the peaks of the travelling wave labelled the afferent volley (AV). Dashed line show the stationary peak labelled as N22 (post-synaptic potential). The highest amplitude of the spinal complex is observed at the lower thoracic sites.
RESULTS

The typical waveform and distribution of the normal EESG are illustrated in Figure 2. The first positive "far-field" potential (P15) is followed by two negative peaks: the earlier peak is an ascending negative wave (AV, afferent volley or N18) gradually increasing in latency from the sacral to the upper thoracic regions; the second is a stationary wave (N22) with a maximum amplitude at the lower thoracic sites. Both these components are clearly distinguishable at lumbosacral sites, while at more rostral leads a prominent negativity merges into the potential labelled N22.

Table 2 shows the reference data for SEPs. Values exceeding the mean plus 2.5 SD were regarded as abnormal.

In both patients (1 and 2) with pure tethered cord there was a caudal displacement of the potentials. The first positive far-field potential has a mean latency of 14.3 msec (1.0 SD). The maximum amplitude of the spinal complex appears at the lower lumbar sites, where a simple negative peak may be observed; the mean latency was 19.8 msec (0.9 SD) and mean amplitude measured 0.26 μV (0.12 SD). N22 was not found at the recording level of T12 and T10. The patients showed a shorter P15-N22 inter-peak time (< 5.2 msec) than the normal P15-N22 value minus 2.5 SD. This change could be due to the anatomical discrepancies between the spine and spinal cord, i.e., the nerve roots take a horizontal course with a shortening of the intracanal length. The later, slow positive wave is not consistent in consecutive recordings. The P37 early scalp potential had a mean latency of 36.2 msec (1.1 SD) displaying normal amplitude and waveform. The EESG for patient 1 is shown in Figure 3.

Patients with tethered cord and associated malformations in the lumbosacral canal showed more marked abnormalities of segmental spinal SEPs, i.e., a loss of N22 potentials. The earlier stationary positive peak occurred with a mean latency of 14.5 msec (0.93 SD). A later negative peak, similar in latency and waveform to N18, is recorded at lower lumbar sites with a mean latency of 18.5 msec (0.83 SD); a second negative peak, i.e., the N22 component, and the subsequent slow negativity are not detectable. At the T12 and T10 recording sites, the spinal components following the plexus potential presented minimal EESG amplitudes. The negative peak reflecting the afferent volley was clearly defined at more rostral sites, suggesting the integrity of dorsal column conduction. Figure 4 illustrates case 3.

The P37 early scalp potential occurred with a mean latency of 37.4 msec (1.25 SD); the waveforms of the cortical responses were normal.

DISCUSSION

Few SEP investigations have been conducted in patients with TCS, and these are extensive only in the early-onset form. Absent, delayed or low-amplitude lumbar spinal potentials following posterior nerve stimulation have been observed. The absence of N14 (N22 lumbar spinal cord EP in the adult) at the L1 site was interpreted as a lesion affecting the posterior columns. N14 abnormalities alone were also considered to reflect the extent of spinal involvement, as shown by myelography, as regards the location and direction of the tethering structure.23

An abnormal surface distribution of the lumbosacral EESG, and particularly of the stationary N22 wave, has been reported in young patients with myelographically confirmed tethered cord: SEP changes were only evaluated to confirm the conus displacement.24

SEPs have also been used to evaluate pre-operative findings in patients with adult-onset TCS due to fibrous diastematomyelia2 and to monitor spinal cord tethering during surgery.6,25

In our cases, we found a characteristic abnormality within segmental spinal SEPs: while the potentials generated by the proximal plexus volley and by the afferent dorsal roots were spared, the post-synaptic spinal potential was caudally displaced and drastically reduced in amplitude or even absent. This selective involvement of spinal potentials was associated with normal scalp SEPs.

In healthy subjects, the N22 peak was greatest between the T10 and L2 spinous processes, a region overlying the spinal

Figure 3: EESG and scalp SEPs in patient 1. The plexus stationary potential is normally represented (arrow at bottom). The spinal complex is reduced in size and caudally displaced as compared to the usual topography in normal subjects. The latency of the major negative peaks (a probable N22) from the L2 and L4 sites is exactly the same (vertical line); a shorter negative peak (afferent volley) is recorded from the S1 site. The arrow in the upper EESG traces shows the afferent volley at rostral level. At the top, the latency (36.2 msec) and amplitude of the scalp responses (CZ-FZ montage) are found to be within normal limits. Calibration: 0.65 μV/div in EESG, 1.3 μV/div scalp SEPs.
segments that receive the afferent fibres from the posterior tibial nerve.

The abnormal field distribution of the EESG over the lumbosacral spine observed in 2 patients may therefore reflect the rostrocaudal displacement of the spinal cord segments generating the N22. In the other patients, with clinical evidence of segmental dysfunction of the lower cord, the absence of an N22 wave suggests a coexisting gray matter lesion.

At least as regards the analogous responses after upper limb stimulation, this pattern has been demonstrated in selective lesions of the cervical gray matter.26-28

The mechanism of lesions to the spinal cord during stretching is very complex and incompletely understood; various types of experimental spinal cord injuries have been studied using
electrophysiological techniques in an attempt to clarify the pathophysiology of nerve damage.

The progressive distraction of the spinal cord involves the stationary post-synaptic wave first, whereas the earlier plexus and dorsal root component are very resistant to the stretching. These electrophysiological findings are related to the different sensitivities of the white and gray matter to ischaemia observed on monitoring the cord blood flow.29-32

Some authors33 believe that the mechanical effect of tethering results in stretching, distortion and kinking of small blood vessels, which may produce anoxia or ischaemia of the spinal cord with impairment of the mitochondrial oxidative metabolism. Hypoxic stress of the lumbosacral spinal cord in the tethering model causes deterioration of a considerable proportion of the neurons, especially the interneurons, before causing long-tract damage.

These experimental data provide strong support for the clinical interpretation of electrophysiological findings. The dorsal horn potential N22 is a response to inputs from axon collaterals and appears to be distinct from the travelling wave in the dorsal columns propagating to the brain. The selective loss of the dorsal horn potential may occur with a complete sparing of the central afferent conduction in TCS. However, in early-onset TCS with malformations there is electrophysiological evidence of involvement of the central pathways: this is probably related to both the extent and the severity of the clinical picture.23

The clinical course in less severe, slowly progressive forms is characterized by symptoms such as low back pain, sphincter disturbance and leg weakness mainly due to lower motor neuron dysfunction. Extensive major gray matter damage is also suggested by the selective involvement of the N22 spinal component in these cases. The occurrence of long-tract signs, such as muscle weakness with hyperreflexia or the Babinski sign, could appear later with worsening of the disease.9,10-34 The absence or the existence of spinal pathway involvement thus reflects the extent and severity of the cord damage and parallel electrophysiological monitoring may be useful, alongside the clinical examination, to identify the nervous dysfunction as early as possible.

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