INTRODUCTION

PROPRIOSPINAL MYOCLONU S (PSM) IS CHARACTERIZED BY RHYTHMIC-ARRHYTHMIC JERKS ARISING IN AXIAL MUSCLES AND SPREADING TO MORE CAUDAL AND ROSTRAL SEGMENTS. In PSM a spinal generator is believed to recruit axial and limb muscles via slowly conducting propriospinal pathways to produce the myoclonic jerks.1 Several cases of PSM have been reported and multiple sclerosis, cervical trauma, thoracic herpes zoster, HIV infection, excision of cervical hemangioblastoma, thoracic arachnoid cyst, syringomyelia, and ischemic myelopathy have occasionally been described as associated lesions.1-10 In many cases, however, PSM remains idiopathic. PSM may be spontaneous and stimulus-sensitive and may be worse with the patient leaning back or lying in bed, as an effect of posture.1,11 In three previous reported cases PSM showed a striking relationship with vigilance level, since it occurred in a semirhythmic fashion only during the wakefulness period preceding sleep onset. In these patients jerks recurred every 10—20 seconds and were of such intensity as to cause severe sleep-onset insomnia. The jerks were absent during sleep proper. It was speculated that changes in supraspinal control peculiar to the pre-dormitum stage set the spinal generator responsible for PSM into motion.8 This peculiar relationship of PSM with relaxed wakefulness and the ensuing disturbance of sleep allowed the proposition that PSM may represent a disorder of the sleep-wake transition period in some patients.

We report here four additional patients with PSM, aged 36—57, in whom we performed videopolysomnographic (VPSG) recordings aimed at clarifying the relationship of PSM with the state of vigilance, in particular the pre- and post-dormitum stages.

PATIENTS AND METHODS

Case 1

This 57-year-old man had a family history of hyperthyroidism. At age 48 he underwent subtotal thyroidectomy for multiple nodules, with subsequent thyroxine treatment. Since 45 years he has suffered repetitive involuntary jerks of the trunk, neck and limbs occurring every night and impeding sleep. The jerks persisted in all positions in bed (supine, prone, on the side). The patient had tried no drugs but had noted some beneficial effects from alcohol. On admission neurological examination and routine blood analysis were normal.

Case 2

This 36-year-old man had a family history positive for breast carcinoma in the mother. Since age five he had a progressive drooping of the eyelids and since age 15 years nocturnal cramps of the legs. Neurological examination revealed bilateral eyelid ptosis with restriction of vertical and horizontal eye movements. Creatine phosphokinase (CPK) was elevated (190 and 330 I.U.; n.v. < 80 I.U.) and blood lactate level after standardized physical effort increased. EMG showed abnormal myopathic....
potentials, and SFEMG of the left orbicularis oculi muscle revealed an abnormal jitter. Tensilon test was negative. Biopsy of the left deltoideus muscle showed mild scattered hypotrophic fibers with fiber type I predominance without ragged-red fibers (RRF). The findings were consistent with ocular myopathy.

At age 35 he began complaining of sudden involuntary jerks of the trunk and limbs arising during relaxed wakefulness, in particular when lying in bed. The jerks recurred many times, one to two hours prior to falling asleep, and reappeared briefly during nocturnal arousals and in the morning upon awakening.

Case 3
This 55-year-old-man had a family history positive for cerebellar neoplasm in the son. At age 53 he noticed the occurrence of sudden involuntary isolated jerks of the head when trying to fall asleep. The jerks were concomitant with a "click" sensation in the head and involved the trunk and limbs. At the beginning the jerks occurred only three to four times when the patient was relaxed and ready to fall asleep. After six months, myoclonic activity increased, recurring in clusters at intervals of 30 seconds to one minute, making falling asleep impossible. Diazepam in the evening reduced the myoclonic jerks and allowed the patient to sleep. On neurological examination, lower limb hypopallesthesia was associated with asymmetric brisk tendon reflexes.

Case 4
This 43-year-old-man developed, at age 32, involuntary jerks involving the trunk and limbs. The jerks occurred during relaxed wakefulness preceding falling asleep and were concomitant with an inner sensation of electrical shock in the head and/or the chest. The jerks recurred 10—30 times per hour, making sleep onset very difficult. Neurological examination was normal. Laboratory tests revealed hepatitis C.

Neurophysiological Studies
All patients underwent 24-hour videopolysomnographic (VPSG) recordings. Detailed study of myoclonic activity was done by means of bipolar silver/silver chloride electrodes placed 2 cm apart longitudinally over the relevant muscle bellies (1024 Hz sampling frequency and low-pass of 300 Hz and high-pass of 30 Hz). In particular EMG activity was recorded from electrodes placed on right masseter, right and left sternocleidomastoideus, right pectoralis, right and left thoracolumbar intercostalis, right and left biceps brachi and triceps brachi, right and left rectus abdominis and thoracolumbar (T10-L2) paraspinalis, right rectus femoris, right biceps femoris, right tibialis anterior and right gastrocnemius.

Back-averaging of the EEG activity preceding the jerks was performed off-line (10-20 International System, with EEG band pass of 1-70 Hz)\(^\text{12}\) (Shibasaki, 1988). Data were acquired on a Grass polygraph (mod. 78 E) and then stored in a computerized system (Neuroscan, SCAN 3.0) for analysis. All patients underwent mental and sensory stimulations aimed at evoking the myoclonic jerks. The day after VPSG, all patients underwent standard somatosensory evoked potentials (SEPs) with stimulation of the median and tibial nerves\(^\text{13}\) and transcranial magnetic stimulation (TMS) with recording from the median and peroneal innervated muscles. Specifically, TMS to the abductor pollicis...
brevis and tibialis anterior muscles was performed with the coil center positioned above vertex and 4—6 cm frontally and 2—3 cm contralaterally respectively. Relaxed motor evoked potentials (threshold MEPs) and contracted MEPs (facilitated MEPs) were evaluated. 3—5 consecutive trials were recorded and onset latencies were read from the earliest MEP. MEPs were analysed for onset latency (cortical latency, CL), peak-to-peak amplitude and duration, the former expressed as ratios related to M-wave amplitude and duration. Root stimulation was performed with coil windings overlying the appropriate nerve roots, C3-4 and S3 spinous processes, with obtained MEPs analyzed for onset latency only. Central conduction time (CCT) was evaluated considering CL and the latency of the earliest reproducible wave of 20 F waves elicited by supramaximal median and peroneal distal nerve stimulation, according to standard formula14. Brain and total spinal MRI were also performed in all patients.

RESULTS

Case 1

The spontaneous jerks were restricted to the prehypnic wake period and appeared only after the EEG alpha rhythm disappeared when the patient was falling asleep, causing sudden arousal (Figure 1). Myoclonic jerks recurred at quasi-periodic intervals (range 15—30 sec) and this pattern was repeated over a hundred times (Figure 2). Sleep structure was abnormal, characterized by increased sleep stages 1—2 (74%, n.v. 50%), decreased deep sleep stages 3—4 (10%, n.v. 25%) and REM sleep (16%, n.v. 25%), and increased number of arousals (Fig. 1). Mental exercise (arithmetic calculations) caused EEG desynchronization and made the jerks disappear. The jerks could not be evoked by sudden auditory and sensory stimuli. Myoclonic activity constantly involved the sternocleidomastoideus (SCM), mylohyoideus, biceps brachi, pectoralis, intercostal, thoraco-lumbar paraspinalis, and rectus abdominis muscles bilaterally. Masseter and rectus femoralis were often involved while the tib-
ialis anterior and gastrocnemius rarely and minimally. The first activated muscle was always the right sternocleidomastoideus with a variable delay to the most caudal and rostral muscles (right masseter and right gastrocnemius) ranging from 16 ms to 155 ms (Figure 3). A crude estimation of the propagation velocity along the spinal cord, obtained by dividing the length from C1 to L1 spinous processes by the mean latency between the right SCM and right gastrocnemius, gave values of 4—6 m/s. Back averaging of the EEG, triggered on the right SCM, disclosed no time-locked cortical potential in the one second preceding the jerks. Median and tibial nerves somatosensory evoked potentials (SEPs), trancranial magnetic stimulation (TMS), and spinal and cranial MRI were negative. Clonazepam (1 mg/day at bedtime) was effective in reducing the jerks.

**Figure 4**—Histograms illustrating the occurrence of myoclonic jerks (bottom) in relation to the sleep-wake cycle in Case 2. Peaks in the lower traces express the number of jerks per 1-minute intervals. Jerks are not limited to the drowsiness period preceding sleep but reappear also during intra-sleep wakefulness and upon awakening in the morning.

**Figure 5**—Sleep-wake histogram (upper trace) in relation to myoclonic activity per 1-minute intervals (lower trace) in Case 3. Note the long sleep latency due to the repetitive occurrence of PSM.
Figure 6—EEG-EMG recording of PSM in Case 3. Left and right panels illustrate the same jerk at different velocities of recording. Mylohyoid, mylohyoideus; Masset, masseter; SCM sternocleidomastoideus; Trapez, trapezius; Delto, deltoideus; Interc, intercostalis; tl Parasp, thoraco-lumbar paraspinalis; Rect abd, rectus abdominis; Rect fem, rectus femoris; Bicep fem, biceps femoris.

Figure 7— Histogram illustrating the occurrence of the myoclonic jerks (number of jerks per 1-minute) (bottom) in relation to the sleep-wake cycle in Case 5. * indicates transient suppression of PSM by mental exercise.
The jerks arose in a semirrhythmic fashion during relaxed wakefulness; the patient did not fall asleep for a full hour after lights out. There was a clear relationship between alpha EEG activity fragmentation and the emergence of the jerks. PSM reappeared briefly during intra-sleep wakefulness and upon awakening in the morning (Figure 4). Sleep structure was abnormal: stages 1—2 were 68% (n.v. 50%), stages 3—4 21% (n.v. 25%), and REM sleep 11% (n.v. 25%) (Fig. 4). Sleep latency was increased to 172 minutes; sleep efficiency was decreased (60%, n.v.>85%). Mental exercise prevented the appearance of the jerks. Sudden auditory and sensory stimuli, including peripheral nerve electrical stimulation, did not evoke any jerk. Polymyographic analysis documented that the originating muscle was the left biceps brachii with subsequent involvement of the SCM and then the truncal and lower limb muscles. The delay between the first activated and the most caudal and rostral muscles was 34—110 ms, giving an intraspinal conduction velocity of 5—16 m/s. EEG back-averaging, triggered on the left bicep brachii, did not show any cortical jerk-related potential. SEPs, TMS, spinal and cranial MRI were negative. Clonazepam (1.5 mg/day at bedtime) dramatically abolished the jerks.

Case 3

Repeated jerks appeared during relaxed wakefulness every two to five minutes for two hours, preventing the patient from falling asleep (Figure 5). The myoclonic contractions emerged when alpha activity became diffuse on the EEG, evident also on the anterior scalp regions and intermixed with theta activity. Sleep structure was abnormal, characterized by increased light sleep stages 1—2 (67%, n.v. 50%), slightly decreased deep sleep stages 3—4 (21%, n.v. 25%) and decreased REM sleep (11%, n.v. 25%), with increased arousals. Sleep latency was increased to 205 minutes and sleep efficiency reduced (72%, n.v. >85%). Mental exercise prevented the emergence of the myoclonus causing EEG desynchronization. Somaesthetic and acoustic stimulation was ineffective in causing jerks. The left intercostalis was the muscle first involved in the myoclonic jerks, with subsequent caudal and rostral propagation (Figure 6) with a delay of 58—87 ms, giving an intraspinal conduction velocity of 5—10 m/s. Jerk-related EEG back-averaging, triggered on the left intercostalis, did not show any cortical jerk-related potential. TMS disclosed increased motor latency to the left abductor pollicis brevis with a prolonged central conduction time. Lumbar SEPs potentials were prolonged in latency and reduced in amplitude from the posterior tibial nerves. A C5-C6 disc protrusion impinging on the cord was present on spinal MRI. Clonazepam (2 mg/day at bedtime) dramatically abolished the jerks.

Case 4

The jerks arose only during sleep-wake transition when alpha activity became diffuse over the EEG, causing arousals. Sleep efficiency was reduced (79%, n.v.>85%) and sleep structure demonstrated increased light sleep stages 1-2 (65%, n.v. 50%), decreased deep sleep stages 3-4 (18%, n.v. 25%) and decreased REM sleep (17%, n.v. 25%). When the patient was mentally activated, with EEG desynchronization, myoclonic jerks never occurred. Auditory and somatosensory stimulation did not evoke

### Table 1—Clinical and laboratory findings of propriospinal myoclonus

<table>
<thead>
<tr>
<th>Patients</th>
<th>Onset (yrs)</th>
<th>State</th>
<th>Starting muscle</th>
<th>Spinal propagation velocity</th>
<th>MRI</th>
<th>Treatment and Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) male, 57 yrs</td>
<td>45</td>
<td>pre-dormitum</td>
<td>R. SCM</td>
<td>4-6 m/s</td>
<td>Normal</td>
<td>Clonazepam +</td>
</tr>
<tr>
<td>2) male, 36 yrs</td>
<td>35</td>
<td>pre-dormitum</td>
<td>L. Biceps Brachialis</td>
<td>5-10 m/s</td>
<td>C5-C6 bulging</td>
<td>Clonazepam +++</td>
</tr>
<tr>
<td>3) male, 55 yrs</td>
<td>53</td>
<td>pre-dormitum</td>
<td>L. Intercostalis</td>
<td>5-7 m/s</td>
<td>Normal</td>
<td>Barbiturate +</td>
</tr>
<tr>
<td>4) male, 43 yrs</td>
<td>32</td>
<td>pre-dormitum</td>
<td>L. SCM</td>
<td>4-13 m/s</td>
<td>Normal</td>
<td>Opianes ++</td>
</tr>
<tr>
<td>5) male, 24 yrs</td>
<td>23</td>
<td>pre-dormitum</td>
<td>R. Rectus Abdominis</td>
<td>2-16 m/s</td>
<td>T8-T9 arachnoid cyst</td>
<td>Clonazepam ++</td>
</tr>
<tr>
<td>6) male, 71 yrs</td>
<td>40</td>
<td>pre-dormitum</td>
<td>L. Paraspinals</td>
<td>2-3 m/s</td>
<td>Normal</td>
<td>Clonazepam +</td>
</tr>
<tr>
<td>7) male, 50 yrs</td>
<td>30</td>
<td>pre-dormitum</td>
<td>L. Paraspinals</td>
<td>2-3 m/s</td>
<td>Normal</td>
<td>Clonazepam +</td>
</tr>
<tr>
<td>8) male, 41 yrs</td>
<td>37</td>
<td>pre-dormitum</td>
<td>L. Paraspinals</td>
<td>2-3 m/s</td>
<td>Normal</td>
<td>Clonazepam +</td>
</tr>
</tbody>
</table>

*patient with oculomotor myopathy; *patient in addendum; *patients previously reported (Montagna et al., Movement Disorders 1997); Treatment responses +, ++, and +++: mild, great, and complete abolition of PSM; SCM: sternocleidomastoideus; R: right; L: left.
<table>
<thead>
<tr>
<th></th>
<th>Clinical Findings</th>
<th>Neurophysiology</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSM</td>
<td>Axial muscle jerks with slow rostral and caudal propagation.</td>
<td>Duration of EMG burst: 100-300 ms.</td>
<td>Benzodiazepines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jitter of intermuscle latencies: 16-200 ms.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intraspinal conduction velocity: 2-16 m/s.</td>
<td></td>
</tr>
<tr>
<td>PLMS</td>
<td>State-dependent periodic (T:20-30 s) dorsiflexion of great toe, foot, and/or flexion of entire leg, with frequent involvement of upper limbs.</td>
<td>Sustained polyclonic EMG activity with inconstant muscular recruitment pattern and extremely variable intermuscle latencies (&gt; 2 s).</td>
<td>Dopa Agonists Benzodiazepines Opioids</td>
</tr>
<tr>
<td>RLS</td>
<td>Incessant bedtime dysesthesia relieved by agitated motor activity with legs and arms flexing, stretching and crossing.</td>
<td>As in PLMS; patients may get out of the bed and walk around.</td>
<td>Dopa Agonists Benzodiazepines Opioids</td>
</tr>
<tr>
<td>Painful Legs &amp; Moving Toes</td>
<td>Severe pain of feet with burning sensation and repetitive semicontinuous movements of toes, not necessarily worse at night or relieved by activity.</td>
<td>Irregular EMG bursts in small muscles of the foot and leg.</td>
<td>Dopa Agonists</td>
</tr>
<tr>
<td>Spinal Myoclonus</td>
<td>Segmental jerks of trunk as well as of limb muscles, involving only one or two adjacent spinal segments and not propagated.</td>
<td>Rhythmic contractions of the same segmentally innervated muscles with EMG-burst duration of 100-200 ms.</td>
<td>Benzodiazepines Baclofen Carbamazepine Tetrabenazine</td>
</tr>
<tr>
<td>Cortical Myoclonus</td>
<td>Irregular and asynchronous jerks involving mainly distal limb and facial muscles.</td>
<td>EEG spikes leading the jerk by about 20 ms (hand muscles) with duration of the myoclonic EMG discharges usually less than 50 ms.</td>
<td>Antiepileptic drugs</td>
</tr>
</tbody>
</table>
any jerks. The left SCM was the muscle first involved in the myoclonic jerks. Latency delay between the SCM and the most caudal muscle involved (i.e., left tibialis anterior) was 81—115 ms, with an intraspinal conduction velocity of 5—7 m/s. EEG back-averaging triggered on the left SCM, disclosed no related cortical potentials in the one second preceding the jerks. SEPs, TMS, and spinal cord MRI were normal. Barbaosclone (200 mg/day at bedtime) reduced the intensity and frequency of the jerks.

**DISCUSSION**

Our four patients had neurophysiologically documented PSM occurring solely at the transition from wake to sleep, or during insles aseep arousals or upon awakenings. There were no clinical or neurophysiological features suggesting a cortical or reticular origin of the myoclonus. In particular, there were no time-locked cortical correlates in back-averaged EEG activity preceding the spontaneous jerks, which, moreover did not involve distal muscles, as is typical of cortical myoclonus. It is more difficult to exclude a reticular origin of the myoclonus, since cranial muscles (masseter and mylohyoides) could sometimes be activated in an ascending fashion. However, cranial nerve involvement was not obligatory, and the jerks were not elicited by auditory or somatosensory stimuli, as usually happens in reticular brainstem myoclonus. The diffusion of the jerks to involve multiple spinal segments, their origin in axial muscles, the long duration of the EMG bursts (100-300 ms, sometimes with polymyoclonic shape), the marked jitter in intermuscle latencies and the low spinal conduction velocity are characteristic of axial myoclonus of propriospinal origin. In all of our cases the jerks had a clear relationship with the sleep-wake transition period. The jerks arose in a semirhythmic fashion only during the relaxation phase prior to sleep, and disappeared with the earliest stages of sleep and throughout all sleep stages. In one case PSM reappeared briefly during intra-sleep wakefulness and upon awakening in the morning. Mental and sensory stimulation during relaxed wakefulness stopped the jerks concomitantly with the disappearance of the EEG alpha activity and independently of any postural changes. Myoclonus there after reappeared as the patients were left undisturbed and the EEG alpha activity returned. All of these four patients had an altered sleep structure and complained of insomnia. There seemed to be no relevant single causative mechanism in these patients, and we consider it possible that the ocular myopathy and cervical myelopathy observed in Cases 2 and 3 respectively were fortuitous associations. Our present report then lumped all together into unspecified “wakefulness” but not involving the trunk and all extremities simultaneously, occurring at sleep onset and frequently associated with a perception of falling. Most normal adults indicate that they have experienced hypnic jerks at the transition between waking and sleep (but is a real blow of luck to record one of them polygraphically). In same patients, however, they may be so severe and frequent to cause a sleep-onset insomnia. The polymyographic characteristics of the physiological sleep starts, in particular whether they show a propriospinal propagation pattern, are unknown. PSM in our cases was indeed reminiscent of the sleep starts encountered in the general population, but we cannot substantiate our suggestion in the absence of polygraphic data on sleep starts.

Vigilance level is an important factor for the manifestation and variability of many movement disorders. The pre-dormitum and post-dormitum periods in particular are characterized by vigilance level fluctuations which modulate the state-dependent motor behavior. In our cases, PSM was precipitated by drowsiness preceding nocturnal sleep. The fact that PSM appeared to be specifically related to sleep inducing mechanisms acting especially during the pre-dormitum stage argues for the neurophysiological independence of these peculiar states of vigilance, the pre- and post-dormitum stages. Pre- and post-dormitum are usually lumped all together into unspecified “wakefulness” but instead possess intrinsic cerebral metabolic patterns on PET studies and mental and neurophysiological characteristics. In our opinion the pre-dormitum and post-dormitum, with the relative changes in firing patterns of many neuronal supra-spinal populations related to the control of motor activity, could act to release a still unknown spinal pacemaker (propriospinal motoneurons?) responsible for PSM.

**Addendum**

**Case 5**

A 24-year-old man presented with a one-year history of sudden involuntary jerks of the head, axial, and limb muscles arising during relaxed wakefulness and drowsiness and impeding falling asleep. Neurological examination and routine tests were normal. VPSG recorded over one hundred massive jerks recurring in a semirhythmic fashion during relaxed wakefulness prior to falling asleep and dramatically disappearing as soon as spindles and K-complexes appeared on the EEG. Isolated jerks could reappear during intra-sleep arousals and repetitively upon awakening in the morning (Fig. 7). Mental exercise stopped the jerks. Sleep structure was nearly normal: stages 1—2 56% (n.v. 50%), stages 3—4 29% (n.v. 25%), and REM sleep 15% (n.v. 25%), sleep latency 40 minutes with normal sleep efficiency (88 %, n.v. >85%). EMG analysis indicated that the left SCM was the starting muscle with subsequent involvement of the truncal and lower limb muscles. The delay between the first activated and the most caudal muscles was 42-132 ms, giving an intraspinal conduction...
velocity of 4—13 m/s. EEG back-averaging, triggered on the left SCM, did not show any cortical potential preceding the jerk. SEPs, TMS, spinal and cranial MRI were negative. Clonazepam (1 mg/day at bedtime) diminished, but did not abolish, the jerks.

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