

**Figure 3.** Features of intranuclear inclusions seen at autopsy. (A) Sympathetic ganglion cell containing an eosinophilic intranuclear inclusion surrounded by a halo (H-E; Patient II-1, Family 1). (B) Intranuclear inclusion in a dorsal root ganglion cell (H-E; Patient II-7, Family 2). (C) Ubiquitin-immunoreactive intranuclear inclusion in a spinal motor neuron (Patient II-1, Family 1). (D) A thoracic spinal cord section shows mild pallor in the posterior funiculus (Klüver-Barraera; Patient II-1, Family 1). (E and F) Ubiquitin-immunoreactive intranuclear inclusions in a myenteric ganglion (E; Patient II-1, Family 1) and parenchymal cells of the gut (F; Patient II-7, Family 2). (G) Electron micrograph of an intranuclear inclusion in a sympathetic ganglion cell (Patient II-1, Family 1). H shows a higher magnification of the same inclusion.

imens obtained from some patients have been found to show intranuclear hyaline inclusions in myenteric autonomic neurons.<sup>16,24,27</sup> Gastrointestinal symptoms in our patients were very similar to those in previous reports, and indeed intranuclear hyaline inclusions were very numerous in myenteric neurons in our patients. Episodic autonomic dysfunction persisting for a few days, including hiccup, vomiting, and ab-

dominal pain, was particularly characteristic of patients from Family 1. Patients with familial visceral neuropathy<sup>15,32,33</sup> have shown vomiting episodes and myenteric neuronal loss. The pathologic substrate of symptoms would appear similar in our patients. In addition, myenteric neuronal loss has been reported to affect immune and secretory function of the gut, giving rise to gastrointestinal tract disease.<sup>34</sup> In our

patients and some patients with NIHID showing severe gastrointestinal symptoms, susceptibility to gastrointestinal infection and gastric ulcer has been high.<sup>2,15</sup> In some patients repeated episodes of gastrointestinal illness may suggest underlying myenteric neuronal damage and provide a clue as to diagnosis of NIHID.

A major question in our patients is restriction of symptoms to those of peripheral neuropathy, despite widespread neuronal intranuclear hyaline inclusions throughout the CNS. As in previous reports,<sup>2,7,11,13,18,22,23,26</sup> distribution of nuclear inclusions did not correlate well with distribution of neuronal loss in our patients. The most severe neuronal loss was observed in sympathetic ganglion neurons and dorsal root ganglion neurons, followed by anterior horn motor neurons in the spinal cord. Neurons in the cerebrum, cerebellum, and brainstem were relatively well preserved despite abundant intranuclear inclusions. Although neurons harboring intranuclear inclusions are found in some settings of neuronal dysfunction such as polyglutamine diseases,<sup>20,22,35</sup> major symptoms in our present patients correlated with loss of peripheral nerve neurons. Densities of myelinated and unmyelinated fibers, especially the latter, in sural nerve biopsy specimens were diminished, correlating with neuropathic symptoms. Additionally, considerable numbers of Schwann cells showed intranuclear inclusions that may have induced dysfunction leading to the segmental demyelination that we found in the sural nerve specimens. Thus, Schwann cell dysfunction as well as peripheral neuronal loss may have contributed to peripheral neuropathy symptoms. In patients with hereditary motor and sensory neuropathy associated with autonomic symptoms, NIHID therefore should be considered in the differential diagnosis. Intranuclear hyaline inclusions in Schwann cells and the myenteric plexus may provide a way to investigate this possible antemortem diagnosis in sural nerve and rectal biopsy specimens.

The specific cause of NIHID currently is unknown, but autosomal dominant inheritance as in our patients has been recognized. Further genetic analysis may disclose the molecular substrate of the intranuclear inclusions and neuronal degeneration.

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# The wide spectrum of clinical manifestations in Sjögren's syndrome-associated neuropathy

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We assessed the clinicopathological features of 92 patients with primary Sjögren's syndrome-associated neuropathy (76 women, 16 men, 54.7 years, age at onset). The majority of patients (93%) were diagnosed with Sjögren's syndrome after neuropathic symptoms appeared. We classified these patients into seven forms of neuropathy: sensory ataxic neuropathy ( $n=36$ ), painful sensory neuropathy without sensory ataxia ( $n=18$ ), multiple mononeuropathy ( $n=11$ ), multiple cranial neuropathy ( $n=5$ ), trigeminal neuropathy ( $n=15$ ), autonomic neuropathy ( $n=3$ ) and radiculoneuropathy ( $n=4$ ), based on the predominant neuropathic symptoms. Acute or subacute onset was seen more frequently in multiple mononeuropathy and multiple cranial neuropathy, whereas chronic progression was predominant in other forms of neuropathy. Sensory symptoms without substantial motor involvement were seen predominantly in sensory ataxic, painful sensory, trigeminal and autonomic neuropathy, although the affected sensory modalities and distribution pattern varied. In contrast, motor weakness and muscle atrophy were observed in multiple mononeuropathy, multiple cranial neuropathy and radiculoneuropathy. Autonomic symptoms were often seen in all forms of neuropathy. Abnormal pupils and orthostatic hypotension were particularly frequent in sensory ataxic, painful, trigeminal and autonomic neuropathy. Unelicited somatosensory evoked potentials and spinal cord posterior column abnormalities in MRI were observed in sensory ataxic, painful and autonomic neuropathy. Sural nerve biopsy specimens ( $n=55$ ) revealed variable degrees of axon loss. Predominantly large fibre loss was observed in sensory ataxic neuropathy, whereas predominantly small fibre loss occurred in painful sensory neuropathy. Angiitis and perivascular cell invasion were seen most frequently in multiple mononeuropathy, followed by sensory ataxic neuropathy. The autopsy findings of one patient with sensory ataxic neuropathy showed severe large sensory neuron loss paralleling to dorsal root and posterior column involvement of the spinal cord, and severe sympathetic neuron loss. Degrees of neuron loss in the dorsal and sympathetic ganglion corresponded to segmental distribution of sensory and sweating impairment. Multifocal T-cell invasion was seen in the dorsal root and sympathetic ganglion, perineurial space and vessel walls in the nerve trunks. Differential therapeutic responses for corticosteroids and IVIg were seen among the neuropathic forms. These clinicopathological observations suggest that sensory ataxic, painful and perhaps trigeminal neuropathy are related to ganglioneuronopathic process, whereas multiple mononeuropathy and multiple cranial neuropathy would be more closely associated with vasculitic process.

**Keywords:** angiitis; autonomic nerve dysfunction; ganglionopathy; neuropathy; Sjögren's syndrome

**Abbreviations:** CMAP = compound muscle action potential; DL = distal motor latency; MIGB = meta-iodobenzylguanidine; MCV = motor nerve conduction velocity; NCS = nerve conduction studies; SNAP = sensory nerve action potential; SCV = sensory nerve conduction velocity; SEP = somatosensory evoked potential

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## Appendix

### Medline search\*

- (i) Cerebrovascular disorders/or exp basal ganglia cerebrovascular disease/or exp brain ischemia/or exp carotid artery diseases/or exp cerebrovascular accident/or exp dementia, vascular/or exp hypoxia-ischemia, brain/or exp intracranial arterial diseases/or exp 'intracranial embolism and thrombosis'/or exp intracranial hemorrhages/or exp vasospasm, intracranial/
- (ii) (Stroke\$ or cerebrovasc\$ or cerebral vasc\$).tw.
- (iii) 1 or 2
- (iv) lacun\$.tw.
- (v) ((lacunar or small or subcortical or silent) adj5 (infarct\$ or stroke)).tw.
- (vi) (small vessel adj5 (stroke\$ or occlusion or disease)).tw.
- (vii) 4 or 5 or 6
- (viii) 3 and 7
- (ix) Limit 8 to human.

\*A similar, appropriately adapted search was used for Embase.

## Introduction

Primary Sjögren's syndrome is a systemic autoimmune disease characterized by xerophthalmia and xerostomia, and is associated with systemic visceral involvement, including pneumonitis, renal tubular acidosis, pancreatitis, myositis, and occasionally lymphocytic proliferation. A wide variety of neurological complications also are characteristic features of primary Sjögren's syndrome (Attwood *et al.*, 1961; Alexander *et al.*, 1982; Delalande *et al.*, 2004). Peripheral neuropathy is a major neurological manifestation of Sjögren's syndrome and its aetiology has been considered to be vasculitis in the peripheral nerves, similar to that observed in other collagen diseases. In 1986 and 1990, it was demonstrated that dorsal root ganglionitis with degeneration of dorsal root ganglion neurons and mononuclear cell infiltration without vasculitis are associated with the sensory ataxic form of Sjögren's syndrome-associated neuropathy, suggesting that ganglion neurons themselves can be a target of Sjögren's syndrome (Malinow *et al.*, 1986; Griffin *et al.*, 1990).

Sjögren's syndrome-associated neuropathy has been shown to manifest as a variety of forms of neuropathy, including sensory ataxic neuropathy (Kennett *et al.*, 1986; Griffin *et al.*, 1990; Kaplan *et al.*, 1990; Sobue *et al.*, 1993), trigeminal neuropathy (Kaltreider *et al.*, 1969), multiple mononeuropathy (Peyronnard *et al.*, 1982; Molina *et al.*, 1985), radiculoneuropathy (Gross *et al.*, 1987; Grant *et al.*, 1997), painful sensory neuropathy without sensory ataxia (Denislic *et al.*, 1995; Mori *et al.*, 2003), autonomic neuropathy with anhidrosis (Kumazawa *et al.*, 1993; Goto *et al.*, 2000) and multiple cranial neuropathy (Touze *et al.*, 1999; Chu *et al.*, 2000; Urban *et al.*, 2001). While the wide spectrum of these neuropathies has been described in anecdotal reports or in studies of the systemic manifestations of Sjögren's syndrome (Mellgren *et al.*, 1989; Gemignani *et al.*, 1994; Mauch *et al.*, 1994), the pathogenic mechanism responsible for most forms of Sjögren's syndrome-associated neuropathy remains unresolved. Furthermore, the spectrum of neuropathy and neuropathic symptoms of each form of neuropathy, particularly in the pathological and electrophysiological background, have not been well elucidated. In addition, since the prevalence of Sjögren's syndrome is growing in the elderly (Lafitte *et al.*, 2001), Sjögren's syndrome-associated neuropathy also has become more prevalent. It is therefore necessary to re-evaluate the clinical spectrum, and pathological and electrophysiological features of Sjögren's syndrome-associated neuropathy.

In this study, we assessed the clinicopathological and electrophysiological features of a large number of patients associated with primary Sjögren's syndrome-associated neuropathy and determined the range of clinical manifestations of neuropathy.

## Patients and methods

### Patients

A total of 92 patients (76 women, 16 men; mean age, 59.7 years), all of Japanese descent, who fulfilled the diagnostic criteria for primary

Sjögren's syndrome and who had been referred to the Hospital of Nagoya University School of Medicine and its affiliated hospitals between 1985 and 2004 were the subjects of this study. The diagnosis of primary Sjögren's syndrome was established by the criteria proposed by the Diagnostic Committee of Health and Welfare of Japan (Fujibayashi *et al.*, 1999) and by the American-European Community (Vitali *et al.*, 2002). These criteria included symptoms of xerophthalmia and xerostomia, objective evidence of keratoconjunctivitis such as an abnormal Schirmer's test and an abnormal Rose Bengal score, evidence of chronic lymphocytic sialoadenitis on a minor salivary gland biopsy specimen, abnormal salivary gland scintigraphy or sialography, decreased salivary flow determined by a gum test and the presence of either anti-Sjögren's syndrome A or B (anti-SS-A or SS-B) autoantibodies (Fujibayashi *et al.*, 1999; Vitali *et al.*, 2002). Patients with other collagen diseases, such as systemic lupus erythematosus, rheumatoid arthritis, mixed connective tissue disease, progressive systemic sclerosis, polyarteritis nodosa, polymyositis and Churg–Strauss syndrome, diagnosed by the diagnostic criteria appropriate to each condition (Anonymous, 1980; Tan *et al.*, 1982; Arnett *et al.*, 1988; Masi *et al.*, 1990) and designated as having secondary Sjögren's syndrome, were excluded from this study. Patients underwent neurological examinations, blood studies, CSF studies, nerve conduction studies (NCS), sural nerve biopsies, somatosensory evoked potentials (SEPs) and spinal MRI.

A patient with the sensory ataxic form of Sjögren's syndrome-associated neuropathy who died at 88 years of age underwent autopsy and histological examination.

## Assessment of neurological symptoms, activities of daily living and autonomic nerve dysfunction

Neurological examinations for somatic motor and sensory symptoms were performed by at least one neurologist. Sensory examinations were performed for light touch, pinprick, vibratory sensation and joint position sense, as well as for the presence of sensory ataxia and pain or painful dysaesthesia. Muscle strength was assessed using the Medical Research Council scale. Cranial nerve function, Romberg's sign, walking pattern, deep tendon reflexes and pathological reflexes were also assessed. Autonomic symptoms were assessed as described elsewhere.

For the assessment of clinical disability on daily life the modified Rankin scale (van Swieten *et al.*, 1988) was used. For the assessment of autonomic nerve dysfunction, we evaluated pupil abnormalities, including presence of Adie's pupils, anisocoria and elliptic pupils, urinary disturbances, diarrhoea and constipation, hypohidrosis and anhidrosis, orthostatic hypotension and  $^{123}\text{I}$ -meta-iodobenzylguanidine (MIBG) cardiac accumulation. Autonomic symptoms generally were assessed by examining or interviewing patients or interviewing patients' family members, or reviewing the clinical records. Urinary symptoms were estimated by nocturnal or diurnal urinary frequency, a sensation of urgency, urinary incontinence, voiding difficulty and retention. Constipation was considered to be present if there were no stools for more than 3 days. Orthostatic hypotension was defined as a fall in systolic blood pressure of  $\geq 30$  mmHg upon standing from a recumbent position. For assessment of  $^{123}\text{I}$ -MIBG cardiac accumulation,  $^{123}\text{I}$ -MIBG 111 mBq (myo-MIBG- $^{123}\text{I}$  for injection; Daiichi Radioisotope Laboratories Co.,

Tokyo, Japan) was given intravenously in Lugol's solution (200 mg iodine) to block the thyroid uptake. Cardiac MIBG uptake was expressed as a heart/mediastinum ratio (H/M ratio) at 30 min (early scan) and 4 h (delayed scan) as described before (Watanabe *et al.*, 2001). Thermography and quantitative sweating measurements were performed on some selected patients as previously described (Kumazawa *et al.*, 1993).

### Nerve conduction studies and somatosensory evoked potentials

Motor and sensory NCS were performed in the median, tibial and sural nerves using a standard method as described before (Sobue *et al.*, 1989). Motor nerve conduction velocity (MCV), distal motor latency (DL) and compound muscle action potential (CMAP) were recorded for the median and tibial nerves. Sensory nerve conduction velocity (SCV) and sensory nerve action potential (SNAP) were assessed for the median and sural nerves. Control values were obtained in 191 normal volunteers (mean age  $\pm$  SD, 48.7  $\pm$  16.5 years; men : women, 97 : 94) for the median nerve, 121 (mean age  $\pm$  SD, 49.9  $\pm$  15.0; men : women, 64 : 57) for the tibial nerve and 133 (mean age  $\pm$  SD, 50.6  $\pm$  15.6; men : women, 74 : 59) for the sural nerve (Koike *et al.*, 2001). Blink reflexes were recorded using a standard technique (Kimura, 2001).

SEPs were recorded using median nerve stimulation at the wrist (Kachi *et al.*, 1994). Cortical (N20), cervical (N13), and Erb's point (N9) peaks were assessed by separate stimulation. Controls of the latency of SEPs were obtained in 37 normal volunteers (mean age  $\pm$  SD, 38  $\pm$  7 years).

### Sural nerve biopsy and autopsy study

Sural nerve biopsies were performed in 55 patients as described previously (Sobue *et al.*, 1989). Informed consent was established beforehand. Sural nerve biopsy specimens were examined by standard light microscopic methods and by teased fibre techniques. Specimens were divided into two portions. The first portion was fixed in 2.5% glutaraldehyde solution in 0.125 M cacodylate buffer (pH 7.4) and then embedded in an epoxy resin for morphometric and ultrastructural study. Density of myelinated fibres and morphological features were assessed in sections embedded in the epoxy resin and stained with toluidine blue using a computer-assisted image analyser (Luzex FS; Nikon, Tokyo, Japan), and densities of small and large myelinated fibres were calculated as described previously (Sobue *et al.*, 1989; Koike *et al.*, 2001). Some parts of specimens were processed for teased fibre study and were assessed for pathological conditions according to criteria described previously (Sobue *et al.*, 1989; Dyck *et al.*, 1993). For electron microscopic examination, epoxy resin-embedded specimens were processed for ultrathin sectioning. To assess the density of unmyelinated fibres, electron microscopic photomicrographs at a magnification of  $\times 4000$  were taken in random fashion to cover the ultrathin transverse section. The density of the unmyelinated fibres was estimated from the photomicrographs using a computer-assisted image analysis system.

For the autopsy study, the brain, spinal cord, sympathetic and sensory ganglia, peripheral nerve trunks, submandibular and subauricular salivary glands as well as various visceral organs were sampled systemically at the time of autopsy and examined in paraffin and epoxy-resin embedded sections.

### MRI assessment of cervical spinal cord

A total of 27 patients underwent MRI of the cervical spinal cord, including the C4 level on a 1.5 T unit. We used axial T2\*-weighted gradient echo images (repetition time/echo time/excitations, 700/21/3; flip angle, 20°; matrix, 256  $\times$  256) as described previously (Yasuda *et al.*, 1994; Sobue *et al.*, 1995; Mori *et al.*, 2001). MRI findings were assessed on their distributions of abnormal high intensity area in the posterior columns of the spinal cord.

### Laboratory data

Routine blood tests were performed, including anti-SS-A and anti-SS-B antibodies. These autoantibodies were detected using enzyme-linked immunosorbent assay and immunoblotting [Mesacup-2 test, according to the manufacturer's instructions (MBL, Ltd. Japan)]. Alpha-fodrin, a candidate autoantigen for Sjögren's syndrome (Haneji *et al.*, 1997) also was examined as follows. The purified recombinant N-terminal portion of alpha-fodrin and GST (glutathione-S-transferase) fusion protein (IS-1) were loaded onto 10% polyacrylamide gels and transferred to nitrocellulose membranes by electroblotting. The membranes were blocked overnight at room temperature with Tris-buffered saline containing 3% non-fat dry milk. The membranes were incubated with sera from patients with Sjögren's syndrome (1 : 200 dilution) for 4 h at room temperature. Then, bound antibodies were detected with biotinylated anti-human IgG antibodies and alkaline phosphatase-conjugated streptavidin (both from Jackson ImmunoResearch, West Grove, PA) using 5-bromo-4-chloro-3-indolyl phosphate and nitro blue tetrazolium as substrates.

### Statistical analysis

All statistical analyses were performed using the Mann-Whitney U-test. *P*-values of <0.05 were considered significant.

## Results

### General clinical features and classification of neuropathy

All 92 patients fulfilled the diagnostic criteria for Sjögren's syndrome (Fujibayashi *et al.*, 1999; Vitali *et al.*, 2002). The majority of patients (86 patients) were diagnosed as having Sjögren's syndrome after neurological symptoms developed, while only six patients were diagnosed with Sjögren's syndrome before the neurological symptoms appeared. Thus most of the patients had been followed for a neuropathy of unknown cause for a while before being diagnosed with Sjögren's syndrome. We classified these patients into seven forms of neuropathy: sensory ataxic neuropathy, painful sensory neuropathy without sensory ataxia, multiple mononeuropathy, multiple cranial neuropathy, trigeminal neuropathy, autonomic neuropathy and radiculoneuropathy, based on the predominant neuropathic symptoms. Sensory ataxic neuropathy was defined as one with sensory neuropathy predominantly manifesting as impairment of joint-position sense leading to sensory ataxia but preserved muscle power, muscle volume and motor nerve function (Sobue *et al.*, 1993). A total of 36 patients were included in the sensory ataxic neuropathy group. Painful neuropathy without sensory ataxia (Mori

*et al.*, 2003) was another form of sensory neuropathy but with predominant involvement of superficial sensation of pain and light touch sense without or with minor impairment of deep sensation resulting in a painful sensory neuropathy without sensory ataxia. Motor function was well preserved with this neuropathy. Eighteen patients were included in this group. Eleven patients were considered to have multiple mononeuropathy. This form of neuropathy was characterized by multiple mononeuropathy mainly distributed in the distal portion of the limbs with both motor and sensory involvement. Sensory involvement generally included both superficial and deep sensation. Twenty patients were classified as having cranial neuropathy. Of the 20, 5 patients had multiple cranial neuropathy and 15 patients had isolated trigeminal neuropathy. Multiple cranial neuropathy affects multiple cranial motor and sensory nerves including the trigeminal nerve. Trigeminal neuropathy was defined as a pure sensory neuropathy restricted to the territory of the sensory trigeminal nerves. Autonomic neuropathy was characterized by predominant autonomic dysfunction. Three patients were considered to have this neuropathy. Radiculoneuropathy was defined by lesions restricted predominantly to the spinal roots or the very proximal portion of the spinal nerves. Radiculoneuropathy often mimics chronic inflammatory demyelinating polyneuropathy. Four patients were included in this category of neuropathy.

The age at first examination and the age of onset of neuropathic symptoms varied to some extent, but did not differ among the forms of neuropathy (Table 1). A female predominance was commonly observed in all of the neuropathies. Sjögren's syndrome-related symptoms also were seen at similar rates among the neuropathies. More than half of the patients had sicca syndrome, manifested by either xerophthalmia or xerostomia. Schirmer's test and the Rose Bengal test were positive in >50% of the examined patients. Almost all of the examined patients had either lymphocytic infiltration of the salivary glands, salivary gland cell destruction or both on minor salivary gland biopsy. Sialography and salivary scintigraphy also were positive in a majority of patients in each neuropathic group. Antibodies to SS-A and SS-B were present in 20–100% and 0–50% of patients in each neuropathic group, respectively. Only 13 patients were both SS-A and SS-B positive. Anti-alpha-fodrin antibodies were detected in 60–100% of patients in each neuropathic group. This positive rate was extremely high as compared with those in the control group without neuropathy (<14% positive), while it was not significantly different between neuropathic groups. Mild increases in the CSF protein concentration were seen in some of the patients examined.

As complicating systemic inflammatory symptoms, hypothyroidism was seen in nine patients, dyshaematopoietic anaemia in two patients, interstitial pneumonia in three patients, myositis in one patient, liver dysfunction in four patients, pancreatitis in two patients, renal involvement in one patient and lymphoma in one patient (Table 1).

## Neuropathic features of each form of neuropathy

### Sensory ataxic neuropathy

A total of 36 patients had this form of neuropathy (Table 2). This neuropathy was characterized by sensory ataxia due to kinaesthetic deep sensory impairment without substantial motor symptoms. The initial symptom was usually paraesthesias in the digits of the foot or hand. These paraesthesias were often unilateral, and gradually spread to the limbs, trunk and face. In three patients, the initial paraesthesia was localized to the trigeminal nerve area. The time from the onset to the development of full-blown symptoms of sensory involvement was variable among the patients, weeks to months in four patients, but usually months to years. The sensory symptoms were mostly asymmetrical, segmental or multi-focal rather than presenting as a symmetrical polyneuropathy, particularly in the progression stage. Ten patients had trigeminal nerve involvement. Muscle weakness and mild atrophy were observed in four patients. Sensory impairment was mostly deep sensory predominant with Romberg's sign and pseudoathetosis being present in all of the patients. Pain or painful dysaesthesia was present in 18 patients. A total of 10 and 20 patients showed facial and truncal sensory involvement, respectively. There was generalized areflexia in all patients. The walking pattern was characteristic of sensory ataxia. In the patients with advanced disease, they were unable to walk and were wheel-chair bound.

With respect to autonomic symptoms, 17 of the 30 assessed patients exhibited abnormal pupils including Adie's pupils associated with anisocoric and elliptic pupils (Table 3). Orthostatic hypotension was present in 12 patients, mostly without syncope. Hypohidrosis or anhidrosis was observed in 21 patients, often with segmental anhidrosis in the trunk (Fig. 1). Marked decreases in <sup>123</sup>I-MIBG cardiac uptake were present in 8 of the 11 patients who were examined.

With respect to nerve conduction, SNAPs in the median and sural nerves were not evoked in 61 and 50% of patients, respectively (Table 4). In contrast, CMAPs were fairly well preserved in most patients. MCV and SCV were not slowed. Temporal dispersion of the CMAPs or conduction block was not seen. SEPs were not evoked in 67, 73 and 40% of the examined patients in N20, N13 and N9, respectively (Table 4). These conduction studies indicate that axonal features were almost exclusively present in this neuropathy, and the central rami of sensory ganglion neurons were also involved in parallel.

T2\*-weighted MRI demonstrated posterior column high intensity signal in 9 of the 12 examined patients (Table 4; Fig. 1). The extent of dorsal column high intensity T2\* signal was well correlated with the distribution and intensity of sensory involvement and sensory ataxia, indicating the presence of central rami involvement due to sensory ganglion neuron damage (Mori *et al.*, 2001).

Sural nerve biopsy was performed in 31 patients (Table 5). Total myelinated fibre density was variably reduced, ranging

**Table 1** Clinical features of patients with peripheral neuropathy associated with Sjögren's syndrome

Clinical features	Sensory neuropathy		Multiple mononeuropathy (n = 11)	Cranial neuropathy		Autonomic neuropathy (n = 3)	Radiculo-neuropathy (n = 4)
	Ataxic (n = 36)	Painful (n = 18)		Multiple (n = 5)	Trigeminal (n = 15)		
Age (years)	65.2 ± 7.8	58.1 ± 15.9	59.1 ± 18.2	55.6 ± 12.7	55.6 ± 9.4	46.3 ± 18.0	57.0 ± 11.0
Age of onset of neuropathy (years)	64.9 ± 12.9	56.0 ± 13.8	58.1 ± 13.5	55.1 ± 14.8	51.7 ± 11.6	42.5 ± 17.4	49.0 ± 12.2
Sex, women:n (n)	26:10	16:2	10:1	4:1	15:0	2:1	3:1
Follow-up (years) (range)	5.7 ± 4.6 (1–18)	3.6 ± 2.8 (1–12)	2.3 ± 1.3 (1–4)	5.2 ± 6.6 (1–7)	7.0 ± 4.1 (2–10)	1.7 ± 1.6 (1–3)	7.3 ± 3.8 (3–10)
Sjögren's syndrome							
Dry eye: n (%)	20 (56)/23 (64)	13 (72)/12 (67)	7 (64)/7 (64)	3 (60)/2 (40)	10 (67)/10 (67)	2 (67)/2 (67)	2 (50)/2 (50)
Dry mouth: n (%)							
Positive findings							
Schirmer's test: n (%)	27/29 (93)	14/15 (93)	7/8 (88)	5/5 (100)	8/10 (80)	3/3 (100)	2/4 (50)
Rose Bengal test: n (%)	20/29 (69)	11/12 (92)	6/6 (100)	3/5 (60)	8/9 (89)	2/2 (100)	ND
Salivary gland biopsy: n (%)	26/28 (93)	13/16 (81)	8/9 (89)	5/5 (100)	11/11 (100)	2/2 (100)	4/4 (100)
Sialography, cistigraphy: n (%)	9/10 (90)	6/6 (100)	3/3 (100)	2/3 (67)	8/8 (100)	1/1 (100)	ND
SS-A: n (%)	19/36 (53)	7/18 (39)	7/11 (64)	1/5 (20)	6/15 (40)	2/3 (67)	4/4 (100)
SS-B: n (%)	4/36 (11)	3/18 (17)	2/11 (18)	1/5 (20)	0/15 (0)	1/3 (33)	2/4 (50)
Alpha-fodrin: n (%)	14/16 (88)	6/7 (86)	3/5 (60)	5/5 (100)	2/2 (100)	1/1 (100)	3/3 (100)
CSF protein elevation: n (%)	8/23 (35)	3/10 (30)	5/8 (63)	1/3 (33)	0/1 (0)	0/1 (0)	4/4 (100)
Associated symptoms (n)	T (4), P (2), Pa (2), L (3), Ly (1)	T (2), A (2), R (1), P (1), M (1)	T (2)	—	—	—	T (1), L (1)

n/n, positive patient number to all examined patient number. As for associated symptoms, T, hypothyroidism; P, interstitial pneumonia; Pa, pancreatitis; A, anaemia; M, myositis; L, liver dysfunction; Ly, lymphoma; R, renal involvement.



Table 2 Neuropathic symptoms

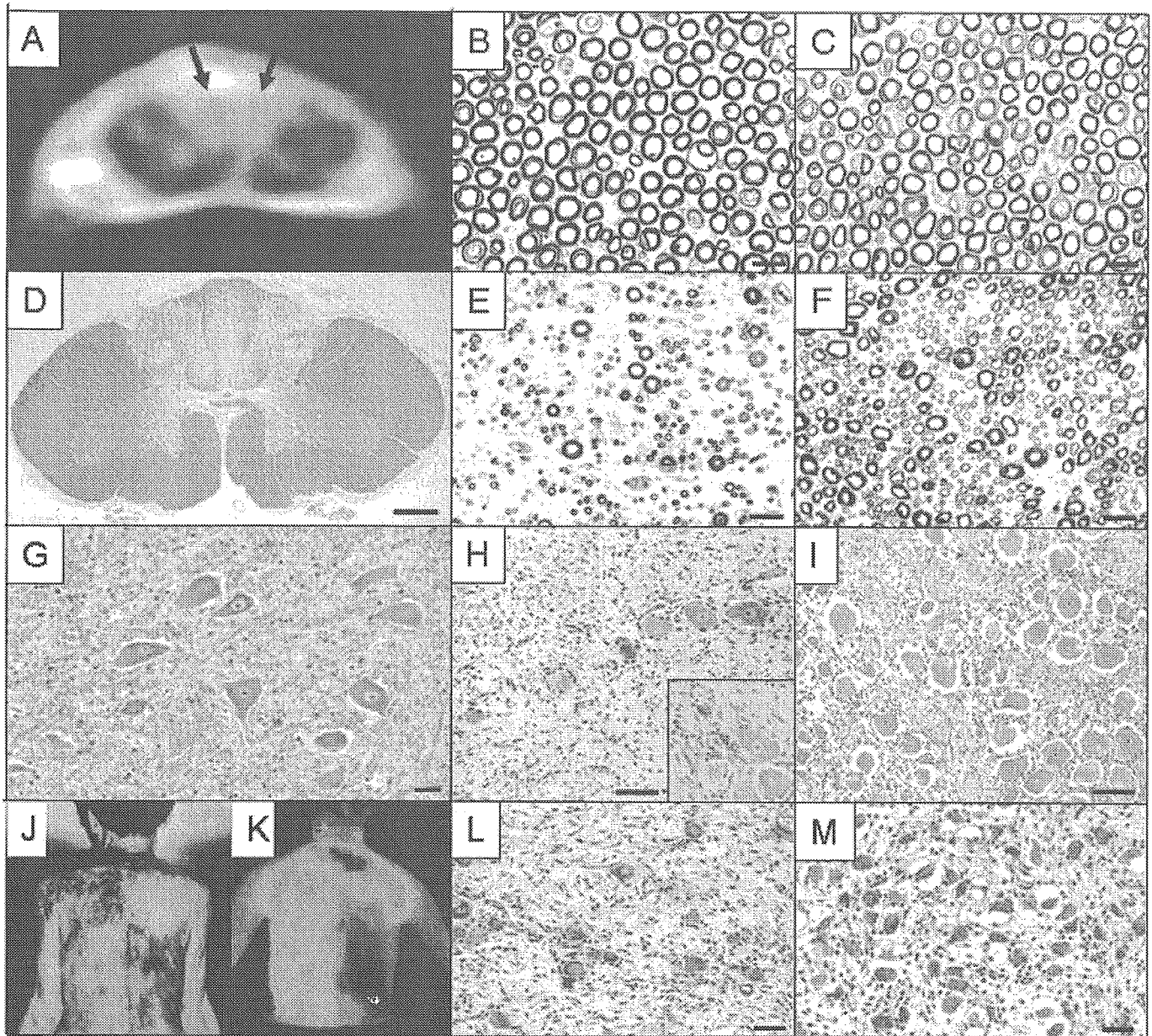
Clinical features	Sensory neuropathy		Multiple mononeuropathy (n = 11)	Cranial neuropathy		Autonomic neuropathy (n = 3)	Radiculoneuropathy (n = 4)
	Ataxic (n = 36)	Painful (n = 18)		Multiple (n = 5)	Trigeminal (n = 15)		
<b>Initial symptom</b>							
Sensory disturbance: n (%)	36 (100)	3 (17)	11 (100)	0 (0)	15 (100)	0 (0)	4 (100)
Pain/painful dysaesthesia: n (%)	0 (0)	18 (100)	1 (9)	1 (20)	2 (13)	0 (0)	0 (0)
Weakness: n (%)	0 (0)	0 (0)	8 (73)	0 (0)	0 (0)	0 (0)	2 (50)
Autonomic symptoms: n (%)	0 (0)	1 (6)	0 (0)	0 (0)	0 (0)	3 (100)	0 (0)
Cranial nerve symptoms: n (%)	3* (8)	0 (0)	1 (9)*	5 (100)	15 (100)	0 (0)	1 (25)**
<b>Initial progression</b>							
Acute: n (%)	0 (0)	3 (17)	2 (18)	3 (60)	0 (0)	1 (33)	0 (0)
Subacute: n (%)	4 (11)	1 (6)	4 (36)	0 (0)	3 (20)	0 (0)	1 (25)
Chronic: n (%)	32 (89)	14 (78)	5 (45)	2 (40)	12 (80)	2 (67)	3 (75)
Cranial nerve involvement: n (nerve)	10 (V)	8 (V)	2 (V)	2 (III), 3 (V), 2 (VI), 3 (VII), 3 (IX), 3 (X), 1 (XII)	15 (V)	1 (V)	1 (III)
Muscle weakness/atrophy: n (%)	4 (11)	1 (6)	10 (91)	0 (0)	0 (0)	0 (0)	2 (50)
Sensory impairment: n (%)	36 (100)	18 (100)	11 (100)	3 (60)	15 (100)	2 (67)	4 (100)
<b>Modality</b>							
Deep > superficial sensation: n (%)	33 (92)	0 (0)	1 (9)	0 (0)	0 (0)	1 (33)	3 (75)
Deep = superficial sensation: n (%)	3 (8)	0 (0)	7 (64)	0 (0)	0 (0)	1 (33)	1 (25)
Superficial > deep sensation: n (%)	0 (0)	18 (100)	3 (27)	3 (60)	15 (100)	0 (0)	0 (0)
Pain/painful dysaesthesia: n (%)	18 (50)	18 (100)	7 (64)	1 (20)	2 (13)	0 (0)	0 (0)
Sensory ataxia: n (%)	36 (100)	2 (11)	1 (9)	0 (0)	0 (0)	2 (67)	2 (50)
<b>Distribution</b>							
Face: n (%)	10 (28)	8 (44)	2 (18)	3 (60)	15 (100)	1 (33)	0 (0)
Trunk: n (%)	20 (56)	10 (56)	2 (18)	2 (40)	0 (0)	2 (67)	1 (25)
Limbs: n (%)	36 (100)	18 (100)	11 (100)	2 (40)	2 (13)	2 (67)	4 (100)
Areflexia: n (%)	36 (100)	9 (50)	7 (64)	0 (0)	0 (0)	2 (67)	4 (100)
Modified Rankin scale (mean ± SD)	3.3 ± 0.8	2.3 ± 0.8	2.3 ± 0.8	—	—	3.3 ± 1.2	2.3 ± 1.3
(range)	(2–5)	(1–4)	(1–3)			(2–4)	(1–4)

Cranial nerve symptoms in initial symptom: \*, trigeminal nerve lesion; \*\*, diplopia and ptosis. Modified Rankin scale: 0, asymptomatic; 1, non-disabling symptoms not interfering with lifestyle; 2, mildly disabling symptoms leading to some restrictions of lifestyle but not interfering with capacity to look after oneself; 3, moderately disabling symptoms significantly interfering with lifestyle or precluding totally independent existence; 4, moderately severe disability precluding independent existence while not requiring constant attention around the clock; 5, severe disability with total dependency requiring constant attention day and night.

Table 3 Autonomic symptoms

Clinical features	Sensory neuropathy		Multiple mononeuropathy (n = 6)	Cranial neuropathy		Autonomic neuropathy (n = 3)	Radiculoneuropathy (n = 4)
	Ataxic (n = 30)	Painful (n = 16)		Multiple (n = 5)	Trigeminal (n = 9)		
Abnormal pupils: n	17	3	0	1	3	3	0
Orthostatic hypotension: n	12	5	0	0	3	3	0
Faint: n	0	0	0	0	0	3	0
Hypohidrosis/anhidrosis: n	21	10	3	2	4	3	2
Diarrhoea: n	6	0	1	0	1	3	0
Constipation: n	6	5	2	1	1	3	2
Vomiting: n	2	0	0	0	0	1	0
Urinary disturbance: n	1	3	0	0	0	2	1
Decreased uptake of <sup>123</sup> I-MIBG: n	8/11	5/7	ND	ND	ND	2/2	0/2
Total: n	21/30	11/16	3/6	2/5	4/9	3/3	2/4

Decreased uptake of <sup>123</sup>I-MIBG = the <sup>123</sup>I-MIBG heart/mediastinum ratio (H/M ratio) of delayed scan was <1.8 (control–2 SD) (Hamada et al., 2003). n/n, positive patient number to all examined patient number; ND, not determined.



**Fig. 1** Pathological findings, MRI and sweating assessment of an autopsied patient with the sensory ataxic neuropathy. (A) Axial T2\*-weighted gradient echo image of the cervical spinal cord (C4) of the patient. A high intensity area is present in the posterior column including both fasciculus cuneatus and gracilis as indicated by arrows. (B and C) Cross-section of the L4 ventral spinal root. Myelinated fibres are well preserved in the patient (B) and control (C). Scale bar = 20  $\mu\text{m}$ . (D) Cross-section of the dorsal column of the cervical spinal cord. Axons are almost completely lost. Klüver–Barrera's stain. Scale bar = 1 mm. (E and F) Cross-section of the L4 dorsal spinal root. Large myelinated fibres are severely lost in the patient (E) compared with the control (F). Scale bar = 20  $\mu\text{m}$ . (G) Cross-section of the L4 ventral horn. The population of the anterior horn cell is well preserved. Klüver–Barrera's stain. Scale bar = 40  $\mu\text{m}$ . (H) Cross-section of the L4 dorsal root ganglion. The population of the nerve cell is decreased (H). Nageotte's nodules are occasionally seen (H). (I) Control. Klüver–Barrera's stain. Scale bar = 100  $\mu\text{m}$ . (J) Thermal sweating measured by Minor's iodine–starch test in an artificial climate chamber at an ambient temperature of 40°C and 40% relative humidity. The area of anhidrosis was very distinct and distributed in a segmental manner. (K) Plain thermograms monitored by infrared thermography. Surface skin temperature was also segmental in distribution (quoted from Kumazawa et al., 1993 with permission for publication). (L) Section of the thoracic sympathetic ganglion. The population of the nerve cell bodies is decreased (L) compared with control case (M). Klüver–Barrera's stain. Scale bar = 40  $\mu\text{m}$ .

from 131 to 6918/mm<sup>2</sup> (mean  $\pm$  SD, 3287  $\pm$  2843/mm<sup>2</sup>), and that of unmyelinated fibres was also reduced. Mean densities of large, small myelinated and unmyelinated fibres were reduced to 18, 56 and 75% of normal controls, respectively,

indicating large fibre predominant loss. Axonal sprouts were not conspicuous in any case. In teased-fibre preparations, axonal degeneration was observed in 30.9  $\pm$  36.1% of samples, while segmental demyelination was seen in only

Table 4 Nerve conduction, sensory evoked potentials, and spinal cord MRI study

Nerve conduction, SEP and MRI	Sensory neuropathy			Cranial neuropathy		Autonomic neuropathy	Radiculo-neuropathy	Controls
	Ataxic	Painful	Multiple mononeuropathy	Multiple	Trigeminal			
Nerve conduction study	n = 36	n = 18	n = 11	n = 5	n = 15	n = 3	n = 4	n = 12 (1–19)
Median nerve								
MCV (m/s)	53.1 ± 4.0	53.3 ± 33.2	51.3 ± 3.7	51.2 ± 8.1	54.7 ± 3.5	53.2 ± 0.7	50.5 ± 10.3	57.8 ± 3.7
DL (ms)	3.7 ± 0.5	3.4 ± 0.2	3.5 ± 0.4	4.0 ± 0.5	3.9 ± 1.3	3.7 ± 0.6	4.4 ± 2.0	3.4 ± 0.4
CMAP (mV)	11.1 ± 2.8	11.2 ± 4.0	10.4 ± 2.4	11.4 ± 3.0	12.7 ± 3.4	10.5 ± 2.7	5.6 ± 3.1**	10.7 ± 3.5
SCV (m/s)	50.0 ± 4.7	51.5 ± 3.5	49.6 ± 7.8	61.4 ± 1.3	55.1 ± 2.6	58.5 ± 0.3	50.8 ± 9.5	57.8 ± 4.7
SNAP (µV)	4.1 ± 9.0***	4.4 ± 6.6***	4.9 ± 4.7***	23.9 ± 1.9	11.3 ± 4.1	25.6 ± 4.0	22.2 ± 1.0	23.5 ± 8.4
N.E. (%)	61	11	18	0	0	33	0	0
Tibial nerve								
MCV (m/s)	43.5 ± 2.8	44.5 ± 3.3	38.6 ± 3.9	48.3 ± 4.2	43.7 ± 2.3	44.7 ± 1.2	43.5 ± 1.1	46.9 ± 3.5
DL (ms)	4.8 ± 0.8	4.5 ± 0.4	5.1 ± 1.1	4.7 ± 1.0	5.1 ± 0.2	4.2 ± 0.9	6.0 ± 3.4	4.5 ± 0.8
CMAP (mV)	10.5 ± 7.0	14.5 ± 6.8	6.5 ± 9.1*	12.2 ± 9.1	16.4 ± 5.2	12.6 ± 1.0	9.2 ± 3.3*	10.9 ± 3.8
Sural nerve								
SCV (m/s)	45.3 ± 2.8	46.7 ± 6.5	46.4 ± 3.1	50.3 ± 3.5	53.4 ± 1.2	46.8 ± 0.0	45.0 ± 5.1	51.0 ± 5.1
SNAP (µV)	2.2 ± 3.6***	8.1 ± 8.1***	1.3 ± 1.5***	20.5 ± 3.5	22.5 ± 2.3	10.3 ± 1.4	18.3 ± 1.5	11.5 ± 4.7
N.E. (%)	50	17	55	0	0	33	0	0
SEP	n = 15	n = 8				n = 3	n = 4	n = 37
Median nerve stimulation								
N20 latency (ms)	20.2 ± 2.1	20.9 ± 2.3	ND	ND	ND	19.5 ± 0.7	21.4 ± 3.2	18.9 ± 1.1
N.E. (%)	67	0	ND	ND	ND	33	0	0
N13 latency (ms)	13.1 ± 0.8	14.4 ± 1.9	ND	ND	ND	13.1 ± 0.6	14.8 ± 2.6	12.8 ± 1.0
N.E. (%)	73	0	ND	ND	ND	33	0	0
N9 latency (ms)	9.1 ± 0.9	9.8 ± 0.9	ND	ND	ND	8.9 ± 0.4	10.1 ± 1.2	8.6 ± 0.6
N.E. (%)	40	13	ND	ND	ND	33	0	0
MRI	n = 12	n = 8	ND	ND	ND	n = 3	n = 4	
Spinal cord abnormality	9†	3†	ND	ND	ND	1†	4†	

Values are expressed as mean ± SD. Control values are those described previously (Kojak et al., 2001). MCV, motor nerve conduction velocity; DL, distal latency; CMAP, compound muscle action potentials; SCV, sensory nerve conduction velocity; SNAP, sensory nerve action potentials; N.E., not evoked; SEP, somatosensory evoked potentials; control values are from 37 conduction times. \*P < 0.05, \*\*P < 0.01, \*\*\*P < 0.001 as compared with control value. †In T2\* weighted gradient echo images, a high intensity area is present in the posterior column. ‡In T1 weighted echo images. Posterior spinal roots and cauda equina are enhanced by gadolinium.

Table 5 Pathological findings in the sural nerve

Clinical features	Sensory neuropathy		Multiple mononeuropathy (n = 8)	Cranial neuropathy		Autonomic neuropathy (n = 2)	Radiculo-neuropathy (n = 4)	Controls (n = 7)
	Ataxic (n = 31)	Painful (n = 9)		Multiple (n = 0)	Trigeminal (n = 1)			
Myelinated fibre density (no./mm <sup>2</sup> )								
Total	3287 ± 2843**	4105 ± 2260**	1153 ± 920**	ND	8010	2974	5985 ± 1890*	8220 ± 614
Large	579 ± 697***	2039 ± 1136*	226 ± 262**	ND	2994	1113	1593 ± 913*	3150 ± 383
Small	2878 ± 2482*	2056 ± 1267**	927 ± 672***	ND	5111	1811	4391 ± 977	5071 ± 397
Small/large	13.7 ± 18.1**	0.9 ± 0.5*	10.3 ± 12.0*	ND	1.7	2.9	3.1 ± 1.2	1.6 ± 0.2
Unmyelinated fibre density (no./mm <sup>2</sup> )	22 643 ± 9477*	9879 ± 9203**	ND	ND	ND	14 822	ND	29 901 ± 2623
Segmental de-/remyelination (%)	9.7 ± 9.4	10.0 ± 2.5	13.3 ± 13.1	ND	2.5	7.0	14.5 ± 9.2	7.2 ± 6.5
Axonal degeneration (%)	30.9 ± 36.1**	19.0 ± 16.1	61.0 ± 53**	ND	0	12.5	3.5 ± 4.9	1.4 ± 1.6
Vasculitis: n (%)	6 (19)	0 (0)	5 (63)	ND	0 (0)	0 (0)	0 (0)	—
Perivascular cell invasion: n (%)	9 (29)	1 (11)	6 (75)	ND	0 (0)	0 (0)	1 (25)	—

Values are expressed as mean ± SD. Control values (mean ± SD) were obtained from autopsy material and expressed as mean ± SD for 7 cases. (Koike et al., 2004). ND, not determined; Small < 6.73 µm; large ≥ 6.73 µm in fibre diameter (Sobue et al., 1989); \*p < 0.05, \*\*p < 0.01, \*\*\*p < 0.001 as compared with control values.

9.7 ± 9.4% of samples, indicating that axonal changes are the predominant pathological feature. Chronic vasculitis of the arterioles in the epineurial space was seen in six patients and mild perivascular lymphocyte infiltrates in the small vessels were also seen in nine patients.

#### Painful sensory neuropathy without sensory ataxia

A total of 18 patients had this form of neuropathy (Table 2). The initial symptoms were painful dysaesthesia in the most distal portions of the limbs, usually in unilateral limbs. In three patients, the initial progression was acute, occurring in days, and painful dysaesthesias were present over the entire body, including the trunk and face. In a majority of patients, spread of the dysaesthesias was chronic, occurring over months to years. The trigeminal nerve was involved in eight patients. Sensory impairment was relatively predominant with respect to superficial sensation of pain, temperature and light touch, and was associated with pain or painful dysaesthesia. Deep sensation was relatively well preserved, and motor function also was preserved. However, mild sensory ataxia in the limbs was seen in two patients. The face and trunk were involved in 8 and 10 patients, respectively, and segmental in distribution in some patients. In contrast to the sensory ataxic form, deep tendon reflexes were fairly well preserved in half of the patients. Seven patients could not walk because of severe pain.

Eleven patients showed symptoms consistent with autonomic neuropathy (Table 3). Abnormal pupils, including Adie's pupils and elliptic pupils, were seen in three patients. Orthostatic hypotension and hypohidrosis or anhidrosis were present in 5 and 10 patients. Segmental distribution of anhidrosis was often seen in the trunk. A severe decrease in <sup>125</sup>I-MIBG cardiac uptake was seen in five of the seven examined patients. These results suggest that autonomic nerves are also widely involved in this form of neuropathy.

In contrast to sensory ataxic neuropathy, unelicited SNAPs were present in only 11 and 17% of median and sural nerves, respectively (Table 4). SCV was well preserved. MCV showed no slowing and CMAPs were well preserved. Cortical (N20) and cervical (N13) SEP were elicited in all of the examined patients and Erb's point (N9) SEP was not elicited in only one patient examined.

T2\*-MRI of the spinal cord showed minimal high intensity signal in the posterior column in three out of the eight patients studied (Table 4). The extent of high intensity signal in these patients was relatively small compared with those seen with sensory ataxic neuropathy. The sural nerve biopsy specimen in nine patients mostly showed small fibre loss (Table 5). Mean densities of large, small myelinated and unmyelinated fibres were reduced to 65, 41 and 33% of normal control, respectively, indicating small fibre predominant loss. Axonal sprouts were essentially absent. In teased-fibre preparations, axonal degeneration was seen in 19.0 ± 16.1% of fibres, predominantly in the small-diameter fibres. Perivascular cell invasion was also present in one patient.

These relatively well preserved SNAPs and SEPs, and mild T2\* posterior column abnormalities on MRI as well as the predominant decrease in small myelinated and unmyelinated fibres in the sural nerve suggest that small sensory neurons are predominantly impaired and large diameter sensory neurons are fairly well preserved in this form of neuropathy.

Patients were followed-up for 1–12 years. Deep sensory impairment developed in three patients over nine years. They showed sensory ataxia in the legs and fingers. Other patients showed persistent painful sensory neuropathy with a gradual extension of the distribution of the neuropathy, without sensory ataxia.

### *Multiple mononeuropathy*

A total of 11 patients showed a form of multiple mononeuropathy (Table 2). The initial symptom of neuropathy was the acute onset of a tingling sensation or painful dysaesthesia in the distal portion of the limbs. Subsequently, motor and sensory symptoms episodically occurred and extended to the distribution of a multiple mononeuropathy pattern mostly restricted to the limbs. Initial progression was acute or subacute in half of the patients. Trigeminal nerves and truncal intercostal nerves were involved in only two patients, respectively. Impairment during one episode subsequently disappeared, and another area of sensory impairment developed in some patients. Sensory impairment involved all modalities of both superficial and deep sensation. Muscle weakness was evident in the involved limbs, but sensory symptoms were generally more pronounced. Perinuclear antineutrophil cytoplasmic antibody (p-ANCA) and cryoglobulins were negative in all the patients examined. Systemic autonomic symptoms were relatively rare (Table 3). CMAPs and SNAPs in the involved nerves were markedly reduced (Table 4). Both large and small myelinated fibres were markedly depleted with prominent active axonal degeneration in the sural nerves. The most prominent histological feature was the frequent occurrence of vasculitic lesions associated with perivascular cellular invasions (Table 5).

### *Multiple cranial neuropathy*

Five patients had multiple cranial neuropathy (Table 2). Involvement of the cranial nerves was bilateral VII nerve involvement in one patient, recurrent III and VI nerve involvement in one patient, III, V, VI, VII, IX and X nerve involvement in one patient, V, IX and X nerve involvement in one patient, and V, VII, IX, X and XII nerve involvement in one patient. Abnormal pupils were seen in one patient (Table 3). Three patients had acute onset of the neuropathy. With respect to extra-cranial symptoms, painful dysaesthesia in the limbs was detected in the initial phase in one patient, and truncal and limb sensory impairment developed in two patients during the follow-up. All patients had cranial motor nerve involvement in spite of the fact that the extent and degree of cranial nerve involvement was variable among the patients.

### *Trigeminal neuropathy*

A total of 15 patients had a pure sensory trigeminal neuropathy (Table 2). Nine patients had unilateral involvement and six had bilateral involvement. Numbness or paraesthesia restricted to the trigeminal nerve region was the characteristic feature. Appreciation of pin prick and soft touch was diminished in the trigeminal nerve region, and dysaesthesia was present. Dysaesthesia of the tongue was present in one patient. Motor symptoms referable to trigeminal nerve involvement were not seen. The progression of these symptoms was indolent in most patients. Sensory disturbances in the limbs were seen in two patients. Pupillary abnormalities were seen in three patients, and orthostatic hypotension and hypohidrosis were observed in three and four patients, respectively (Table 3). There were no marked abnormalities in the routine nerve conduction of the limbs (Table 4). Blink reflex tests were performed in three patients with unilateral involvement, which confirmed trigeminal nerve involvement on the affected side (data not shown). Nerve biopsy was obtained from one patient, the findings of which were normal (Table 5).

### *Autonomic neuropathy*

Three patients had predominant and severe autonomic symptoms and were designated as autonomic neuropathy (Tables 2 and 3). All three patients showed Adie's pupils and all patients also showed severe orthostatic hypotension with syncope. Hypohidrosis or anhidrosis also was present in the trunk and all four limbs. All patients developed abdominal pain, constipation and diarrhoea. Cardiac <sup>123</sup>I-MIBG uptake was reduced in two patients examined. Lack of plasma norepinephrine increase in response to standing and hypersensitive blood pressure increase beyond 25 mmHg in response to low concentration of norepinephrine infusion at 3 µg/min were seen in two patients examined. These observations suggest that peripheral sympathetic nervous system was severely involved in this form of neuropathy. Limb and truncal sensory impairment was present with sensory ataxia, but without motor involvement. These symptoms appeared chronically. The SNAPs and SEPs were unelicited and high intensity MRI signal in the posterior column of the spinal cord was seen in one patient (Table 4). A moderate reduction in the myelinated and unmyelinated fibre populations was seen in the sural nerve (Table 5).

### *Radiculoneuropathy*

Four patients had this form of neuropathy (Table 2). All patients had chronic sensorimotor polyradiculoneuropathy with progressive sensory impairment and muscle weakness. The sensory disturbance was in a glove and stocking pattern in all of the patients, with an associated sensory ataxia in three patients. Apparent muscle weakness was seen in two patients. Autonomic symptoms were generally absent, except for constipation, hypohidrosis and urinary disturbances (Table 3). The CSF protein concentration was elevated, ranging from

98 to 146 mg/dl, without pleocytosis. F-wave abnormalities, poor occurrence and prolonged latencies, were present in all patients, while motor and sensory nerve conductions were almost normal, except in one patient with mild elongated distal latency and decreased conduction velocities in the median and tibial nerves (Table 4). This nerve conduction feature was unusual in chronic inflammatory demyelinating polyradiculoneuropathy. SEPs were also substantially prolonged. MRI of the lumbar spine showed abnormal gadolinium enhancement predominantly of the dorsal spinal roots and cauda equine, in all four patients. Sural nerve biopsy showed variable degrees of myelinated fibre loss with minor to moderate demyelinating changes in all patients (Table 5). These clinicopathological features suggest that the primary lesion in these patients is in the spinal nerve roots or most proximal nerve trunks, consistent with an inflammatory radiculoneuropathy.

### Overlapping clinical features among the neuropathic forms

Each neuropathic form had principal and predominant clinical features characterizing each individual neuropathic form, while the clinical symptoms overlapped to some extent with each other. Sensory-ataxic neuropathy frequently had painful features, autonomic symptoms and trigeminal nerve involvement. Painful sensory neuropathy also had autonomic and trigeminal nerve involvement, as well as sensory ataxic features. Multiple mononeuropathy had painful and sensory ataxic features. Trigeminal neuropathy had autonomic and painful features. Multiple cranial neuropathy had some degree of trigeminal, painful and autonomic features. Autonomic neuropathy also had sensory ataxic and trigeminal nerve involvement. These overlapping symptoms were the common features in the present analysis, while overlapping symptoms occurred during the long-standing clinical course. For instance, some patients with painful sensory neuropathy without sensory ataxia later developed sensory ataxia, or alternatively, patients with sensory ataxic neuropathy often developed painful dysaesthetic features during the clinical course. These overlapping clinical features strongly suggest that each individual neuropathic form is not the absolute clinical entity, but these individual forms share a common underlying pathological process.

### Findings in an autopsied patient with the sensory ataxic form of neuropathy

An 88-year-old woman with the sensory ataxic form of neuropathy was examined at the time of autopsy. She had numbness on the right side of her face since the age of 64 years, and developed unsteadiness of gait and pseudoathetosis in the fingers at 71 years of age. She was diagnosed as having Sjögren's syndrome at the age of 71. Severe sensory ataxia in the limbs was present. A marked segmental distribution of sensory impairment, particularly with respect to a deep

sensation and anhidrosis, was noted (Kumazawa *et al.*, 1993) in the limbs and trunk (Fig. 1). Severe orthostatic hypotension, with a decrease of up to 70 mmHg in systolic pressure, and marked decrease in cardiac MIBG uptake was present. T2\*-high intensity signal lesions in the spinal dorsal column were observed (Fig. 1). Respiratory failure due to pneumonia was the cause of death. The autopsy was performed 5 h postmortem.

The population of sensory ganglion neurons was severely, but variably, diminished among the spinal segments; 45% of the control value in the C5, 37% in the Th11 and 26% in the L4 segments (Fig. 1). Nageotte's nodules (Fig. 1) and mild cell infiltrations that contained mainly T-cells were seen (Fig. 2). The large sensory ganglion neurons were diminished predominantly. Myelinated fibre density in the dorsal spinal roots was also variably diminished among the spinal segments; 48% of the control value in the C5, 42% in the Th11 and 22% in the L4 segments (Fig. 1). The large myelinated fibres also were depleted predominantly. The extent of fibre loss in the dorsal spinal roots correlated well with the corresponding dorsal root ganglion cell population. The spinal dorsal column fibre population was also markedly depleted (Fig. 1). These observations strongly suggest that ganglioneuritis affecting the sensory neurons is the major pathological process. The sympathetic ganglion cells also were severely, but variably, diminished among the segments (23–51%), with mild T-cell invasion (Fig. 1). These segmental variations in the extent of sensory ganglion neuron involvement and sympathetic ganglion neuron involvement seem to correspond to segmental variation of sensory and sweat impairments seen in this patient (Fig. 1). These clinicopathological correlates also may support the view that the major responsible lesion is of sensory and sympathetic neurons. The myelinated fibres in the sciatic, median and tibial nerves in the proximal portion of these nerve trunks showed a remarkable multifocal patchy distribution of myelinated fibre loss, present mainly in the large diameter fibres. The sural nerve revealed loss of large myelinated fibres with active axonal degeneration. Multifocal and disseminated perivascular T-cell infiltrations were seen in the endoneurial and perineurial space of the peripheral nerve trunks (Fig. 2), although the extent of cell invasion was mild. Features of arterial vasculitis, mostly in the post-active state, were seen throughout the peripheral nerve trunks (Fig. 2). Examination of the skeletal muscles showed an almost normal appearance and spinal motor neurons and ventral roots also were normal in appearance and in population (Fig. 1). Submandibular and subauricular salivary glands had T-cell invasion and acinar cell destruction (Fig. 2). Relatively mild inflammatory cell invasion in this patient may be due to the extensive therapies including prednisone.

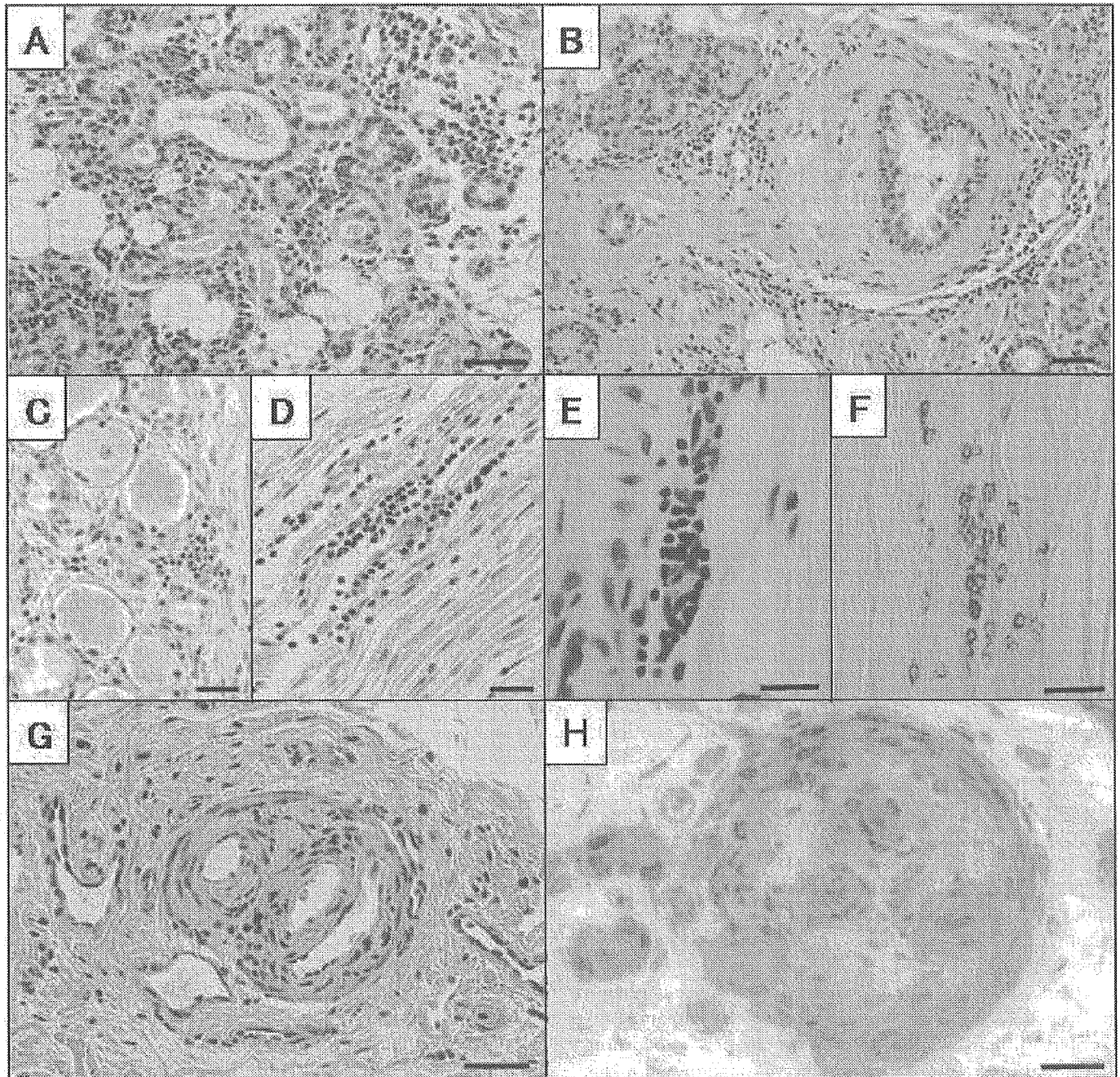
### Therapeutic profiles for individual neuropathic forms

Corticosteroids (prednisone, 1 mg/kg/day) and intravenous immunoglobulin (IVIG) (400 mg/kg for 5 days) were

prescribed for some of the patients (Table 6). Definite improvement in the modified Rankin scale measurement or in sensory impairments, including pain and painful dysesthesias, after treatment was considered a favourable response (Table 6). Presence or absence of favourable response was evaluated 1 month after treatment.

Multiple mononeuropathy and multiple cranial neuropathy showed the most favourable response to corticosteroid

therapy. Sensory ataxic neuropathy showed a favourable response to corticosteroid treatment in only 18% of the patients (Table 6). The rate of favourable response to IVIG therapy for radiculoneuropathy, painful sensory neuropathy and sensory ataxic neuropathy was 100, 67 and 23%, respectively, although the number of patients treated was limited (Table 6). This suggests that the rate of favourable response to corticosteroid or IVIG therapy was different among the



**Fig. 2** Inflammatory aspects of the autopsied patient. (A and B) Lymphocytic infiltration at parotid gland (A) and submandibular gland (B). Haematoxylin-eosin stain. Scale bar = 40  $\mu$ m. (C and D) Lymphocytic infiltration at the L4 dorsal root ganglions on axial section (C), and on longitudinal section (D). Haematoxylin-eosin stain. Scale bar = 20  $\mu$ m. (E and F) Longitudinal section of the median nerve. Perivascular lymphocytic infiltrates in the endoneurium. Klüver-Barrera's stain (E) and UCHL-1 positive cells (F). Scale bar = 20  $\mu$ m. (G and H) Chronic vasculitis in the perineurial space. (G) Median nerve. Haematoxylin-eosin stain. (H) Sural nerve. Toluidine blue stain. Scale bar = 20  $\mu$ m.

**Table 6** Therapeutic profiles in prednisone- and IVIG-treated patients

Neuropathic form	Prednisone				IVIG			
	Treated patients (n)	Favourable response (n)	No response (n)	% Response	Treated patients (n)	Favourable response (n)	No response (n)	% Response
Sensory neuropathy								
Ataxic*	22	4	18	18	13	3	10	23
Painful**	6	1	5	17	3	2	1	67
Multiple mononeuropathy*	11	8	3	73	1	0	1	0
Cranial neuropathy								
Multiple***	4	3	1	75	0	ND	ND	ND
Trigeminal****	3	1	2	33	0	ND	ND	ND
Autonomic neuropathy†	2	0	2	0	1	0	1	0
Radiculoneuropathy*	3	0	3	0	4	4	0	100
Total	51	17	34	33	22	9	13	41

IVIG, intravenous immunoglobulin therapy; ND, not determined. Favourable response: \*For sensory ataxic neuropathy, multiple mononeuropathy and radiculoneuropathy, positive therapeutic response with reduction of one or more points of the modified Rankin scale. \*\*For painful neuropathy, positive therapeutic response with three or more reduction of Visual Analogue Scale (VAS) rating for pain, ranging from 0 = no pain to 10 = maximal pain intensity. \*\*\*For cranial neuropathy, therapeutic response was assessed for the improvement of the symptoms of each cranial nerve. Favourable response was designated as definite subjective and objective improvement. †As for autonomic neuropathy, autonomic symptoms did not show a definite favourable response to the therapy.

neuropathic form, probably reflecting the underlying pathology. However, these favourable therapeutic responses were rather short-lived. In the long-term follow-up, these patients ultimately showed progression of symptoms.

## Discussion

### Underlying pathological features in each form of neuropathy

In this study, we assessed that Sjögren's syndrome-associated neuropathy has a broad clinical spectrum, including sensory ataxic neuropathy, painful sensory neuropathy without sensory ataxia, multiple mononeuropathy, multiple cranial neuropathy, trigeminal neuropathy, autonomic neuropathy and radiculoneuropathy. Here, we discuss the pathological background underlying several forms of neuropathy. Sensory ganglion cell destruction associated with lymphocytic infiltration detected by dorsal root ganglion biopsy provided direct proof that ganglioneuritis is responsible for lesions in the sensory ataxic form of neuropathy (Malinow *et al.*, 1986; Griffin *et al.*, 1990). Most of our patients with sensory ataxic neuropathy had lesions of the central rami as well as the peripheral rami of the sensory neurons, as assessed by low amplitude or unelicitable SEPs and SNAPs, dorsal spinal column T2\*-high intensity signal lesions and segmental sensory impairment. Furthermore, the autopsy findings of a patient with the sensory ataxic form had severe depletion of large-sized sensory ganglion neurons accompanied by T-cell invasion, which strongly support this view. In addition, substantial preservation of motor nerve function and a lack of axonal sprouting with large axon loss in the sural nerve biopsy specimens also support the view that the sensory neurons are primarily affected.

In contrast, in the painful sensory neuropathy form without sensory ataxia there is predominantly superficial sensory

impairment, well preserved motor nerve function and small axon loss with relative preservation of large axons. SEPs are relatively well preserved compared with the sensory ataxic form, but T2\*-high intensity signal lesions in the dorsal column of the spinal cord were observed, although the extent of high intensity was smaller than those in sensory ataxic neuropathy. Lack of axonal sprouts in the sural nerve biopsy also argues against the presence of a primary axonal lesion. We did not perform histological examination of the dorsal root ganglion. However, based on our clinical, laboratory, and electrophysiological data, we can speculate that this form of neuropathy is another form of sensory ganglioneuronopathy that affects small ganglion neurons. Some patients with painful sensory neuropathy eventually developed sensory ataxia due to the impairment of deep kinaesthetic sensation during long-term follow-up, although its distribution was restricted. Alternatively, some of the patients with sensory ataxic neuropathy had impairment of superficial sensation with painful dysaesthesias. These overlapping symptoms, observed in these two forms of neuropathy, may also support the hypothesis that these two neuropathies are part of a spectrum of disorders with a similar pathology.

The pathological basis of trigeminal neuropathy is not known. However, isolated sensory deficits along the territory of the trigeminal nerve are characteristic, and motor nerve dysfunction, even trigeminal motor dysfunction, is not present. Furthermore, pure sensory trigeminal neuropathy is occasionally the initial symptom of the sensory ataxic form of neuropathy or can present as one of the subsequent symptoms of sensory ataxic and painful sensory neuropathies. In addition, nature of autonomic symptoms such as pupillary abnormality and orthostatic hypotension, and highly chronic initial progression pattern in trigeminal neuropathy are similarly shared with those in sensory ataxic and painful neuropathy forms. These clinical features would suggest



that trigeminal neuropathy is a cranial nerve version of sensory ganglionopathy, although further evidence is necessary to confirm this hypothesis.

In contrast to sensory ataxic neuropathy, painful sensory neuropathy and trigeminal neuropathy, multiple mononeuropathy and multiple cranial neuropathy often include motor nerve involvement with predominantly acute and sub-acute onset. Motor nerve involvement can be assessed accurately using the electrophysiological findings in these forms of neuropathy. In some patients with multiple mononeuropathy, evidence of motor nerve denervation on EMG or NCS can be detected. These observations suggest that this form of neuropathy represents a combined sensory and motor neuropathy, rather than an isolated sensory neuropathy. Furthermore, multiple cranial neuropathy and multiple mononeuropathy are not seen in the sensory ataxic and painful sensory forms of neuropathy, suggesting that these neuropathies are distinct from the sensory neuropathies. Vasculitis in the small arteries or arterioles in a sural nerve biopsy were detected in five out of eight patients with multiple mononeuropathy, the frequency of which was significantly higher than those in other forms of sensory neuropathies. Based on these observations, vasculitis and subsequent axonopathy might be the aetiology of multiple mononeuropathy, and possibly of multiple cranial neuropathy.

With respect to the pathological basis of Sjögren's syndrome-associated neuropathy, the autopsy findings of the patient with the sensory ataxic form suggest that there may be a continuous spectrum of pathological processes among the different forms of neuropathy. Sensory and autonomic ganglionitis accompanied by T-cell invasion was present in this patient, while disseminated vasculitis and perivascular T-cell infiltration were also present throughout the peripheral nerve trunks. The patients in whom the ganglionitis process was predominant, as in this autopsied patient, will present with the sensory ataxic form. In contrast, if the vasculitic process in the nerve trunk predominates, the patient would show the features of multiple mononeuropathy, including motor symptoms rather than symptoms of sensory or autonomic ganglionitis. We need further histological studies to confirm these findings, while we may speculate that sensory ganglionopathic lesions would contribute more profoundly to the sensory ataxic, painful sensory and trigeminal neuropathy forms, and vasculitic lesions would result in the multiple mononeuropathy and possibly multiple cranial neuropathy forms.

### **Neuropathy and other non-sicca symptomatic manifestations of Sjögren's syndrome**

The striking feature was that the clinical manifestations of neuropathy preceded the development of sicca syndrome or laboratory findings consistent with Sjögren's syndrome in most patients. Thus, in most patients, neuropathy developed first and then the diagnosis of Sjögren's syndrome

was made up to 12 years later, well in agreement with previous studies from our group and other groups (Sobue *et al.*, 1993; Grant *et al.*, 1997; Mori *et al.*, 2001, 2003). This chronological sequence is true for all forms of neuropathy, but is more characteristic in the ganglionitis-related neuropathy forms, such as sensory ataxic and painful sensory neuropathy. Extraneural symptoms, such as pancreatitis and interstitial pneumonia, also can precede the clinical manifestations of Sjögren's syndrome (Garcia-Carrasco *et al.*, 2002). These observations strongly suggest that neural tissues, particularly dorsal root sensory ganglion cells and probably autonomic ganglion cells, are the primary targets in Sjögren's syndrome in addition to the salivary and lacrimal glands (Greenspan *et al.*, 1974), and visceral organs including the pancreas, lung, and thyroid (Swigris *et al.*, 2002).

Antigens primarily responsible for the Sjögren's syndrome, which could be universally present among the target tissues, have been investigated. Whether alpha-fodrin antibody is specific to Sjögren's syndrome or not has been debated (de Seze *et al.*, 2004; Ruffatti *et al.*, 2004), but alpha-fodrin has still been proposed as a candidate antigen (Haneji *et al.*, 1997). We examined anti-alpha-fodrin antibodies in the serum of patients from the present study and found that this antibody is elevated in patients with Sjögren's syndrome-associated neuropathy. However, increases in this antibody were also observed in other types of neuropathy (data not shown) suggesting that this antibody is a candidate marker for Sjögren's syndrome, but its specificity needs to be assessed further. Additional antigens responsible for Sjögren's syndrome that are expressed in all of the target organs need to be identified.

We still do not know why the neuropathic symptoms precede the manifestations of sicca symptoms and other characteristic features in the Sjögren's syndrome-associated neuropathy patients. One possible situation would be that the patients with neuropathic symptoms as the initial symptom would first be referred to a neurology clinic rather than to a rheumatology clinic, while in the case of patients with sicca syndrome they would be referred to a rheumatology clinic. In the case of patients presenting with pancreatitis as the initial symptom, these patients tended to be referred to the gastroenterology clinic rather than to rheumatology clinic. The low prevalence of anti SS-A and SS-B antibodies in our neuropathic patients may also contribute to the earlier occurrence of neuropathies before the diagnosis of Sjögren's syndrome. Taken together, the current diagnostic criteria for Sjögren's syndrome based on the sicca syndrome may need to be re-evaluated.

### **Autonomic symptoms and the autonomic neuropathy form**

Autonomic symptoms are widely present in Sjögren's syndrome-associated neuropathy, particularly in the sensory ataxic, painful sensory and autonomic neuropathy form. Autonomic symptoms may be attributed to a different

pathologic cause, such as autonomic ganglioneuritis and peripheral autonomic nerve involvement due to direct T-cell attack of the nerves or ischaemia due to vasculitis. The findings from the autopsied patient, including the loss of sympathetic ganglion neurons associated with T-cell invasion, strongly support the view that autonomic ganglion cells are primarily involved, in a fashion similar to the involvement of sensory ganglion cells. In this patient, the segmental distribution of anhidrosis and skin temperature changes corresponded to the segmental variation in the extent of autonomic ganglion cell involvement, also supporting the hypothesis that the primary lesions in autonomic ganglion cells are responsible for autonomic symptoms (Fig. 1). Two of three autonomic neuropathy patients also had sensory ataxia, suggesting that the autonomic ganglionopathy has a similar aetiology as sensory ataxic neuropathy. The presence of Adie's pupils, which is often associated with Sjögren's syndrome-associated neuropathy, is also probably attributable to ciliary ganglion cell involvement (Waterschoot *et al.*, 1991), although further histological assessment is needed. The degree of orthostatic hypotension, anhidrosis, constipation and loss of  $^{123}\text{I}$ -MIBG uptake were unexpectedly severe when the autonomic system was involved. Autonomic symptoms in Sjögren's syndrome-associated neuropathy are generally considered mild in their manifestations compared with the sensory symptoms (Wright *et al.*, 1999). Our three patients with autonomic neuropathy were exceptions, since the autonomic symptoms, including bowel dysfunction, were extremely prominent symptoms, suggesting that severe autonomic neuropathy can be present in the spectrum of neuropathies associated with Sjögren's syndrome (Goto *et al.*, 2000; Sakakibara *et al.*, 2004). The present observations suggest that autonomic symptoms are one of the major symptoms in this neuropathy.

### Therapeutic approach to Sjögren's syndrome-associated neuropathy

Corticosteroids and immunosuppressants have been employed for the treatment of Sjögren's syndrome, resulting in improvement of non-neuropathic Sjögren's syndrome-associated symptoms, such as sicca syndrome and pneumonitis (Zandbelt *et al.*, 2001; Swigris *et al.*, 2002).

For the therapy of neuropathy associated with Sjögren's syndrome, corticosteroids (Griffin *et al.*, 1990; Noguchi *et al.*, 2003), immunosuppressants (Griffin *et al.*, 1990), plasmapheresis (Chen *et al.*, 2001), D-penicillamine (Asahina *et al.*, 1998), infliximab (Caroyer *et al.*, 2002) and immunoglobulin (Molina *et al.*, 1996; Pascual *et al.*, 1998; Takahashi *et al.*, 2003) administration have been reported anecdotally and suggest a favourable therapeutic response. In the present study, a favourable response to treatment was assessed in an open manner, and both standard corticosteroid and IVIG treatment had similar frequencies of favourable response. Based on the limited number of patients treated, there may be marked differences in the rates of favourable therapeutic response among the neuropathic forms, reflecting major

differences in the causes of neuropathy. Corticosteroid therapy is likely a good candidate for multiple mononeuropathy and multiple cranial neuropathy, and favourable improvement may be seen in the painful dysaesthesias of the painful sensory neuropathy and radiculoneuropathy forms with IVIG therapy. Although these symptomatic therapeutic responses were seen in certain patients, overall progression of the neuropathic symptoms as well as of Sjögren's syndrome itself occurred. The findings of this study suggest that IVIG and corticosteroids may be efficacious in treating the neuropathic symptoms of Sjögren's syndrome, although these favourable responses were only seen in certain subpopulations of patients. Randomized controlled studies are needed to assess the efficacy of these treatments for neuropathic symptoms of Sjögren's syndrome.

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