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ORIGINAL ARTICLE

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Intraoperative control by somatosensory evoked potentials in the treatment of cervical myeloradiculopathy. Results in 210 cases

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Abstract Somatosensory evoked potentials (SEPs) were used for continuous monitoring of 210 patients during anterior surgery for cervical myeloradiculopathy, to test how effectively they help avoid irreversible neurological damage during surgery. The pathologies differed in severity and were treated by diskectomy or by extended corporectomy using the Senegas technique. Intraoperative SEP changes were recorded in 84 patients (40%); in 13 (6.2%) of these, changes in SEP amplitude and latency were caused by mechanical stress. SEPs revealed transient episodes of regional ischaemia or neurophysiological anomalies during anaesthesia (mainly hypotension) in 27 patients (12.8%). The traces detected incipient and potentially dangerous mechanical pressure on, or metabolic anomalies of, the spinal cord during manipulation and placement procedures of spinal fixation devices. They were particularly sensitive indicators of ischaemia; one of the most common causes of irreversible injury. The traces of 44 patients (21.0%) improved markedly during surgery. There were no false-negatives in this series and, thanks to the fact that SEPs gave immediate warnings of incipient ischaemia to the surgical team, we had no case of irreversible medullary or nerve-root deficit.

Key words Cervical surgery · Evoked potentials · Somatosensory evoked potentials · Spinal cord monitoring · Spondylotic myelopathy

Introduction

The most effective treatments of cervical myelopathy are anterior decompressive surgery, diskectomy and extended corporectomy, followed by vertebral fusion [9, 14, 24, 31, 37, 39, 40, 42, 43].

The risk of irreversible neurological complications after these spinal surgery procedures ranges from 0.5 to 6.9% for corrections of vertebral deformities [8, 22, 26, 36], to 20% for tumour resections and trauma surgery [12]. Other researchers report different statistical percentages of irreversible neurological complications for cervical myelopathies. They range from 3.7%, reported by Epstein et al. [10] (associated with 0.5% mortality), through 10.5%, reported by Harsh et al. [13], to 23%, which was the rate of tetraparesis reported by McAfee et al. [25] following surgery to correct ossification of the posterior longitudinal ligament.

In 1986, we operated on a patient with severe cervical myelopathy. A transient medullary ischaemia went undetected during surgery and caused an immediate flaccid tetraplegia, which subsequently developed into a Nurick grade IV tetraparesis [29]. This led us, from 1987 onwards, to carry out intraoperative monitoring of sensory evoked potentials (SEPs) during aggressive spinal surgery to detect instantly any metabolic or haemodynamic anomalies that might lead to medullary ischaemia.

Table 1 Nurick neurological gait classification in 210 patients with a myelopathic syndrome

Nurick grade	Percentage of patients
Grade 0: normal gait	48.5%
Grade 1: myelopathy with normal gait	35.2%
Grade 2: myelopathy – walking < 1 km	6.6%
Grade 3: myelopathy – walking < 400 m	8.0%
Grade 4: myelopathy – walking with sticks	0.5%
Grade 5: myelopathy – unable to walk	1.0%

Fig. 1 Titanium CS plate with four corner spikes for attachment to the anterior cortex

Material and methods

Clinical data

A prospective study was carried out on 210 patients with myelopathic or cervical nerve-root syndromes. All were operated on by one surgeon. The patients' SEPs were continuously monitored during the operations. Average patient age was 47.2 years (SD 11.05 years; range 21–80 years). Sex distribution differences were not significant (45.5 vs 54.5%). The mean postoperative observation period was 5 years (SD 1.52 years; range 2–8 years).

Patient classifications were: nerve-root syndrome, 37.1%; spinal cord syndrome 6.6%; radiculo-medullary syndrome 45.2%; Brown-Sequard syndrome 2.8%; transverse spinal cord syndrome 1.4%; and post-traumatic cervical instability syndrome 6.66%. Table 1 gives the Nurick grades [29].

All patients were evaluated clinically and radiologically with MRI or myelo-CT; they also underwent neurophysiological tests using electroneurography, electromyography and SEPs. In addition, the last 90 patients of the series were studied preoperatively with motor evoked potentials (MEPs). Surgery was indicated when conservative treatment had failed and when basic neurophysiological examination detected a progressive deterioration of radicular or medullary neurological function.

Table 2 Number of levels operated on

No. of levels	Percentage of patients (n = 210)
One level	48.5%
Two levels	32.0%
Three levels	16.6%
Four levels	2.8%

Surgical technique

A right anterior approach was used, helped routinely by an operating microscope. One hundred patients (47.6%) received a simple, one-level diskectomy and partial corporectomy, 30 (14.2%) received segmentary diskectomies at several levels, and 80 (38%) received extended Senegas corporectomies [40]. In all patients interbody fusions were carried out with tricortical iliac autografts. These were stabilised systematically by a cervical spine (CS) plate [37, 38] (Fig. 1). The levels treated are shown in Table 2.

The CS plate was developed for this purpose, and its curved profile fits closely the anterior surface of the vertebral bodies, while at the same time restoring the physiological lordosis.

Each plate has 5 mm-long spikes at each corner, and when the fixing screws are tightened, these press into the anterior cortex and make the plates self-stable. The rigidity of this low-profile, MR-compatible, titanium plate fixation prevents "windscreen wiper" movement against the fixed vertebral bodies. The plates are retained by self-tapping screws with a 4.0 mm outside diameter. The entire screw surface is sand blasted and retention in cancellous bone is so good that there is no need to penetrate the posterior cortex.

Medullary monitoring technique

All patients were continuously monitored during surgery, but SEP traces were only recorded in the following four phases (1) post-intubation; (2) bone removal and decompression; (3) fusion and fixation; (4) closing and waking.

The SEP recorder (Nihon-Koden Mini-Neuro-Pack Four) permits simultaneous and independent study of up to four signal traces. Filter bandpass was 20–3,000 Hz, with a 20-mV input amplification by screen division. SEPs were elicited by stimulating both median nerves at the wrists. Maximum intensities were those just sufficient to contract thenar musculature at a rate of 5/s. SEPs were recorded by subdermal needle electrodes implanted following the International 10–20 system [46]. An average minimum of 1,000 responses was obtained in each case.

Comparison of evoked responses after simultaneous or independent stimulations of the left and right median nerves helped us recognise immediately any incipient unilateral or bilateral spinal nerve abnormality. In bilateral conditions, the traces show the different functional deterioration of each lateral nerve. We generally used subcortical SEPs, which for the upper extremities produce a response within the first 20 ms of the stimulation and provide very stable information from their anatomic generators in the presence of anaesthetic drugs and gases (halotane, isofluorane and N_2O) [7, 32, 33, 35, 44]. The subcortical SEP response consists of a se-

Table 3 Results of intraoperative monitoring

	No. of cases	Rates
Incident-free patients	125	59.5%
Negative disturbances	40	19.0%
Unstable response due to hypotension, gases, hypothermia	24	11.4%
N-9 and/or N-11 destructuring due to hypotension (ischaemia)	3	1.4%
N-11 destructuring: compression (screw, graft, haematoma)	13	6.0%
Positives changes	44	21.0%
N-9 and/or N-11 improvement after decompression	11	5.2%
N-9, N-11, N-13/14, N-20 improvement after decompression	32	15.2%
Complete normalisation	1	0.4%
Poor signal quality	1	0.4%

quence of waves termed N-9, N-11, N-13/14 complex and N-20. The "N" of these terms signifies negative polarity, and the number, the average time in milliseconds before they appear within the response. The anatomic generators of each wave are situated as follows: N-9 in the brachial plexus and nerve roots; N-11 in the cervical spinal cord; the N-13/14 complex in the brain stem, and N-20 in the cerebral cortex.

The predetermined parameter thresholds set to trigger an alarm signal were a drop of more than 50% in wave amplitude, and an increase of more than 10% in latency in comparison with the trace of the post-intubation phase [1, 7, 10, 16, 21, 27].

Disturbances in the traces that did not trigger an alarm were considered unstable signals, more indicative of transient haemodynamic disturbances, hypothermia [4, 10, 28] or a deepened anaesthesia. According to our protocol, when an alarm sounded we stopped all surgical manoeuvres and immediately checked the position of separators, grafts and screws to look for haematomas and free bone or disk fragments. At the same time, the anaesthetist checked blood pressure, pulse, temperature, anaesthetic stage, O_2 concentration and state of airways.

Results

The average hospital stay for this group of patients was 3.5 (SD 1.7) days. No patient suffered irreversible spinal cord or nerve root injury following surgery and patients left the hospital unaided wearing, only a hard collar to support the fused cervical spine.

Quality of traces was good, they were stable and showed very little radiofrequency interference. Only one patient gave a poor signal. We divided the results of patient monitoring into three groups (Table 3). The Incident-free group (n = 125) comprised those patients whose traces showed no alteration throughout the operation. The Negative disturbances group (n = 40) comprised patients whose intraoperative traces showed losses of amplitude or increases of latency that lasted more than 10 min. The: Positive changes group (n = 44) comprised patients whose trace amplitudes or latencies improved after spinal cord or root decompression.

The traces of a sub-group of 24 patients of the Negative disturbances group (n = 40) were notably unstable, but showed no important loss of amplitude or increase in latency. This instability was attributed more to physiological alterations, such as deeper anaesthesia, hypothermia

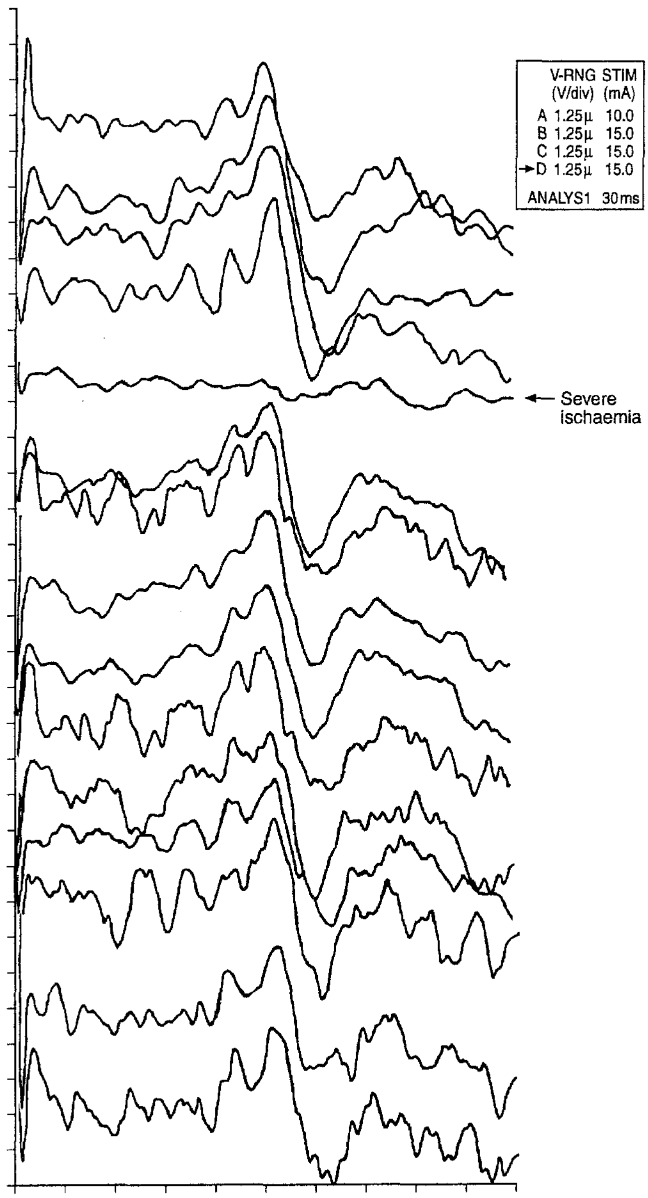

Fig. 2 Trace of a patient with severe ischaemia caused by serious hypotension (*arrow*). The trace recovered after intervention by the anaesthetist

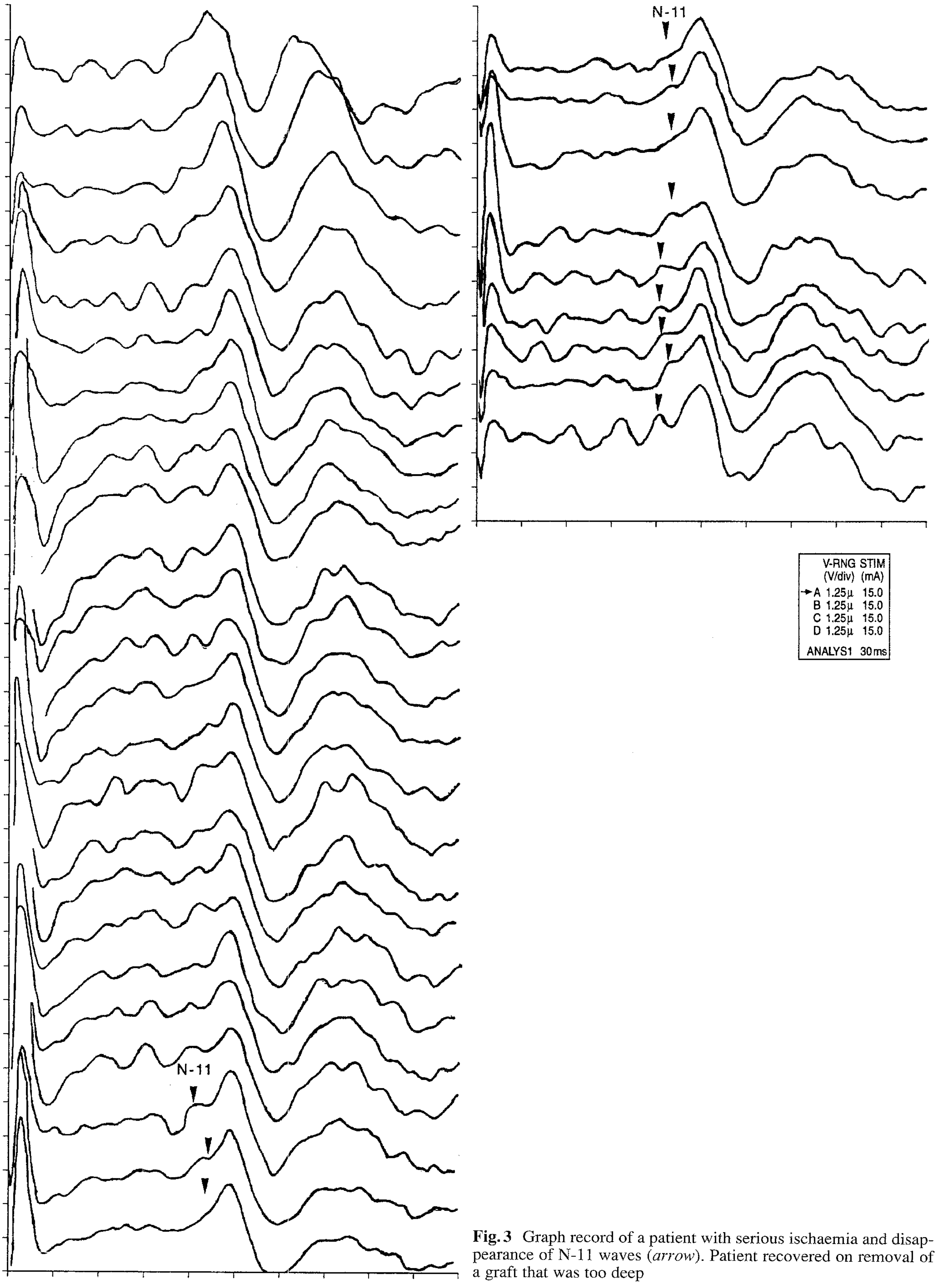

Fig. 3 Graph record of a patient with serious ischaemia and disappearance of N-11 waves (*arrow*). Patient recovered on removal of a graft that was too deep

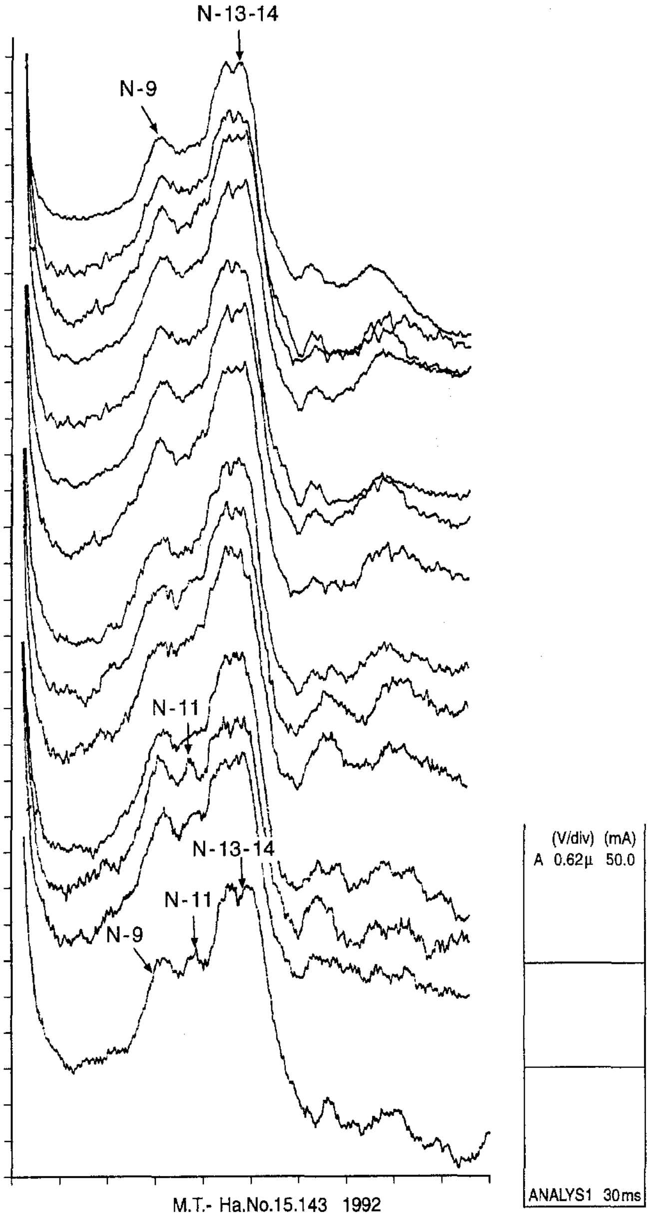

Fig. 4 Patient trace that shows the re-appearance of N-11 wave (*arrow*) following decompression of a voluminous disk prolapse

or slight hypotension, or both. Traces quickly became normal when the physiological perturbations were corrected.

The traces of a sub-group of three patients showed, on the one hand, a profound destructuring of N-9 or N-11 waves, or both, together with an almost complete loss of amplitude and greatly increased latency, and on the other, a significant disturbance of the whole trace, which included the N-13/14 complex and the N-20 cortical wave, caused by severe ischaemia secondary to profound hypotension, and which required immediate correction by the anaesthetist (Fig. 2). The traces of another sub-group of 13 patients from the Negative disturbances group revealed significant changes in N-11 latency and amplitude caused by mechanical stress, the result of direct compression by a graft, a screw or a compressive haematoma below the tricortical graft. In one patient, the trace disturbance was caused by direct compression of the carotid artery by the retractor. In all the above alarm situations, once the destructuring of the trace was confirmed, immediate surgical correction was made (Fig. 3).

The traces of the 44 patients (21%) in the Positive changes group were characterised by immediate, partial or total improvement of the preoperative trace or of the post-intubation baseline following surgical decompression of the spinal cord or roots (Fig. 4). No patient had a severe neurological deficit in the immediate postoperative period. Other complications were: four leaks from small dural tears, six incidents of intense pain from haematomas or localised disk fragments, two Claude-Bernard-Horner syndromes (now almost completely recovered) and six cases of recurrent nerve paresis (spontaneous recoveries after 6 weeks). These minor complications necessitated eight reoperations (three to repair the dura, four to clean a haematoma or remove disk fragments, and one to correct a level error). It is noteworthy that the CS plates displaced slightly in the early postoperative period in three patients.

Although not one of the aims of this study, the final outcomes of our patients were evaluated according to the following criteria: progression of the clinical symptoms; fusion consolidation; improvement by one, two, or three Nurick grades [29]; postoperative electroneurophysiological examination; and return to previous work or way of life (Fig. 5).

Assessed according to the above five parameters, the outcomes of our patients were: 84.1% excellent, 13.8% fair and 2% poor.

Discussion

Researchers claim that monitoring SEP during surgery is effective in helping to prevent subsequent irreversible neurological lesions [3–6, 10, 11, 16, 19–21, 27, 28, 33, 41]. This technique gives very good results in corrective surgery for spinal deformities, but in the literature consulted there are few references to the monitoring of anterior decompressive surgery for cervical pathologies. We therefore designed this study to test (1) the application of electrophysiological techniques to anterior decompressive surgery, and (2) the reliability and safety of the procedure. Any technique designed to control surgical risk must include a continuous monitoring system that immediately detects the early onset of neuronal hypoxia and signals the need for rapid correction well before cellular necrosis develops [15].

Continuous monitoring during surgery will reveal any medullary malfunction. The cervical spinal cord and particularly the brain stem are very sensitive, and vulnerable

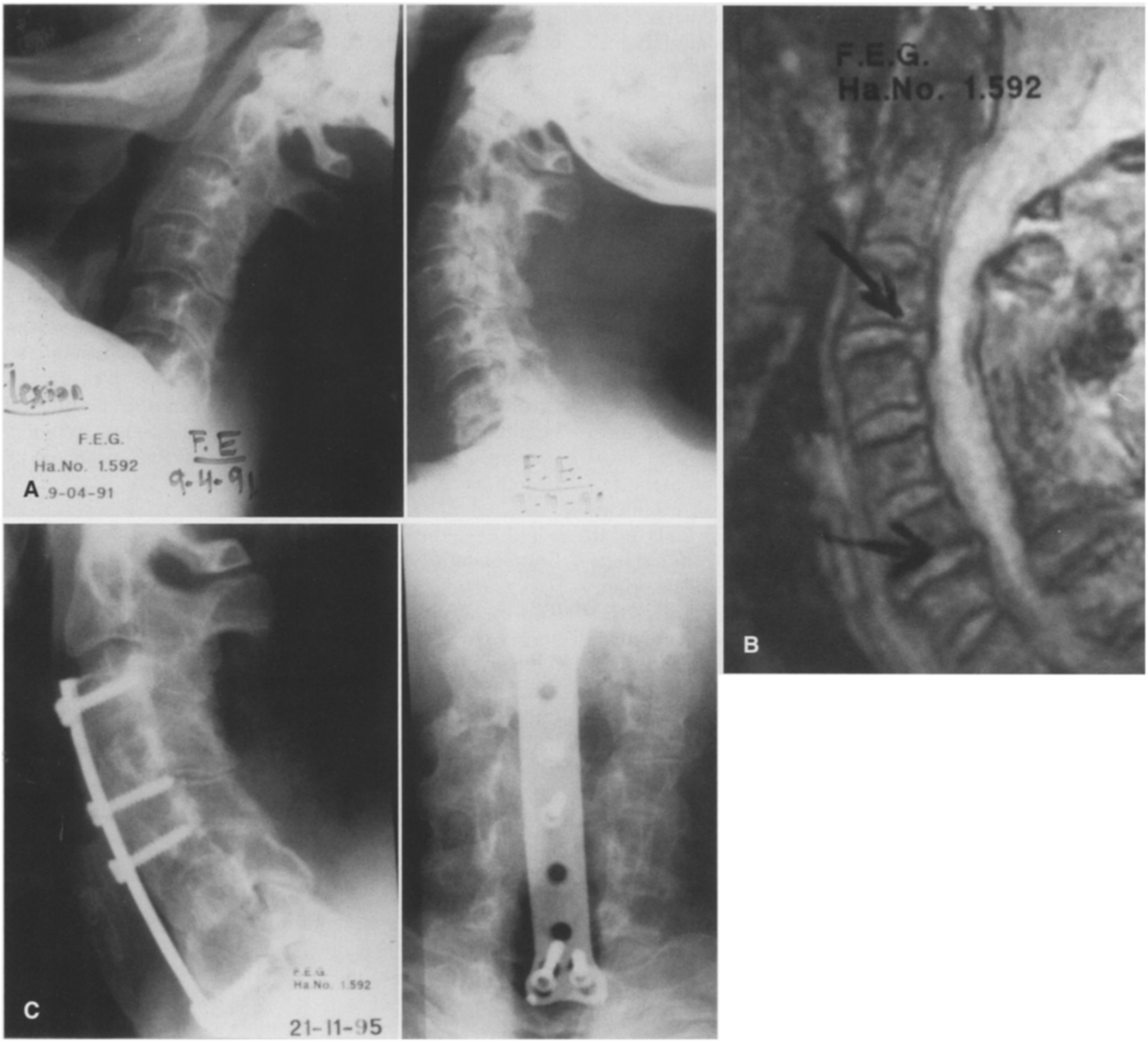

Fig. 5 **A, B** This patient with severe myelopathy was previously laminectomised five times. There is serious spinal instability. The patient presented a syndrome of progressive tetraparesia. **C** The same patient following decompression and anterior fusion

to hypoxia [18, 45]. An ischaemic medullary lesion may develop as a result of any fall in arterial pressure or any deterioration of a metabolic or physiological parameter and will quickly lead to deteriorating traces. For example, as little as 0.8°C of hypothermia increases latency [28]. This can be caused by a deeper level of anaesthesia [4, 10, 32, 33, 44] or by haemodynamic disturbances such as hypotension, tachycardia or bradycardia, and also by local vascular abnormalities such as arterial occlusions or spasms, or external compression of vessels by a haematoma, bone graft, screw or bone or disk fragment [15, 19, 30]. It could be argued that we are testing the function of the posterior cord (sensory pathway) and not the more important and interesting anterior motor pathway. This is certainly so, and may explain in part some of the incidences of false-negatives cited in the literature. These range from 0.4 to 1.0% and are always found either in patients with a previous neurological deficit [2, 7, 21, 27, 36] (it is difficult to interpret these traces) or in patients treated by the anterior procedure when ligation of one or more segmentary arteries produces a transient medullary ischaemia, which shows as a temporary loss of amplitude and an increase in latency.

In patients with cervical myelopathy, both ischaemic and compressive factors [15, 30] are usual in the physiopathology, and the slightest decrease of collateral blood flows will cause rapid hypoxia of the posterior cords, which are very vulnerable to malfunction by being pressed against posterior anatomical structures. Like Epstein et al. [10], we had no false-negatives in 210 monitored cases. Perhaps our meticulous use of a microscope helped us to avoid making mechanical lesions, but our good results owed much to the excellent initiative of the anaesthetist, who had continually to adapt his protocols to each new emergency situation. Our patients had two types of negative disturbances: some were caused by severe ischaemia and would have caused permanent neuropathy had they not been detected in time; other disturbances reflected mechanical problems, and our surgical procedure had to be modified immediately. Good results were obtained in all these cases. The 44 improved traces were recorded either immediately or at the end of the operations; most were in patients suffering acute disk prolapses. The traces of some patients failed to recover amplitude or latency, or both, and prompted us to search for loose disk fragments in the foramen until the trace normalised. Epstein et al. [10] also report significant improvements in intraoperative traces of 18% of patients with initial SEP deterioration. This information demonstrates that subcortical potentials are very sensitive to both ischaemic phenomena and mechanical stress, and thus, traces are valuable indicators of surgical effectiveness. Unfortunately true-positives cannot be applied as standard criteria, since they were obtained only in patients with acute myeloradiculopathy, whose postoperative symptoms tended to progress towards a complete cure. However, we can state that when a true-positive appears, the effectiveness of the procedure is assured.

We analysed the number of levels decompressed, the technique employed, and the possible association between the disturbances observed in the intraoperative recordings and both clinical classification and neurological gait category (Nurick grades) of the patients. We also analysed the possible effect of SEP intraoperative disturbances on the final result of this series, and found no significant difference between the clinical classification groups. Analysis of the effects of both the number of levels treated and the technique employed revealed notably that while the difference was not statistically significant ($P < 0.5$), the patients operated on at more than two levels had twice as many negative disturbances as those operated on at only one level. Comparisons of isolated and segmentary diskectomies with extended corporectomy revealed that the Senegas technique improved traces in 24% of the cases, while segmentary diskectomies improved traces in only 13.3% ($P < 0.05$).

The results of our series were not significantly influenced by trace disturbances. We believe that the monitoring of SEPs to minimise the surgical risks had a favourable influence on the final outcomes of the surgical treatment: 84.1% of our patients had a good or excellent outcome, which compares well with the 85% achieved by Epstein et al. [10].

Conclusion

The monitoring of the SEPs of patients during anterior surgery for cervical radiculopathy or myelopathy appears to be a very reliable support for the spinal surgeon. In this series of 210 patients we had not one false-negative. The trace deteriorations recorded (19%) showed us that we had to modify surgical management during the operation. Consequently, we had no case of irreversible medullary or nerve-root deficit.

We consider that our experience with the monitoring procedure has justified itself: it is a very sensitive method that immediately detects any incipient ischaemic phenomena during the surgical treatment of cervical myeloradiculopathy. The information in real time to the surgical team not only helped their precision, but was a key element in the safe outcome of their operations.

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