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## PAPER

## Effects of surgery on the sensory deficits of syringomyelia and predictors of outcome: a long term prospective study

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**Objective:** To quantify the effects of surgery on the thermal deficits of syringomyelia and assess the predictors for such effects.

**Methods:** The subjects were 16 consecutive patients (12 men, 4 women; mean (SD) duration of sensory symptoms, 5.1 (4.5) years) presenting with the typical symptoms of syringomyelia related to Chiari I malformation or trauma, and requiring surgical treatment. They were evaluated before surgery, then at six months and two years. Sensory evaluation included determination of the extent of thermal deficits and quantitative assessment of thermal, mechanical, vibration detection, and pain thresholds. Neuropathic pain intensity was evaluated on visual analogue scales. Magnetic resonance imaging was done before and after surgery to measure syrinx dimensions.

**Results:** The magnitude and extent of thermal deficits improved in a subgroup of patients and this was best predicted by the duration of sensory symptoms: patients operated on less than two years after the onset of their symptoms tended to improve, while those operated on later were stabilised or deteriorated slightly. The effect of surgery on thermal deficits was correlated with the duration of sensory symptoms. Surgery also affected vibration deficits in patients with the Chiari malformation, neuropathic pain on effort, and syrinx dimensions.

**Conclusions:** The duration of sensory deficits is the best predictive factor of the efficacy of surgery for the thermal symptoms of syringomyelia. Early surgery is required if these deficits are to be minimised.

Patients with syringomyelia generally present with sensory deficits and a sensory level; the deficits predominantly affect thermoalgesic sensitivity and are often associated with neuropathic pain. Surgical treatment of syringomyelia is now commonly undertaken in patients with neurological deterioration.<sup>1–8</sup> This procedure is expected to result in improvement or at least stabilisation of the main clinical symptoms of syringomyelia. However, few studies have specifically analysed the effects of surgery on sensory deficits.<sup>1–7,9</sup> In particular the outcome of thermal deficits—which represent the core symptoms of syringomyelia—has not been evaluated previously, and no prospective study has assessed the predictors of such an outcome.

Quantitative sensory testing is considered to be the method of choice for assessing pain and sensory deficits in patients with peripheral or central nervous system lesions.<sup>10–11</sup> It is particularly suitable for assessing thermal deficits (using a thermotest device), mechanical deficits (using Von Frey filaments) and vibration (using a vibrometer). We have previously shown that this method is particularly suitable for analysing the extent and magnitude of sensory deficits in patients with syringomyelia.<sup>12–13</sup>

Our main objectives in this prospective study were to quantify the effects of surgery on the thermal deficits of syringomyelia and to look for possible predictors of such effects. We also evaluated the effects of surgery on other sensory deficits, on neuropathic pain, and on the radiological dimensions of the syrinx.

## METHODS

## Patients

Sixteen consecutive patients (12 men, four women; mean (SD) age, 36.9 (10.2) years) with typical symptoms of

syringomyelia associated with Chiari type I malformation ( $n = 11$ ) or spinal cord trauma with syringomyelia above the injury ( $n = 5$ ) were recruited for the study (table 1). They were evaluated before surgery and then at six and 24 months postoperatively. These patients had all experienced a significant progression of neurological dysfunction and radiological worsening of their syrinx. They were able to date the onset of their sensory symptoms (mean duration, 5.2 (4.4) years, range 6 months to 14 years). The patients with post-traumatic syrinx had experienced their first symptoms 13.9 (11.8) years after their trauma, and their syrinx was identified 12.5 (13.1) years after the trauma. Eight patients suffered from neuropathic pain.

## Surgery

All the patients were operated on by the same neurosurgeon. The patients with Chiari malformation underwent foramen magnum decompression, according to a procedure largely described previously.<sup>1–6</sup> This consisted in suboccipital craniectomy and removal of the posterior arc of C1, opening the dura and arachnoid, and resecting arachnoid adherences when present. In suboccipital craniectomy, limited bone resection was undertaken medially and laterally at the level of the foramen magnum.<sup>4</sup> Intraoperative ultrasonography was carried out before opening the dura and after dural grafting to confirm the decompression of the tonsil and pulsatile flow of the cerebrospinal fluid around the cranio-vertebral junction. No tonsillar resection was done and no patient underwent obex plugging.

In the patients with post-traumatic syringomyelia, the operative procedure consisted in opening and resecting the arachnoid membrane, microsurgical lysis of arachnoid adherences when present, and subarachnoid space reconstruction with autogenous fascia duraplasty.<sup>8</sup>

There were no cardiac, respiratory, or infectious complications related to surgery.

**Table 1** Clinical and demographic characteristics of the 16 patients who completed the study

Patient	Sex	Age (years)	Duration of symptoms (months)	Type of syrinx	Extension of syrinx	Area of maximal sensory deficit	Dermatomal extension of thermal deficits	Neuropathic pain
1	M	44	120	Chiari	C2–T1	Shoulder (right)	C2C8 right+C5 left	Yes
2	M	27	30	Chiari	C1–T12	Hand (right)	C2T2 bilateral	Yes
3	M	31	18	Chiari	C2–T8	Hhand (left)	C5T7 right+C2T5 left	Yes
4	F	29	6	Chiari	C3–T8	Hhand (right)	C8T1 right	Yes
5	M	27	18	Chiari	C1–T10	Hand (right)	C5T1 right+C4T2 left	No
6	F	22	6	Chiari	C4–T12	T5 (right)	D5T7 right	No
7	F	46	132	Chiari	C7–T4	T2 (right)	C8T2 right	No
8	M	31	132	Chiari	C2–T6	Shoulder (right)	C2T4 right+C2T4 left	No
9	F	43	30	Chiari	C2–T8	Hand (left)	C2T4 left	Yes
10	M	31	168	Chiari	C1–T12	Shoulder (left)	C4C5 right+T2T9 bilat	No
11	M	39	72	Chiari	C1–T12	Forearm (right)	C2C7 bilateral	Yes
12	M	23	6	Trauma	C1–T7	Shoulder (left)	D2T9 left+C5 G	No
13	M	44	60	Trauma	C1–T10	Hand (right)	C3T3 right+C4T3 left	No
14	M	47	108	Trauma	C1–T12	Hand (left)	C2T4 left+C5T4 right	No
15	M	55	48	Trauma	C1–L1	Hand (right)	C3L2 right	Yes
16	M	45	36	Trauma	T4–L1	T7 (left)	T6–T10 bilateral	Yes

### Sensory evaluation

#### Extension of sensory deficits

The extent of the thermal stimuli was determined using two thermorollers (Somedic) placed at constant temperatures of 40°C (heat) and 25°C (cold). The determination was completed by measuring detection thresholds to warm and cold stimuli using a thermotest (see below). Extension of hypoalgesia to pinprick (using a pinwheel) and hypoaesthesia to touch (using a cotton swab) was also determined. As most sensory deficits had an asymmetrical distribution, we used a metameric score corresponding to the sum of affected right and left dermatomes (for example, a T5T6 left and T5 right thermal deficit was given a score of 3).

#### Quantitative sensory tests

Quantitative sensory tests were carried out in a quiet room at a constant temperature (22°C) by the same investigator, who was not part of the surgical team. Measurements were made in the area of maximal thermoalgesic deficits—the hand (on the side of maximal impairment), and the lower limbs in the patients with the Chiari malformation.

Thermal sensation was assessed with a Somedic thermotest (Somedic AB, Stockholm, Sweden). A contact thermode of Peltier elements (25×50 mm) was applied to the skin. The thermal thresholds were adjusted to take into account the skin temperature. Thresholds were measured according to the method of limits.<sup>14</sup> The maximum and minimum temperatures were set at 50°C and 10°C for detection thresholds and 50°C and 4°C for pain thresholds. A thermal rate of change of 1°C/s was used. All thresholds were calculated as the average of three successive determinations.

The detection and pain thresholds for mechanical stimuli were assessed using calibrated von Frey filaments, following a procedure described in detail previously.<sup>12–13</sup> Briefly, von Frey filaments were applied in ascending and descending order of stiffness. The detection threshold was defined as the lowest pressure perceived by the subject within three seconds of the stimulus. The pain threshold was defined as the lowest pressure which the patient considered to be painful. The force required to bend the filaments (0.057 to 140 g) was converted into log units.

Vibration thresholds (Hz) were measured using a vibrometer by the method of limits.

#### Evaluation of neuropathic pain

Neuropathic pain was defined according to the International Association for the Study of Pain as “pain initiated or caused

by a primary lesion or dysfunction of the nervous system.”<sup>15</sup> It has also been referred to previously as “dysaesthetic pain” in patients with central injury.<sup>16</sup> Patients were asked to report the pain severity (ongoing pain at rest and pain induced by effort) over the last 24 hours using a 100 mm visual analogue scale (VAS) graduated from 0 (no pain) to 100 (worst possible pain). No patient was receiving regular analgesics at the time of evaluations, and three patients took weak opioids on an as-needed schedule.

#### MRI of the spine

All the patients underwent preoperative and postoperative magnetic resonance imaging (MRI) at six and 24 months, with both T1 and T2 weighted images obtained in the sagittal and axial planes. MRI was done using the same apparatus (1.5 T) at the department of neuroradiology of the Kremlin Bicêtre hospital. Quantitative evaluation of the syrinx dimensions was undertaken before and after surgery on one sagittal and one axial image (considered to illustrate the syrinx dimensions best). The mean length of the syrinx was measured (in cm). The degree of foramen stenosis was evaluated as previously described<sup>17</sup> with scores of 0 (normal foramen), 1 (partial stenosis), or 2 (major stenosis). The syrinx/canal index was measured<sup>18</sup> in order to provide an indirect value of the syrinx diameter and intramedullary tension (using the greatest width of the spinal canal at the same level). The axial diameter of the syrinx (in cm) was measured at the widest level.

#### Statistical analyses

Data provided by the entire group are expressed as mean (SD). Wilcoxon’s signed ranked test was used for comparisons of paired data. To evaluate predictive factors for the effect of surgery on thermal deficits, we expressed thermal detection, pain thresholds, and the extent of thermal deficits as the difference between baseline and postoperative values. Relations between two variables were tested by the Kendall rank correlation ( $\tau$ ). Analysis of variance (ANOVA), with the Fisher’s post hoc least significant difference test, was used for intergroup comparisons. In all instances, a probability ( $p$ ) value of <0.05 was regarded as significant.

## RESULTS

### Baseline clinical characteristics of the patients

All patients presented with thermal and mechanical (pinprick) deficits (table 1). Six patients had anaesthesia to heat and eight had anaesthesia to cold. Eleven patients presented

with vibration deficits or fine tactile impairment at the sensory level and seven patients with Chiari malformation presented with vibration deficits in the feet (not tested in patients with post-traumatic syrinx). The magnitude and extent of the thermal and mechanical deficits was similar in patients with Chiari malformation and post-traumatic syrinx, while vibration thresholds at the sensory level were more impaired in patients with the Chiari malformation ( $p < 0.05$ ).

### Effects of surgery on thermal deficits and predictors of response

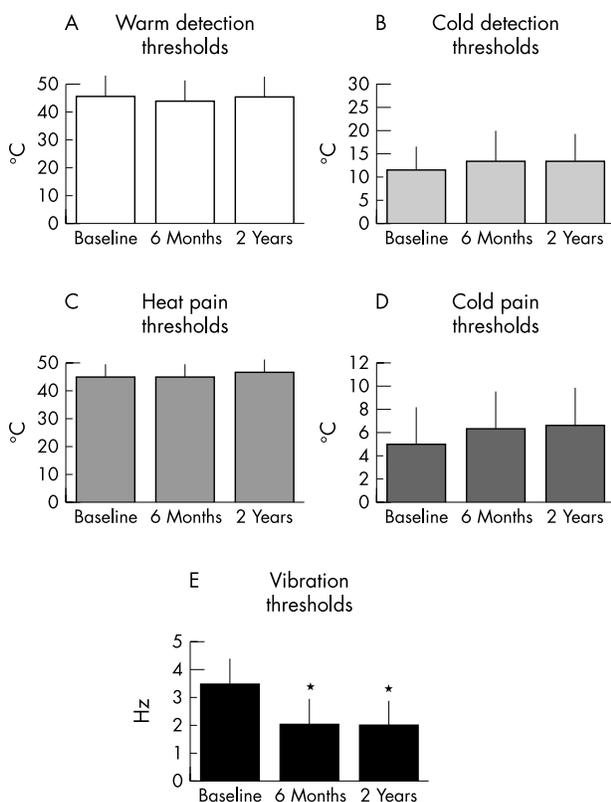
Surgery had no overall effect on the extent of thermal deficits or on thermal detection and pain thresholds at the site of maximal impairment (fig 1) or in the hand. However, some patients recovered partially or totally from their thermal deficits, while others remained stable or seemed to deteriorate.

Several possible predictive factors for these effects of surgery were assessed. Neither the aetiology of the syrinx (Chiari I or trauma) nor the presence or absence of vibration deficits was predictive of the outcome of thermal deficits (warm and cold detection and pain thresholds, extent of warm and cold deficits). There was no correlation between the magnitude of thermal and vibration deficits, the radiological dimensions of the syrinx at baseline, and the outcome of thermal deficits. In contrast, in patients operated on early after the onset of their sensory deficits (within less than two years) ( $n = 6$ ), the magnitude and extent of the thermal deficits tended to improve, with subjective improvement in three patients, whereas in those operated on after this limit ( $n = 10$ ) these deficits remained stable ( $n = 5$ ) or deteriorated slightly ( $n = 5$ ) (fig 2). We also found a

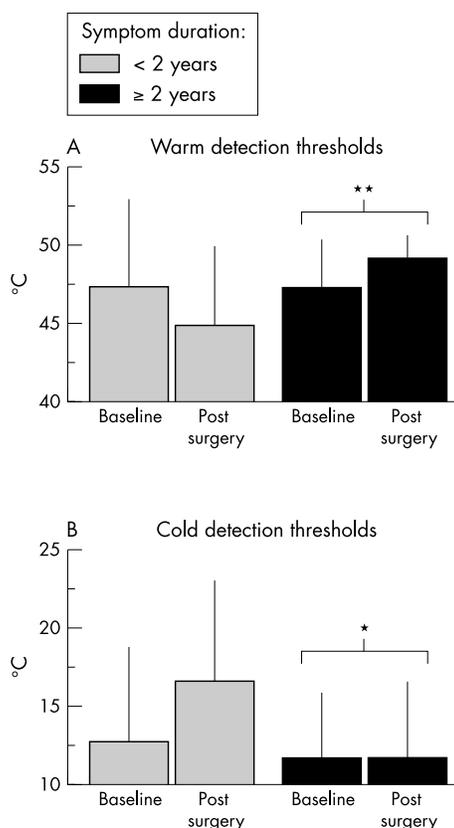
correlation between the duration of sensory symptoms and the evolution of thermal detection thresholds two years after surgery, particularly in the area of maximal deficits (fig 3). Similar data were obtained for heat pain thresholds (Kendall  $\tau$ ,  $-0.51$ ;  $p < 0.01$ ). Thus the shorter the duration of the preoperative symptoms, the more improved were the thermal detection and pain thresholds after surgery, and vice versa.

### Effects of surgery on mechanical and vibration deficits

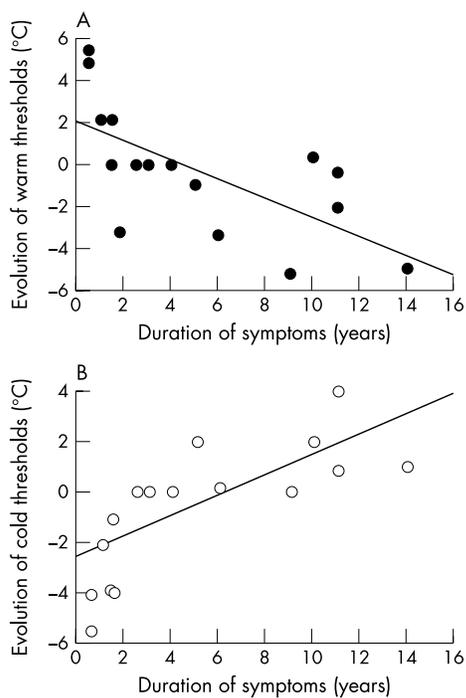
Vibration detection thresholds improved significantly at the site of maximal impairment (fig 1) and in the hand ( $p = 0.04$ ). This improvement was only significant in patients with the Chiari malformation ( $p = 0.03$ ) and was more pronounced in the lower limbs ( $p < 0.01$ ). It was associated with resolution or strong improvement in other signs and symptoms of Chiari malformation, whereas signs of muscle weakness and atrophy remained stable. The effects of surgery on vibration deficits were not correlated with their severity at baseline or with the duration of sensory symptoms. Similarly there was no correlation between the effects of surgery on vibration and thermal deficits.



**Figure 1** Effects of surgery on thermal and vibration thresholds measured at the site of maximal impairment at six months and two years in the 16 patients with syringomyelia. Only vibration thresholds improved significantly (\* $p < 0.05$ ; \*\* $p < 0.01$ , Wilcoxon signed rank test).



**Figure 2** Evolution of the warm (A) and cold (B) detection thresholds two years after surgery, measured at the site of maximal thermoalgesic impairment as a function of the duration of the patient's neurological symptoms. There was improvement in warm and cold detection thresholds (that is, a decrease in warm thresholds and an increase in cold thresholds;  $p < 0.05$  for cold detection thresholds) in patients operated on less than two years after the onset of their symptoms (mean (SD) duration, 1.0 (0.5) years,  $n = 6$ ), whereas an increase or stability of thermal thresholds was observed in patients operated on more than two years after the onset of their symptoms (mean duration, 7.0 (4.1) years,  $n = 10$ ). The effects of surgery on warm and cold detection thresholds (expressed as the difference between baseline and postoperative thresholds) were significantly different between the two groups of patients ( $F = 8.8$ ,  $p = 0.01$  for warm detection;  $F = 8.0$ ,  $p = 0.04$  for cold detection, ANOVA).



**Figure 3** Correlation between the preoperative duration of neurological symptoms (years) and the evolution of warm (A) and cold (B) detection thresholds two years after surgery in the area of maximal deficit. The evolution of detection thresholds was expressed as a difference score between baseline and postoperative thresholds. Kendall  $\tau$ ,  $-0.62$  for warm detection thresholds ( $p < 0.001$ );  $0.78$  for cold detection thresholds ( $p < 0.001$ ).

The extent of mechanical hypoalgesia to pinprick was unchanged at six months but was significantly reduced at two years (metameric score, 7 (8);  $p = 0.02$ ). Tactile deficits and pain sensation (pain detection and mechanical thresholds, using Von Frey hairs) remained stable.

**Effects of surgery on neuropathic pains**

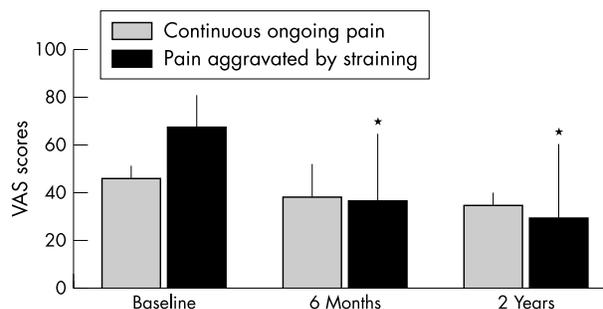
Eight patients had neuropathic pain at the sensory level (mean duration, 3.9 (3.2) years), described as burning or squeezing, and reported that their pain was aggravated by effort, as well as by cough and by the Valsalva manoeuvre in four cases. Surgery had no overall effect on ongoing pain at rest (fig 4). However, in patients with symptoms of less than two years' duration ( $n = 3$ ), pain improved by at least 70%, while it was stable in the other patients. Pain intensity after effort was reduced significantly (fig 4) whatever the duration of sensory symptoms, and was no longer aggravated by cough or the Valsalva manoeuvre.

**Effects of surgery on the radiological dimensions of the syrinx**

There was a significant effect of surgery on the degree of foramen stenosis (in patients with Chiari malformation), syrinx diameter, and canal/syrinx index, but not on the length of the syrinx (table 2). The syrinx collapsed in 12 patients—that is, the diameter became zero—which generally involved the whole syrinx. There was no correlation between the effects of surgery on the radiological dimensions of the syrinx and the outcome of deficits and pains. Syrinx collapse was not associated with a better outcome for sensory deficits.

**DISCUSSION**

Although surgical decompression is increasingly undertaken in patients with syringomyelia and neurological



**Figure 4** Evolution of the ongoing neuropathic pain intensity at rest and after straining (visual analogue scale scores over 24 hours) at baseline, six months, and two years post-surgery. There was a significant decrease in the pain scores induced by effort at six months and two years postoperatively ( $p < 0.05$ , Wilcoxon signed rank test).

deterioration,<sup>1-5 7 8</sup> few studies to date have attempted a specific evaluation of the effects of surgery on the sensory deficits related to syringomyelia.<sup>1 7 9</sup> In these studies, the clinical results were graded as global categories, based essentially on the subjects' clinical impression. In the present prospective two year study we aimed to quantify for the first time the effects of surgery on the thermal deficits in syringomyelia, which represent the core symptoms of such conditions, and to look for various possible predictors of these effects. For this we used quantitative sensory tests, based on a determination of the thresholds of various somesthetic modalities (detection and pain thresholds).<sup>11</sup> These techniques allow thermal, mechanical, and vibratory stimuli to be applied in a non-invasive manner. They are considered the method of choice for assessing sensory deficits in patients with neurological disorders.<sup>10</sup> Specifically they have been particularly helpful in quantifying the thermal deficits associated with central post-stroke and spinal cord injury pain.<sup>19-23</sup> We have previously shown that they could detect minor thermal deficits more effectively than the standard neurological examination in patients with syringomyelia<sup>12</sup> and also frequently identify tactile and vibration deficits, showing that the sensory deficits of syringomyelia are not necessarily dissociated.<sup>24</sup>

The main results of this study are that the effects of surgery on the thermal deficits of syringomyelia were best predicted by the duration of the patients' sensory symptoms. Thus, although there was no overall effect of surgery on the magnitude and extent of thermal deficits, we observed that the patients in whom the duration of symptoms was less than two years tended to improve and some even recovered,

**Table 2** Effects of surgery on the syrinx/canal index, axial diameter of the syrinx, degree of foramen stenosis, and length of the syrinx evaluated using magnetic resonance imaging at baseline and two years

	Baseline MRI	Postoperative MRI
Syrinx/canal index (%)	51 (21)	22 (13)*
Syrinx diameter (cm)	0.7 (0.3)	0.1 (0.1)*
Foramen stenosis	1.7 (0.4)	0.2 (0.4)*
Length of the syrinx (cm)	27 (12)	25 (6.5)

Values are mean (SD). Surgery had no effect on the length of the syrinx but improved syrinx diameter, the syrinx/canal index ( $n = 16$ ), and the degree of foramen stenosis (in the 11 patients with Chiari malformation). \* $p < 0.01$  (Wilcoxon signed rank test).

whereas those whose symptoms exceeded this limit remained stable or deteriorated slightly. Furthermore, we found a correlation between the effects of surgery on the magnitude of thermal deficits and the duration of symptoms, indicating that the shorter the duration of the preoperative symptoms the more improved were the thermal deficits after surgery, and vice versa. In contrast, neither the aetiology of the syrinx, the magnitude or extent of thermal deficits at baseline, nor the radiological dimensions of the syrinx were predictive of these effects.

Surgery induced consistently different effects on vibration deficits. These deficits were significantly reduced after six months and two years, although only in patients with the Chiari malformation, and were associated with an improvement in other signs and symptoms of that condition. Such improvement was not related to the duration of sensory symptoms. Thus our results show that surgical decompression of syringomyelia not only improves the signs and symptoms of the Chiari malformation, which is in line with previous observations,<sup>2 6 7 9</sup> but may also reduce the thermal deficits, provided that the operation is done less than two years after the onset of such symptoms.

From a pathophysiological point of view, the observed effects of surgery on vibration deficits appear to result from relief of the medullary compression caused by the Chiari malformation rather than from an influence on the syrinx.<sup>7</sup> In contrast, the thermal deficits of syringomyelia seem to depend more on intrinsic spinal cord damage. These data are in keeping with previous pathological studies that showed the importance of damage to the spinal cord in syringomyelia—such as oedema,<sup>25</sup> gliosis, ischaemia, necrosis, and wallerian degeneration.<sup>26 27</sup> Interestingly, our results point to the initial reversibility of such damage. In contrast, the late deterioration observed in some patients could indicate progression of the disease despite surgery, or be related to specific neurotoxic factors. Thus recent studies in animals have emphasised the role of toxicity mediated by excitatory amino acids (EAA) on spinothalamic tract neurones following spinal cord injury.

Another objective of our study was to assess the effects of surgical decompression on the neuropathic pain of syringomyelia. Up to now these effects have rarely been assessed specifically. Some studies have reported improvement in pain,<sup>1-3 28-30</sup> while others showed no effect of surgery.<sup>7 16 31</sup> However, these studies were mostly retrospective, used a minimal evaluation of pain, and did not always draw a distinction between neuropathic and non-neuropathic pain. In fact, the few studies which did this reported disappointing results in neuropathic pain, in contrast to the positive effects on nociceptive pain associated with the Chiari malformation, such as headache.<sup>7 31</sup> In our study, we focused on neuropathic pain at the sensory level,<sup>32</sup> which is the pain that results from direct injury to the spinal cord. As is the case for other central pain syndromes, these pains are among the most difficult to treat, may be particularly incapacitating, and are poorly understood.<sup>12 13 16 20 21 33-35</sup> Eight of the patients suffered from such pain, which presented as a continuous burning or squeezing sensation. Surgery produced no overall effect on ongoing pain intensity. However, as with thermal deficits, any effect of surgery seemed to depend on the duration of sensory symptoms, although the small size of the sample does not allow definite conclusions to be drawn. In contrast, pain induced by straining—sometimes associated with other types of dynamic symptoms (that is, pain induced by coughing or the Valsalva manoeuvre)—was relieved by surgery in all cases and did not depend on the duration of the patients' sensory symptoms. Such pain is probably more dependent on the dynamic characteristics of the syrinx fluid and flow. As such, it may be particularly affected by surgical

decompression, which allows reduction in the subarachnoid pressure.

In this study, we also looked for correlations between the clinical symptoms and signs and the dimensions of the syrinx, as assessed by MRI. There was a significant effect of surgery on the degree of foramen stenosis, the canal/syrinx index, and the syrinx diameter. The syrinx collapsed in 81% of patients, in line with previous reports.<sup>6 36</sup> However, no correlation was obtained between these effects and the outcome of sensory deficits or of neuropathic pain. Similarly, the absence of any correlation between the dimensions of the syrinx and the patient's clinical symptoms<sup>18 37</sup> or outcome<sup>18 38</sup> has been reported. Our results again point to the importance of a clinical assessment of the benefit of surgery and to the lack of predictive value of variables such as the axial diameter of the syrinx, the longitudinal extent of the syrinx, and the degree of foramen stenosis. However, they do not rule out the possibility that the qualitative patterns of the syrinx cavity (that is, central, paracentral, or eccentric cavities), rather than its dimensions, are better correlated with the clinical findings.<sup>39</sup>

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