Intraoperative ultrasonography as a guide to patient selection for duraplasty after suboccipital decompression in children with Chiari malformation Type I

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Object. Indications for duraplasty in treatment of Chiari malformation Type I (CM-I) remain unclear. In the present study, the authors evaluate their surgical experience to determine whether intraoperative ultrasonography is effective in the selection of patients with CM-I who can be adequately treated with craniectomy alone without duraplasty.

Methods. The authors reviewed the records of 256 children who underwent first-time hindbrain decompression for CM-I. Cranietomy alone (without duraplasty) was performed when intraoperative ultrasonography suggested adequate decompression of the subarachnoid spaces ventral and dorsal to the tonsils after suboccipital cranietomy alone. Duraplasty was performed if intraoperative ultrasonography demonstrated persistent dural compression of the tonsils following cranietomy. Symptom recurrence as a function of time was compared between cases of duraplasty versus suboccipital decompression alone stratified by extent of tonsillar herniation.

Results. Duraplasty was performed in 140 patients (55%), and suboccipital decompression alone was performed in 116 patients (45%). Patients underwent follow-up for 29 ± 15 months. Symptoms included headache in 192 patients (75%) and lower cranial nerve and brainstem dysfunction in 68 (27%). In 38 patients (15%) there was tonsillar herniation rostral to the C-1 lamina, in 195 (76%) it extended between the C-1 and C-2 lamina, and in 23 patients (9%) there was herniation caudal to the lower border of the C-2 lamina. In children with tonsillar herniation caudal to C-1, ultrasonography-guided suboccipital decompression alone was associated with a 2-fold increase in the risk of symptom recurrence compared with those who also underwent duraplasty (p = 0.01). In children with tonsillar herniation rostral to C-1, outcome was equivalent between suboccipital decompression alone and duraplasty (p = 0.41).

Conclusions. In the setting of moderate-to-severe tonsillar CM-I, intraoperative ultrasonography demonstrating decompression of the subarachnoid spaces ventral and dorsal to the tonsils may not effectively select patients in whom bone decompression alone is sufficient. Duraplasty may be warranted in cases of tonsillar herniation that extends below the C-1 lamina regardless of intraoperative ultrasonography findings. More objective cerebrospinal fluid flow or volumetric measures may be needed intraoperatively to guide duraplasty in patients with more pronounced tonsillar herniation. (DOI: 10.3171/PED/2008/2/7/052)

KEY WORDS • Chiari malformation • duraplasty • outcome • ultrasonography

CHIARI malformation Type I—a caudal displacement of the cerebellar tonsils through the foramen magnum—was first described by Chiari in 1891. This anatomical abnormality has been associated with symptoms of multiple cerebellar, brainstem, and spinal cord lesions. Although the standard treatment is surgical posterior fossa decompression, considerable debate exists as to the degree of decompression necessary. Surveys conducted by the American Association of Neurological Surgeons have shown that a majority of surgeons prefer to perform both duraplasty and bone decompression of the posterior fossa and dural patch grafting (duraplasty). Evidence for 83–100% symptom improvement with duraplasty has been reported in some series, depending on the patient population studied. Authors of other studies have suggested that there is a subset of patients in whom bone decompression alone is adequate for symptom resolution. These previous studies focus on decompression with primarily a single method, with few series directly comparing methods of decompression. Authors of comparison studies have suggested both increased success with duraplasty and the same outcome regardless of duraplasty. Studies have been limited by smaller sample size, lack of multivariate analysis, outcome prediction based on level of herniation.
and a rigid definition of treatment success confined to initial improvement without regard to future symptom recurrence.

We set out to determine whether intraoperative ultrasonography can be used to identify patients who can be treated sufficiently without duraplasty. In this series of 256 consecutive pediatric patients, we evaluate whether the decision not to perform duraplasty, made with intraoperative ultrasonographic guidance, resulted in an outcome equivalent to that achieved in patients in whom duraplasty was performed.

Methods

Presenting symptoms, neurological deficits, patient demographics, comorbidities, results of pre- and postoperative radiological studies, operative records, and follow-up clinical records were reviewed in 256 consecutive patients who underwent first-time posterior fossa decompression for CM-I at the Johns Hopkins Hospital between 1995 and 2005. An electronic database was maintained, cataloging patient demographics, presenting symptoms, and degree of tonsil herniation. Additionally, the presence of syringomyelia, scoliosis, hydrocephalus, basilar invagination, fused cervical vertebrae, platybasia, atlantoaxial assimilation, or cervicomedullary kinking on MR imaging were also identified and recorded. Degree of tonsillar herniation was expressed as the relationship of the tonsils to the lower edge of the C-1 and the C-2 lamina on MR images obtained with the cranio cervical spine in the neutral position, and classified as follows: 5-mm below the foramen magnum but above C-1 lamina; between C-1 and the C-2 lamina; or caudal to the C-2 lamina.

All patients were offered surgical decompression if they presented with symptoms consistent with CM-I (tussive headache, cervical pain, central apnea, dysphagia, aspiration, vertigo, vocal cord paralysis, motor/sensory deficits, nystagmus, ataxia, lack of coordination, and syringomyelia) and demonstrated cerebellar tonsil herniation below the foramen magnum. Appropriate otolaryngological, pulmonary, and ophthalmological consultations were obtained to determine a central origin of apnea, cranial nerve, and ophthalmological findings. Patients with “mild” herniation (tonsils extending 5-mm below the foramen magnum but not below the C-1 lamina) generally presented with more subjective symptoms, and the decision for surgery in these patients was approached with caution. Surgery was considered only in patients with symptoms typical of CM-I, as listed above. To qualify, headaches had to be tussive in nature, reproducible, and their medical management had to have failed. The majority of patients with “mild” ectopia seen in our clinic were deemed not to be good surgical candidates and were therefore excluded from this study. All included patients underwent suboccipital bone decompression of the foramen magnum and a C-1 cervical laminectomy.

Surgical Technique

The surgical technique for craniectomy and duraplasty was standardized in all included patients and performed by 3 surgeons (J.W., B.C., and G.J.). All patients underwent surgery in the prone position with the head fixed in a Mayfield or a horseshoe head holder. A small suboccipital craniectomy and a C-1 laminectomy were performed. The craniectomy usually extended upward from the foramen magnum and included the inferior nuchal line of the occipital bone, the insertion area of the rectus capitis posterior minor muscle, and the medial insertion area of the rectus capitis posterior major muscle. The craniectomy typically measured 3 × 3 cm. The surgeons ensured an adequate decompression of the rim of the foramen. The tonsils were visualized using intraoperative ultrasonography. If the tip of the tonsils could not be sufficiently exposed, a C-2 laminectomy was also performed. When performing the duraplasty, the dura mater was opened in a Y-shaped fashion spanning the majority of the 3 × 3-cm craniectomy. The dura was closed with a triangular synthetic dural graft, ensuring the reconstruction of open CSF space at the craniospinal junction. The choice of graft was surgeon-specific (B.C.: pericranial autograft; G.J.: Gore, W. L. Gore and associates; and J.W.: Dura-guard, Bio-Vascular, Inc.).

The preoperative surgical plan in all patients was to perform duraplasty unless there was evidence of adequate bone hindbrain decompression on intraoperative ultrasonography (Prosound SSD 1000, Aloka Inc.). The intraoperative decision not to perform duraplasty was based on each surgeon’s subjective interpretation of the ultrasonography findings. As previously described, patients believed to have evidence of adequate decompression on intraoperative ultrasonography after suboccipital craniectomy did not undergo duraplasty. After bone decompression, ultrasonography images frequently demonstrate a pathological loss of normal cerebellar systolic pulsation due to dural compression and hindbrain crowding. In these cases the proximal tonsils are often fixed by dural compression, attenuating normal brain pulsation, while the most distal tonsils demonstrate caudally directed, pathological piston-like pulsations. Furthermore, the subarachnoid spaces ventral and dorsal to the cerebellum and tonsils are usually compressed in this setting. When these findings were noted on ultrasonography after craniectomy and C-1 laminectomy, a duraplasty was performed. Duraplasty was not performed if decompression of the subarachnoid spaces dorsal and ventral to the tonsils was demonstrated and if piston-like pulsations of the distal tonsils or tonsillar dural compression were absent on ultrasonography. All 3 surgeons consistently used these criteria.

Outcome Measures

The database of cases of CM-I was retrospectively analyzed to assess presenting symptoms, findings on physical examination, radiological variables, operative variables, and postoperative symptom recurrence. The primary end point of treatment response was whether symptoms associated with CM-I persisted or recurred to any degree after surgery. A secondary outcome end point (repeated decompression for significant persistent symptoms) was also included. Revision decompression surgery was performed only if no improvement was noted or if symptoms recurred to a level of severity similar to preoperative levels.

Statistical Analysis

Univariate comparison of symptom-free survival was assessed via Kaplan–Meier plots and compared between the duraplasty and nonduraplasty groups via log-rank analysis. A multivariate proportional hazards regression model was then created to model symptom recurrence hazard as a func-
tion of duraplasty versus cranial decompression alone adjusting for all variables differing between these treatment cohorts (child age and the presence of syrinx, scoliosis, or hydrocephalus).

Results

Patient Population

Over the reviewed time period, 256 children underwent first-time surgery for CM-I at our institution. The mean age (± standard deviation) at the time of surgery was 10 ± 5 years, and 121 patients (47%) were male. Presenting symptoms included headache in 192 patients (75%; mean duration 12 months) and brainstem or cranial nerve symptoms in 68 patients (27%; mean duration 8 months). Sixty patients (23%) presented with headaches alone, and 68 (27%) presented with brainstem or cranial nerve dysfunction alone (Table 1). Tonsillar herniation was rostral to the lower border of the C-1 lamina in 38 patients (15%), between the lower borders of the C-1 and C-2 laminae in 195 patients (76%), and caudal to the lower edge of the C-2 lamina in 23 patients (9%). Eight patients (3%) had epilepsy, 35 (14%) hydrocephalus, 69 (27%) syringomyelia, and 29 patients (11%) had scoliosis at the time of surgical decompression.

Duraplasty was performed in 140 patients (55%). Suboccipital decompression alone was performed in 116 cases (45%) due to intraoperative ultrasound evidence of adequate hindbrain decompression. Patients who underwent cranial decompression without duraplasty more frequently presented with dysphagia or shunted hydrocephalus, but were younger and less likely to have scoliosis or syringomyelia. Eighteen patients (13%) in the duraplasty group underwent tonsil coagulation. All other variables were similar between treatment cohorts.

Overall Outcome

Patients attended follow-up for a mean of 29 ± 15 months, and follow-up did not differ between treatment cohorts. Surgical site infection and incisional CSF leaks occurred in 4 (2%) and 2 (1%) cases, respectively, and was not increased in the duraplasty cohort. In 2 patients who underwent duraplasty, the symptoms of aseptic meningitis with negative CSF cultures developed. Bacterial meningitis did not arise in any patients. The length of hospital stay was similar between treatment cohorts (4 ± 1 days).

Overall, symptoms completely resolved in 200 patients (78%), and recurred or persisted to a lesser degree in 56 patients (22%). In the majority of these cases, the severity of symptoms was less than at preoperative levels, but did not resolve. Recurrent symptoms were marked enough to warrant revision decompression surgery in 19 patients (7%).

### TABLE 1

Summary of patient characteristics in 256 children who underwent first-time surgical decompression for CM-I*

<table>
<thead>
<tr>
<th>Variable</th>
<th>All Patients</th>
<th>w/ Duraplasty (140 patients)</th>
<th>Suboccpital Decompression Alone (116 patients)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean age (yrs)</td>
<td>10 ± 5</td>
<td>12 ± 4</td>
<td>8 ± 5</td>
<td>0.001†</td>
</tr>
<tr>
<td>male sex</td>
<td>121 (47%)</td>
<td>61 (43%)</td>
<td>60 (52%)</td>
<td>0.763</td>
</tr>
<tr>
<td>headache alone</td>
<td>60 (23%)</td>
<td>30 (21%)</td>
<td>30 (26%)</td>
<td>0.412</td>
</tr>
<tr>
<td>brainstem/CN symptoms alone</td>
<td>68 (27%)</td>
<td>34 (24%)</td>
<td>34 (29%)</td>
<td>0.498</td>
</tr>
<tr>
<td>mean duration of headache (mos)</td>
<td>12 ± 10</td>
<td>16 ± 10</td>
<td>10 ± 8</td>
<td>0.185</td>
</tr>
<tr>
<td>mean duration of brainstem/CN symptoms (mos)</td>
<td>8 ± 6</td>
<td>10 ± 7</td>
<td>6 ± 6</td>
<td>0.321</td>
</tr>
<tr>
<td>dysphagia</td>
<td>45 (17%)</td>
<td>13 (9%)</td>
<td>32 (28%)</td>
<td>0.001†</td>
</tr>
<tr>
<td>apnea</td>
<td>16 (6%)</td>
<td>6 (4%)</td>
<td>10 (9%)</td>
<td>0.134</td>
</tr>
<tr>
<td>CN III–VII deficits</td>
<td>19 (7%)</td>
<td>11 (8%)</td>
<td>8 (7%)</td>
<td>0.663</td>
</tr>
<tr>
<td>vertigo</td>
<td>49 (19%)</td>
<td>28 (20%)</td>
<td>21 (18%)</td>
<td>0.800</td>
</tr>
<tr>
<td>balance difficulty</td>
<td>42 (16%)</td>
<td>21 (15%)</td>
<td>21 (18%)</td>
<td>0.539</td>
</tr>
<tr>
<td>ataxia</td>
<td>11 (4%)</td>
<td>4 (3%)</td>
<td>7 (6%)</td>
<td>0.153</td>
</tr>
<tr>
<td>nystagmus</td>
<td>17 (7%)</td>
<td>10 (7%)</td>
<td>7 (6%)</td>
<td>0.647</td>
</tr>
<tr>
<td>incontinence</td>
<td>8 (3%)</td>
<td>2 (1%)</td>
<td>6 (5%)</td>
<td>0.080</td>
</tr>
<tr>
<td>tonsils FM to C-1</td>
<td>38 (15%)</td>
<td>18 (13%)</td>
<td>20 (17%)</td>
<td>0.279</td>
</tr>
<tr>
<td>tonsils C1–2</td>
<td>195 (76%)</td>
<td>105 (75%)</td>
<td>90 (78%)</td>
<td>0.806</td>
</tr>
<tr>
<td>tonsils below C-2</td>
<td>23 (9%)</td>
<td>12 (9%)</td>
<td>11 (9%)</td>
<td>0.364</td>
</tr>
<tr>
<td>C-2 laminectomy</td>
<td>33 (13%)</td>
<td>20 (14%)</td>
<td>13 (11%)</td>
<td>0.394</td>
</tr>
<tr>
<td>syringomyelia</td>
<td>69 (27%)</td>
<td>60 (43%)</td>
<td>9 (8%)</td>
<td>0.001†</td>
</tr>
<tr>
<td>scoliosis</td>
<td>29 (11%)</td>
<td>24 (17%)</td>
<td>5 (4%)</td>
<td>0.001†</td>
</tr>
<tr>
<td>hydrocephalus w/ shunt</td>
<td>35 (14%)</td>
<td>7 (5%)</td>
<td>28 (24%)</td>
<td>0.001†</td>
</tr>
<tr>
<td>platybasia</td>
<td>2 (1%)</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>0.987</td>
</tr>
<tr>
<td>basilar invagination</td>
<td>2 (1%)</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
<td>0.987</td>
</tr>
<tr>
<td>perip infection</td>
<td>4 (2%)</td>
<td>3 (2%)</td>
<td>1 (1%)</td>
<td>0.627</td>
</tr>
<tr>
<td>CSF leak</td>
<td>2 (1%)</td>
<td>2 (1%)</td>
<td>0</td>
<td>0.802</td>
</tr>
<tr>
<td>mean LOS</td>
<td>4 ± 1</td>
<td>4 ± 2</td>
<td>4 ± 1</td>
<td>0.314</td>
</tr>
<tr>
<td>mean FU (mos)</td>
<td>29 ± 15</td>
<td>23 ± 18</td>
<td>23 ± 15</td>
<td>0.726</td>
</tr>
</tbody>
</table>

* Patients who underwent cranial decompression alone more frequently presented with dysphagia, urinary incontinence, or with shunted hydrocephalus, but were younger and less frequently presented with scoliosis or syringomyelia. All other variables were similar between treatment cohorts. Mean values are presented ± standard deviations. Abbreviations: CN = cranial nerve; FM = foramen magnum; FU = follow-up; LOS = length of hospital stay; perip = perioperative.

† Indicates statistical significance.
**Duraplasty and Symptom Recurrence**

Despite intraoperative ultrasonographic evidence of adequate hindbrain decompression, suboccipital bone decompression alone compared with decompression and duraplasty was associated with a 2-fold increase in the risk of symptom recurrence (OR 1.69, 95% CI 1.13–3.38, \( p = 0.01 \)) in children with tonsillar herniation extending caudal to the C-1 lamina (Fig. 1B and C). Adjusting for the differences between the cohorts of patients treated with and without duraplasty in multivariate analysis (age, dysphagia, syringomyelia, scoliosis, and hydrocephalus), suboccipital decompression without duraplasty remained independently associated with a 2-fold increased risk of symptom recurrence (OR 2.05, 95% CI 1.04–3.78, \( p = 0.034 \)) in children with tonsillar herniation caudal to C-1. In children with tonsillar herniation rostral to the lower border of the C-1 lamina, suboccipital decompression alone yielded an equivalent rate of symptom recurrence compared to duraplasty when intraoperative ultrasonography results suggested adequate hindbrain decompression (OR 1.16, 95% CI 0.33–4.05, \( p = 0.41 \); Fig. 1A).

Ten patients (7.1%) in the duraplasty cohort and 9 patients (7.8%) in the nonduraplasty cohort underwent repeated operations. After decompression alone failed in 7 of these patients, symptom resolution was achieved with duraplasty in a revision surgery.

**Discussion**

In our review of cases of CM-I treated at our institution over the past decade we found that intraoperative ultrasonography can be used to guide the decision whether to perform bone decompression alone or in combination with duraplasty by effectively identifying patients with “mild” CM-I-tonsillar herniation rostral to C-1. However, ultrasonography was not helpful in guiding the extent of decompression in patients with moderate (between C-1 and C-2) and severe (caudal to C-2) herniation. In these groups, patients who underwent treatment with suboccipital bone decompression alone showed a 2- and 1.5-fold increase in symptom recurrence compared with those who also underwent duraplasty, despite intraoperative ultrasonographic evidence of hindbrain subarachnoid spaces decompression after bone decompression. Our results suggest that in patients with moderate and severe tonsillar herniation, subjective interpretation of intraoperative ultrasonography may not be effective in selecting patients in whom decompression alone is sufficient. More objective ultrasonographic measures of volumetric hindbrain expansion or CSF flow (as described by Milhorat and Bolognese) may be necessary for this technique to be effective.

Although expanding the volume of the posterior fossa is the primary aim of Chiari decompression, the precise strategy of this process is controversial and the subject of multiple studies. Past studies evaluating initial response to surgery have not defined treatment failure by recurrence of symptoms at long-term follow-up and often show analysis without stratifying by level of herniation. In addition, few series have directly compared bone decompression with additional duraplasty at a single institution. Similar to our findings, Galarza and associates have shown increased success in decompression for moderate and severe herniation when using duraplasty and bone decompression together rather than decompression alone. In their color Doppler ultrasonography study, Milhorat and Bolognese demonstrated that duraplasty was necessary to achieve adequate retrocerebellar space and achieve normal physiological bidirectional CSF flow. In contrast, Munshi et al. reported that a subset of their patients improved after bone decompression alone. Anderson and coauthors showed that most of the improvement in brainstem auditory evoked potentials in patients with CM-I occurs after bone decompression rather than af-
ter opening the dura. Ventureyra and colleagues\textsuperscript{19} found that decompression with duraplasty was superior to decompression alone in the presence of syrinx, but added that no additional benefit was noted in cases without a syrinx. Similarly, Genitori et al.\textsuperscript{6} demonstrated that bone decompression alone yielded symptomatic improvement in all 16 cases without a syrinx, and 29 of 32 patients with a syrinx. Due to the range in reported outcomes and variability in Chiari-associated disease, no consensus exists concerning the appropriate degree of decompression for specific Chiari subgroups.

The association of a higher complication rate with duraplasty over laminectomy alone, reported in previous studies, was not observed in our series.\textsuperscript{15,16,20} Galarza et al.\textsuperscript{7} reported no increased rate of complications with duraplasty versus decompression alone. Authors of previous reports have also suggested a small but significant increase in the duration of hospitalization after duraplasty.\textsuperscript{20} The length of hospital stay was unaffected by duraplasty in our series.

Underlying the outcomes in our study is the subjective interpretation of intraoperative ultrasonography to decide which patients do not need duraplasty in decompressing the posterior fossa. Cerebrospinal fluid flow abnormalities by cine phase-contrast MR imaging have been shown to improve after decompression, paralleling symptom resolution.\textsuperscript{2,6,12} Theoretically, once adequate hindbrain CSF flow is established, further decompression may not yield increased efficacy. The use of ultrasonography in Chiari decompression surgery has been advocated by multiple authors, comparing removal of the outer dural layer with duraplasty to assess the need for increased invasiveness.\textsuperscript{10,11} Most recently, Yeh and coworkers\textsuperscript{20} demonstrated the use of ultrasonography in assessing CSF flow and guiding posterior fossa decompression. These authors reported success rates of 90 and 97\% in suboccipital craniectomy alone and duraplasty groups, respectively, and suggest that the good outcomes observed in both cohorts were a result of duraplasty selection based on intraoperative ultrasonography. However, in our outcomes assessment of recurrent symptom complaints and repeated operation rates, ultrasonography-defined restoration of physiological systolic tonsillar pulsation with decompressed subarachnoid spaces may not have been adequate criteria for patient selection for decompression without duraplasty. Milhorat and Bolognese\textsuperscript{22} demonstrated that optimal CSF flow through the foramen magnum in a patient positioned prone and under general anesthesia as measured on ultrasonography color-coded flow velocity is a peak velocity of 3–5 cm/second with bidirectional movement and a waveform exhibiting clear vascular and respiratory variations. Utilizing these CSF flow velocity goals or identifying other more objective measures may have improved the predictive value of intraoperative ultrasonography in our series.

There were also significant differences in the baseline characteristics of the cohorts of patients treated with and without duraplasty. Patients who did not undergo duraplasty were younger, more commonly presented with dysphagia, urinary incontinence, and/or hydrocephalus with shunt implantation, but less frequently with scoliosis or syringomyelia. In 12\% of patients who underwent duraplasty, tonsillar coagulation was also performed. It is possible that tonsillar resection may have contributed to improved outcomes, further highlighting the notion that patients in whom duraplasty and potential tonsil resection is not performed must be carefully selected. Adjusting for these specific variables, suboccipital decompression alone continued to be associated with a 2-fold risk of treatment failure independent of syringomyelia, scoliosis, or other factors. Furthermore, in our series, patients in the duraplasty cohort more frequently presented with syringomyelia and scoliosis. One would expect the duraplasty cohort to show greater symptom recurrence given that these are risk factors for treatment failure, as shown in a recent meta-analysis.\textsuperscript{7} Chiari-associated scoliosis is associated with a 38\% failure rate at best reports.\textsuperscript{4} Despite a greater proportion of patients with syrinx and scoliosis in the duraplasty group, better outcomes were observed in this cohort than in the patients who underwent bone decompression alone.

Although the correlation in the present study between duraplasty and increased success in the setting of moderate and severe tonsillar herniation does draw important trends from a large consecutive series, conclusions are nevertheless limited by our population and retrospective study design. Although they show significant associations, our data cannot prove causality. Because our patients were not selected prospectively, patients were subject to treatment biases based on presentation and intraoperative treatment decisions, conceivably affecting individual outcomes. Furthermore, the present study focuses primarily on a subjective interpretation of ultrasonography data to determine whether bone decompression is sufficient to restore CSF flow. Although all surgeons utilized ultrasonography to determine whether the subarachnoid spaces had been decompressed adequately and that abnormal piston-like pulsations had resolved with decompression alone. These measures were subjective without volumetric measurements of CSF flow assessment. Because a single surgeon performed each case, test/retest reliability of ultrasonography interpretation could not be assessed between surgeons. With this practice pattern, application of our conclusions in scenarios without availability of intraoperative ultrasonography may not be relevant. Different outcomes may be seen in different populations of patients with CM-I at other institutions. In patients with mild tonsillar herniation, avoiding duraplasty in patients after adequate decompression may be an acceptable treatment algorithm for the safe selection of a population that will do well with minimal invasiveness. More objective measures are needed to guide the intraoperative decision in patients with more pronounced tonsillar herniation.

**Conclusions**

Despite intraoperative ultrasonographic evidence of adequate hindbrain decompression, we found that suboccipital decompression without duraplasty was associated with an increased risk of symptom persistence in patients with tonsillar herniation extending below the lamina of C-1. In patients with mild tonsillar herniation rostral to C-1, ultrasonography-guided bone decompression alone provided the same outcome as would be achieved with duraplasty. In the setting of moderate-to-severe tonsillar CM-I, intraoperative ultrasonography without objective CSF flow or volumetric recordings may not be effective in the selection of patients in whom decompression alone is sufficient. Duraplasty may be warranted in patients with tonsillar herniation that extends caudal to the C-1 lamina regardless of findings on intraoperative ultrasonography.
Intraoperative ultrasonography for duraplasty in CM-I

References


Manuscript submitted January 5, 2008. Accepted March 18, 2008. This work was supported by the American Syringomyelia Alliance Project, Monktin Institute Fellowship. Address correspondence to: Matthew J. McGirt, M.D., 3553 Newland Road, Baltimore, Maryland 21218. email: mnmcgirt1@jhmi.edu.