Syringomyelia complicating myelomeningocele: review of the evidence

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Syringomyelia is frequently found in association with myelomeningocele. Although often asymptomatic, it can, in exceptional cases, cause severe morbidity. The author performed a structured literature review to address the following aspects of this clinical problem.

What is the natural history? There are data concerning the imaging prevalence, the autopsy prevalence, and the prevalence of clinically active syringomyelia among patients with myelomeningocele, but literature provides no description of the course of this condition over time.

What is the clinical significance? That correlations among symptoms, signs, treatments, and imaging findings are poorly described is no surprise in view of the large fraction of patients with syringomyelia who are asymptomatic. There is, however, an impressive mass of anecdotal evidence associating progressive syringomyelia with untreated (or inadequately treated) hydrocephalus.

How to make the diagnosis? There is no disagreement that magnetic resonance imaging is the diagnostic modality of choice, but the literature provides very little guidance about who should undergo this investigation. There is no analysis of the costs and benefits of screening or periodic surveillance.

What is the best treatment? Many surgical procedures have been reported to be useful as components of complex algorithms relating clinical factors and imaging data to treatment recommendations. There have been no controlled studies. There have been no prospective studies. There have been no multiinstitutional studies. No studies in which outcomes have been evaluated using objective, validated instruments. No studies in which the robustness of treatment effects over time have been documented.

The complexity of treatment selection in contemporary practice makes syringomyelia unsuitable for randomized controlled trials of different therapies. Prospective cohort studies are feasible, however, and hold the potential to address many important questions about natural history and patient outcomes.

Key Words • hydrocephalus • hydromyelia • myelomeningocele • spina bifida • syringomyelia

MYELOMENINGOCELE is the most complex congenital anomaly of the central nervous system compatible with survival. Historically the prevalence of myelomeningocele has been cited as approximately two per 1000 live births, but recent advances in prenatal diagnosis and greater understanding of the benefits of periconceptional folate supplementation have caused the prevalence to plummet to its current level of approximately 20 per 100,000.28 A countervailing trend has been the proliferation of MR imaging units, in which noninvasive monitoring can provide exquisite visualization of every level of the craniospinal axis. Consequently, investigators at spina bifida programs are seeing fewer new patients but are studying in much greater detail those who do present.

Syringomyelia is commonly associated with myelomeningocele, as are such other potentially surgically treatable lesions as Chiari II malformation, diastematomyelia, dermoid and epidermoid cysts, neurenteric cysts, spinal arachnoid cysts, spinal lipomata, and meningeal cicatrix associated with secondary SCT. Each of these entities, however, has a distinct natural history, is associated with a distinct risk of progressive neurological disability, and responds to surgical treatment in its own distinctive way.

What follows is a critical review of the existing medical literature concerning syringomyelia in the setting of myelomeningocele. Attention has been paid to the following four aspects: natural history, clinical significance (that is, the correlation between disease process and symptoms), diagnosis, and treatment.

Attention has also been paid to other particular issues raised in the literature in relation to the quality of the evidence.

Abbreviations used in this paper: CSF = cerebrospinal fluid; CT = computerized tomography; MR = magnetic resonance; SCT = spinal cord tethering.
other causes. Reports concerning syringomyelia in patients with myelomeningocele and syringomyelia could were discarded, as were reports in which the outcomes of ringomyelia in the setting of the Chiari I malformation were identified. The titles and the abstracts were inspected tor (Table 1).

Additionally, PubMed was searched using the following matrix of terms linked by the boolean “AND” operator (Table 1).

Excluding duplicate citations, nearly 300 references were identified. The titles and the abstracts were inspected for relevance. Reports exclusively concerning syringomyelia in the setting of myelomeningocele that provided no generalizable data pertinent to the study questions were also discarded. Reports in languages other than English and French were discarded if English-language abstracts were not provided. Reports in languages other than English and French were evaluated on the basis of their abstracts only. Observations extracted solely from abstracts are cited as “abstract only” in this review. Promising reports cited in these references but not identified by PubMed were pursued as well. A total of 114 reports and abstracts form the basis for this review; 37 reports actually yielded useful information.

For each general question that was queried in the literature, evidence tables (Tables 2–5) are provided in this review.

The terms “syrinx,” “syringomyelia,” “hydromyelia,” “syringohydromyelia, hydrosyringomyelia,” and “spinal cord cavitation” are used with variable meanings in the literature. In summarizing the observations of other authors, I will use the authors’ terminology. Otherwise, I will use the term “syringomyelia” in a nonspecific fashion to encompass all abnormal CSF collections within the spinal cord.

Natural History

Because MR imaging is the gold standard in diagnosing syringomyelia, the ideal method for determining its prevalence in the setting of myelomeningocele would be to perform MR imaging in all patients with myelomeningocele at one moment in time. In the absence of such a perfect study, one might attempt to identify and examine a representative unbiased sample of patients with myelomeningocele. The best approximation of this ideal is a complete survey of institutional program populations (Table 2).

Syringomyelia has been recognized in autopsy examinations of children with myelomeningocele as early as 1922, before its modern terminology had been formulated. In 1943, Ingraham and Scott reported hydromyelia in eight of 19 children with myelomeningocele during autopsy examination. In 1957 Cameron described hydromyelia in 20 (77%) of 26 autopsy cases performed in young children with myelomeningocele, including nine of 11 newborns. “Severe internal hydrocephalus,” the author wrote, was “usually” present in his cases. In 1972 Emery and Lendon reported 100 apparently unselected necropsies in patients with myelomeningocele. All but six of these cases were infants at the time of death. Forty-three individuals (43%) exhibited spinal cord cavitation. No clinical data were provided for correlation. In a relatively recent autopsy study, the authors documented hydromyelia in 68% and syringomyelia in 36% of 25 consecutive cases. The terms “hydromyelia” and “syringomyelia” were not defined. The implications of these reports in relation to contemporary, living patients are uncertain. Causes of death often were not stated, but many of these infants died, no doubt, of complications of hydrocephalus, and inadequate treatment of hydrocephalus is believed by some authorities (vide infra) to contribute to the development of syringomyelia.

Evidence more relevant to clinical practice can be derived from imaging surveys focusing on institutional myelomeningocele program populations. Such surveys are essentially cohort studies, because their investigators attempt to study all subjects in a defined population. In a myelomeningocele population of 200 patients, Caldarelli, et al., evaluated spinal MR imaging studies obtained for both screening and for symptoms in 142 patients. Spinal cord cavitation was present in 32 patients (23%), but it was judged to be symptomatic in only 14 patients (9.8%). Dilation of the central canal less than 25% of the width of the spinal cord was not considered a significant finding. Breningstall, et al., conducted a similar survey of a program in the US. Only four of 49 patients did not undergo neuroimaging, because they were younger than 18 months of age. Hydrosyringomyelia was present in 24 (53%) of 45 patients. Only one patient (2.2%) undergoing observation developed symptoms related to syringomyelia, and this patient responded to shunt therapy. One other patient developed asymptomatic dilation of a syrinx during an episode of ventricular CSF shunt failure. Seven other patients in whom more than one imaging examination was performed were considered clinically and radiologically stable during an unstated period of follow up. The authors’ impression was that syringes detected first in an asymptomatic state seldom become symptomatic at a later time, and others have supported this notion. Azimullah, et al., surveyed patients with myelomeningocele who were followed at a European hospital-based myelomeningocele program. There was a clear accounting for the small percentage of the program-based individuals who did not undergo imaging. Thirteen (32.5%) of 40 patients exhibited cavitation of the spinal cord with (10 patients) or without (three patients) expansion of the cord. In only two

**TABLE 1**

<p>| Matrix of terms used in searching PubMed |</p>
<table>
<thead>
<tr>
<th>&quot;AND&quot;*</th>
<th>Syrinx</th>
<th>Syringomyelia</th>
<th>Hydromyelia</th>
</tr>
</thead>
<tbody>
<tr>
<td>myelomeningocele</td>
<td>13</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>meningo(myelo)cele</td>
<td>7</td>
<td>48</td>
<td>33</td>
</tr>
<tr>
<td>dysraphism</td>
<td>16</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>spina bifida</td>
<td>17</td>
<td>44</td>
<td>24</td>
</tr>
<tr>
<td>tube</td>
<td>22</td>
<td>52</td>
<td>18</td>
</tr>
</tbody>
</table>

* Boolean operator.
Syringomyelia complicating myelomeningocele

**Summary of reports in the literature detailing the natural history of syringomyelia**

<table>
<thead>
<tr>
<th>Author &amp; Year</th>
<th>No. of Cases</th>
<th>Study Type</th>
<th>Conclusions</th>
<th>Class of Evidence†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingraham &amp; Scott, 1943</td>
<td>19</td>
<td>consecutive necropsy series</td>
<td>prevalence of hydromyelia: 8 (42%) of 19</td>
<td>III</td>
</tr>
<tr>
<td>Cameron, 1957</td>
<td>26</td>
<td>consecutive necropsy series</td>
<td>prevalence of hydromyelia: 20 (77%) of 26</td>
<td>III</td>
</tr>
<tr>
<td>Emery &amp; Lendon, 1972</td>
<td>100</td>
<td>consecutive necropsy series</td>
<td>prevalence of spinal cord cavitation: 43 (43%) of 100</td>
<td>III</td>
</tr>
<tr>
<td>Gilbert, et al., 1986</td>
<td>25</td>
<td>consecutive postmortem series</td>
<td>prevalence of hydromyelia: 17 (68%) of 25; prevalence of syringomyelia: 9 (36%) of 25</td>
<td>III</td>
</tr>
<tr>
<td>Lapras &amp; Patet, 1988</td>
<td>110</td>
<td>retrospective clinical survey</td>
<td>only 2 (1.8%) of 110 patients w/ MM w/ op closure came to clinical attention subsequently, over an unstated follow-up period, w/ syringomyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Azimuthull, et al., 1991</td>
<td>40</td>
<td>program-based imaging survey (cohort study)</td>
<td>imaging prevalence of spinal cord cavitation: 13 (32.5%) of 40; only 2 (5%) of 40 were symptomatic</td>
<td>III</td>
</tr>
<tr>
<td>Breningstall, et al., 1992</td>
<td>45</td>
<td>program-based imaging survey (cohort study)</td>
<td>imaging prevalence of hydrosyringomyelia: 24 (53%) of 45; only 1 (2.2%) of 45 was symptomatic</td>
<td>III</td>
</tr>
<tr>
<td>McEnery, et al., 1992</td>
<td>14</td>
<td>cohort study</td>
<td>in a convenience sample of stable patients w/ MM selected for screening MRI, 4 (29%) of 14 had spinal cord cavitation</td>
<td>III</td>
</tr>
<tr>
<td>Bono, et al., 1993</td>
<td>25</td>
<td>prospective program imaging survey (cohort study)</td>
<td>from MM clinic population of 110, convenience sample of 25 underwent MRI survey: 5 patients w/ MM (20%) had syringomyelia; only 1 was symptomatic</td>
<td>III</td>
</tr>
<tr>
<td>Caldarelli, et al., 1998</td>
<td>142</td>
<td>program-based imaging survey (cohort study)</td>
<td>from MM clinic population of 200, 142 underwent MRI for screening &amp; symptoms; spinal cord cavitation in 32 (23%); symptomatic in 14 (9.9%); dilution of central canal &lt; 25% of cord width not considered significant</td>
<td>III</td>
</tr>
<tr>
<td>Craig, et al., 1999</td>
<td>220</td>
<td>retrospective population-based review</td>
<td>5 (2.3%) of 220 adults followed in a regional MM clinic experienced symptomatic syringomyelia</td>
<td>III</td>
</tr>
</tbody>
</table>

* MM = myelomeningocele.
† Levels of evidence: Class Ia, evidence obtained from metaanalysis of randomized controlled trials; Ib, evidence obtained from at least one randomized controlled trial; Iia, evidence obtained from at least one well-designed controlled study without randomization; Iib, evidence obtained from at least one other type of well-designed quasiexperimental study; III, evidence obtained from well-designed nonexperimental descriptive studies, such as comparative studies, correlation studies, and case studies; IV, evidence obtained from expert committee reports or opinions and/or clinical experiences of respected authorities.

The literature supports a wide range of estimates for the prevalence of syringomyelia in patients with myelomeningocele (Table 2). In autopsy studies, this ranges between 42 and 77%. Data obtained in autopsy studies may be of limited clinical relevance for several reasons. Autopsy reports reflect clinical practices remote in time and, in some instances, remote in geography from contemporary North American practice. Death rates in patients with myelomeningocele are probably much lower at present than in the decades during which the published autopsy material was collected because of more attentive management of neurogenic bladder dysfunction and hydrocephalus. Neglect of the latter condition may introduce particular bias, because inadequate treatment of hydrocephalus may promote both syringomyelia and death. Prevalence estimates derived from imaging-based surveys of institutional multidisciplinary myelomeningocele program pop-
### TABLE 3
Clinical significance

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases</th>
<th>Study Type</th>
<th>Conclusions</th>
<th>Class of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall, et al., 1975</td>
<td>4</td>
<td>case reports</td>
<td>4 patients studied (pre-MRI) because of progressive paraparesis were found to have hydromyelia; 2 improved clinically &amp; 1 radiologically after ventricular CSF shunt insertion</td>
<td>III</td>
</tr>
<tr>
<td>Batnitzky, et al., 1976</td>
<td>18</td>
<td>retrospective imaging review</td>
<td>14 patients untreated for hydrocephalus had accumulation of tracer activity in syringomyelic cavities; 4 w/ working ventricular shunts had syringomyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Day, et al., 1977</td>
<td>1</td>
<td>case report</td>
<td>upper-extremity paralysis precipitated by removal of infected CSF shunt; hydromyelia demonstrated on ventriculography; symptoms &amp; signs relieved by shunt replacement</td>
<td>III</td>
</tr>
<tr>
<td>Hall, et al., 1979</td>
<td>11</td>
<td>case reports</td>
<td>11 w/ progressive developmental scoliosis treated with ventricular CSF shunt; 7 (64%) shown to have hydromyelia; scoliosis improved in 7, stabilized in 3, &amp; progressed in 1</td>
<td>III</td>
</tr>
<tr>
<td>Sherk, et al., 1983</td>
<td>17</td>
<td>retrospective institutional op series</td>
<td>17 patients w/ MM required op for developmental scoliosis &amp; underwent preop CT myelography: 10 (59%)</td>
<td>IV</td>
</tr>
<tr>
<td>Kuharik, et al., 1985</td>
<td>10</td>
<td>retrospective institutional imaging series</td>
<td>prevalence among patients w/ MM w/ clinical indications for MRI: 3 (30%) of 10</td>
<td>IV</td>
</tr>
<tr>
<td>Park, et al., 1985</td>
<td>17</td>
<td>retrospective institutional op series</td>
<td>9 (53%) of 17 studied (pre-MRI) because of spasticity or scoliosis had “hydromyelia”</td>
<td>IV</td>
</tr>
<tr>
<td>Samuelsson &amp; Skoog, 1988</td>
<td>35</td>
<td>retrospective imaging review</td>
<td>14 (40%) of 35 had syringomyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Williamson, et al., 1989</td>
<td>22</td>
<td>retrospective institutional imaging series</td>
<td>6 (27%) of 22 imaged because of neurological complications had hydromyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Gupta, et al., 1990</td>
<td>5</td>
<td>retrospective imaging review</td>
<td>2 of 5 w/ spina bifida cystica w/ spinal cord symptoms had syringohydromyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Just, et al., 1990</td>
<td>114</td>
<td>retrospective institutional imaging series</td>
<td>13 (11%) of 114 studied for unstated reasons had syringohydromyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Breningstall, et al., 1992</td>
<td>2</td>
<td>case reports</td>
<td>2 symptomatic patients w/ syringomyelia improved clinically after ventricular CSF shunt insertion/revision</td>
<td>IV</td>
</tr>
<tr>
<td>Stovner &amp; Rinck, 1992</td>
<td>6</td>
<td>retrospective institutional imaging series</td>
<td>1 of 6 w/ CM2 had syringomyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Herman, et al., 1993</td>
<td>100</td>
<td>retrospective institutional op series</td>
<td>13% prevalence in MM patients w/ symptomatic secondary SCT</td>
<td>IV</td>
</tr>
<tr>
<td>Bono, et al., 1993</td>
<td>25</td>
<td>case reports</td>
<td>5 (20%) MM patients had syringomyelia; all 5 had persistent ventriculomegaly despite a CSF shunt; the only patient w/ symptomatic syringomyelia improved after shunt revision</td>
<td>III</td>
</tr>
<tr>
<td>Aronin &amp; Kerrick, 1995</td>
<td>3</td>
<td>case reports</td>
<td>3 symptomatic patients w/ syringomyelia or “presumed” syringomyelia improved clinically after shunt revision</td>
<td>IV</td>
</tr>
<tr>
<td>Caldarelli, et al., 1995</td>
<td>72</td>
<td>retrospective institutional series</td>
<td>6 (23%) of 26 symptomatic patients had hydromyelia; 9 (20%) of 46 asymptomatic patients had hydrosyringomyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Koyanagi, et al., 1997</td>
<td>9</td>
<td>retrospective institutional imaging series</td>
<td>7 patients w/ MM studied for unstated clinical indications had syringomyelia; 2 of 7 required treatment at diagnosis; no clinical or imaging progression or deterioration during follow-up period</td>
<td>IV</td>
</tr>
<tr>
<td>La Marca, et al., 1997</td>
<td>11</td>
<td>retrospective institutional op series</td>
<td>7 of 11 w/ symptomatic syringomyelia improved after ventricular CSF shunt insertion or revision</td>
<td>IV</td>
</tr>
<tr>
<td>Moskowitz, et al., 1998</td>
<td>—</td>
<td>—</td>
<td>three w/ symptomatic hydromyelia had larger cross-sectional spinal cord area than 19 w/o or 21 w/ “minimal” hydromyelia</td>
<td>IV</td>
</tr>
<tr>
<td>Rand-Hendriksen &amp; Christensen, 1998</td>
<td>60</td>
<td>retrospective program imaging series</td>
<td>8 (13%) prevalence in adult patients w/ MM w/ clinical indications for MRI (abstract only)</td>
<td>IV</td>
</tr>
<tr>
<td>Gencovich, et al., 1999</td>
<td>107</td>
<td>prospective institutional imaging series</td>
<td>41 (38%) MRIs obtained for various clinical indications showed hydromyelia or syrinx development of syringomyelia demonstrated by MRI at time of ventricular CSF shunt failure; resolution w/ shunt revision</td>
<td>III</td>
</tr>
<tr>
<td>McDonnell, 2000</td>
<td>25</td>
<td>prospective institutional imaging series</td>
<td>12 of (48%) adults selected from an MM clinic population of &gt;200 had hydrosyringomyelia</td>
<td>IV</td>
</tr>
</tbody>
</table>

*CM2 = Chiari II malformation; — = not available.
Syringomyelia complicating myelomeningocele

Clinical Significance

The aforementioned cohort studies suggest that syringomyelia is asymptomatic in many patients with myelomeningocele; thus, the clinical significance of these lesions is a matter that deserves scrutiny (Table 3). If a large percentage of syringes in patients with myelomeningocele cause clinical manifestations, then one might expect reports of institutional experiences concerning imaging findings—that is, reviews of imaging studies with clinical indications—to be enriched with examples of syringomyelia compared with cohort studies. In general they are not. Caldarelli, et al.,7 actually compared MR imaging findings in 26 patients with myelomeningocele who were experiencing late neurological deterioration with 46 patients with asymptomatic myelomeningocele who were studied to establish baseline imaging features in a myelomeningocele clinic population of 206 patients. Six (23%) of 26 symptomatic patients suffered hydromyelia, and nine (20%) of 46 asymptomatic patients had hydromyelia/syringomyelia. Just, et al.,25 identified syrinx/hydromyelia in 13 (11%) of 114 patients of all ages with myelomeningocele who underwent MR imaging for unstated clinical indications. Gerscovich, et al.,23 identified hydromyelia or a syrinx in 41 (38%) of 107 MR imaging studies obtained for various clinical indications. Herman, et al.,18 reported experiences with 100 myelomeningocele patients treated for secondary spinal cord tethering. All patients underwent whole-spine MR imaging during preoperative evaluation, and hydromyelia was present in 13 cases (13%). Syringomyelia was present in 14 (40%) of 35 patients with myelomeningocele in whom imaging was conducted for unstated reasons in a report by Samuelsson and Skoog.18 In an attempt to survey their clinic population (≥ 200 adults with myelomeningocele) for syringomyelia, McDonnell, et al.,25 performed MR imaging in 25 patients. The selection process for imaging was not explained. Hydro/syringomyelia was identified in 12 (48%) of 25 patients. Williamson, et al.,47 identified hydro/syringomyelia in six (27%) of 22 pediatric patients in whom imaging was performed for neurological complications occurring late after the initial myelomeningocele closure. Park, et al.,34 found hydro/syringomyelia in nine of 17 patients with myelomeningocele who underwent investigation prior to the availability of MR imaging because of progressive spasticity and scoliosis. Sherk, et al.,36 described 17 patients with myelomeningocele who required fusion for developmental scoliosis and who underwent preoperative CT myelography. Ten of 17 had syringomyelia. In 10 patients with myelomeningocele who underwent MR imaging for unstated clinical indications, Kuharik, et al.,24 noted "syringohydromyelas" in three cases. Koyanagi, et al.,23 found syringomyelia in seven of nine myelomeningocele patients studied with CT myelography or MR imaging for unstated clinical indications. Stovner and Rinck45 found one syrinx among six studies of patients with Chiari II malformation. Rand-Hendriksen and Christensen46 reported a 13% prevalence of syringomyelia among adult patients with myelomeningocele enrolled in a Norwegian national social service program and studied for unstated clinical indications (abstract only). Gupta, et al.,19 found syringohydromyelia in two of five children with spina bifida cystica.

Because syringomyelia is asymptomatic in so many cases, the question of imaging characteristics that distinguish symptomatic from asymptomatic lesions is salient. Moskowitz, et al.,22 reported spinal cord morphometric features in 43 patients with myelomeningocele who had undergone tethered cord release or who exhibited symptomatic spinal cord hypoplasia. Only three patients suffered symptomatic hydromyelia; nevertheless, the authors stated that the spinal cord cross-sectional area was significantly greater in symptomatic patients than in patients without hydromyelia or with "minimal" hydromyelia.

Closely related to the question of the natural history of asymptomatic syringes is the correlation between imaging features and clinical responses to treatment. Of the 45 patients treated by La Marca, et al.,23 23 underwent postoperative imaging studies. In five patients clinical benefit developed without any reduction in the volume of their syringes, which were described as “severely dilated.” In two patients with holocord syringomyelia there was reduction in syrinx volume without clinical benefit.

There seems to be an association between untreated (or inadequately treated) hydrocephalus and syringomyelia in patients with myelomeningocele. Batnitzky, et al.,3 performed radionuclide ventriculography in 18 patients with myelomeningocele who had progressive myelopathy, 14 of whom suffered untreated hydrocephalus and in four of whom there were working ventricular CSF shunts. In all

Summary of reports detailing diagnostic modalities for syringomyelia

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases</th>
<th>Study Type</th>
<th>Conclusions</th>
<th>Class of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venes, et al., 1986</td>
<td>14</td>
<td>expert opinion</td>
<td>grip dynamometry is useful for clinical surveillance of patients w/ MM</td>
<td>IV</td>
</tr>
<tr>
<td>Aronin &amp; Kerrick, 1995</td>
<td>16</td>
<td>cohort study (retro- or prospective?)</td>
<td>sequential declines in grip &amp; pinch dynamometry are highly predictive (5 of 5) of sp or indications, most commonly syringomyelia</td>
<td>III</td>
</tr>
</tbody>
</table>
patients not treated for hydrocephalus, there was a \textit{failure} of tracer activity in syringomyelic cavities; no evidence of syringomyelia was demonstrated in treated patients.\textsuperscript{3} The association between syringomyelia, hydrocephalus, and spinal deformity was emphasized by Hall, et al.,\textsuperscript{16} who reported on 11 patients with myelomeningocele referred for evaluation of progressive developmental scoliosis. Functioning ventricular CSF shunts were not demonstrated in any patient. Radionuclide ventriculography revealed hydromyelia in the first seven referred patients, in whom ventricular shunts were then placed. The subsequent four patients underwent ventricular shunt placement without ventriculographic evaluation. Scoliosis improved in seven, stabilized in three, and progressed in one patient. Bono, et al.,\textsuperscript{4} identified five cases of syringomyelia in their myelomeningocele clinic population; in all five ventriculomegaly persisted despite treatment with CSF shunts. The only symptomatic patient in their series improved after CSF shunt revision.

Examples of ventricular CSF shunt therapy (or shunt revision) for syringomyelia with subsequent imaging or clinical improvement appear as case reports or as comments or illustrative examples in larger series.\textsuperscript{1,6,11,17,25,31,39} La Marca, et al.,\textsuperscript{25} observed that patients with holocord syringomyelia were more likely to benefit clinically from ventricular shunt revision than those with segmental syringes. In contemporary reports addressing the management of syringomyelia in the setting of myelomeningocele, the authors have recommended confirming adequate ventricular CSF shunt function before proceeding to other surgical measures.\textsuperscript{19,25,35,48} Data that underscore the contrary have been published. Samuelsson, et al.,\textsuperscript{17} reported on 30 patients with myelomeningocele in whom MR imaging was predominantly conducted because of scoliosis. In 17 patients with “clinically functioning shunts,” syringomyelia was identified in seven. In 13 patients who were never or are no longer treated for hydrocephalus, syringomyelia was found in five.

\textbf{Summary of Clinical Details}

Syringomyelia is common in patients with myelomeningocele, but in only a minority of cases does it seem to be active clinically. The prevalences of syringomyelia reported by authors of MR imaging studies obtained for clinical indications range from 11 to 77%. These values are indistinguishable from those of autopsy and imaging survey incidences. Correlations between disease (imaging findings) and clinical manifestations are therefore problematic. Various symptoms and signs have been attributed to syringomyelia, including segmental amyotrophy, dissociated segmental sensory disturbances, spasticity, scoliosis, weakness, bladder dysfunction, and pain. Many of these same symptoms and signs have also been attributed to other complications of myelomeningocele, such as hydrocephalus, Chiari II malformation, spinal arachnoid cysts, spinal cord hypoplasia,\textsuperscript{32} and SCT, which often accompany syringomyelia. Furthermore, there are qualitative and quantitative differences among syringes that one might expect to correlate with their propensity to cause symptoms. Although many questions are raised in the existing literature, little evidence is brought to bear on the many potential clinicopathological correlations, with the possible exception of an association supported by Level III and Level IV evidence between inadequately treated hydrocephalus and clinically active syringomyelia.

\textbf{Diagnosis}

The contemporary imaging modality universally used to identify and characterize syringomyelia is MR imaging.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|}
\hline
Authors & Year & No. of Cases & Study Type & Conclusions & Class of Evidence \\
\hline
Stanley, et al., 1984 & 5 & retrospective institutional imaging series & 5 children treated w/ PCD & IV \\
Hoffman, et al., 1987 & 30 & retrospective institutional surgical series & 22 patients were treated by PCD, opening of the 4th ventricle & IV \\
van Hall, et al., 1992 & 2 & case reports & 2 children treated w/ SPerS; 1 improved clinically & IV \\
Koyanagi, et al., 1997 & 2 & retrospective institutional imaging series & 7 of 9 patients w/ MM studied for unstated clinical indications had syringomyelia; syringosubarachnoid shunt caused collapse of the syrinx in the 2 w/ clinical improvement in 1 & IV \\
La Marca, et al., 1997 & 45 & retrospective institutional surgical series & 45 patients w/ MM & syringomyelia, (variable presentations & lesions) received different treatments w/ variable results (see Discussion) & IV \\
Caldarelli, et al., 1998 & 14 & retrospective institutional surgical series & 14 symptomatic patients w/ spinal cord cavitation required treatment: PCD in 5; SPerS in 5; VSR in 2; syringomyelia; syringosubarachnoid shunt in 2; & IV \\
Craig, et al., 1999 & 5 & retrospective institutional surgical series & 5 adults w/ advanced neurological signs at diagnosis treated variably w/ PCD & IV \\
McLone, 2000 & 1 & case report & syringomyelia demonstrated on MRI at time of ventricular CSF shunt failure; resolution w/ shunt revision & III \\
\hline
\end{tabular}
\caption{Summary of treatments for syringomyelia reported in the literature}
\end{table}

\textsuperscript{*} PCD = posterior cervical decompression; SPerS = syringoperitoneal shunt; TCR = tethered cord release; VSR = ventricular shunt insertion.
Syringomyelia complicating myelomeningocele

There are a small number of reports dating to the mid-1980s, when MR imaging was introduced, in which investigators compare the accuracy of MR imaging with other imaging modalities and with surgical findings (Table 4). This literature will not be reviewed here, because in the succeeding 15 years MR imaging supplanted all other competing technologies.

Correlations between imaging findings and clinical presentations and those between imaging findings and response to treatment are reviewed in the preceding and succeeding sections of this article, respectively.

The issue of indications for MR imaging has received scant systematic study. Aronin and Kerrick reported experiences with routine clinical surveillance in which they used grip and pinch dynamometry (Table 4). Whether this study was performed pro- or retrospectively was not stated, but all patients enrolled in the institutional myelomeningocele program were examined at each clinic visit over a 42-month period. Sixteen patients underwent two or more sequential examinations. In five of 16 there were documented declines in grip strength, and in all five patients indications for surgery were identified. Clinical deterioration was attributed to syringomyelia in three cases and to “presumed” syringomyelia in one. Other authorities have endorsed dynamometry as a surveillance tool without providing analysis.

Summary of Indications

There is no dispute that the modality of choice for diagnosing syringomyelia is MR imaging. The literature provides very little evidentiary guidance, however, about indications for MR imaging. That it does not should not be a surprise because of the scant information on the natural history of syringomyelia and the confusion regarding correlations between imaging findings and clinical issues. The only pertinent report is a very small cohort study concerning grip and pinch dynamometry. Larger questions, such as the cost-effectiveness of surveillance MR imaging, are completely unprobed.

Treatment of Syringomyelia

Symptomatic syringomyelia in the setting of myelomeningocele is a surgically treatable condition. This review did not identify any reports of nonsurgical therapies. A range of surgical interventions have been applied in the management of syringomyelia in the setting of myelomeningocele: posterior cervical decompression with or without obex plugging, placement of a ventricular CSF shunt or revision, syringosubarachnoid shunt, syringopleural or -peritoneal shunt, myelotomy with lumboperitoneal shunt, and tethered cord release. There have been no randomized controlled trials of any of these therapies, nor prospective studies of any kind. No studies have had meaningful controls. All the reports in which authors described surgical interventions have been either case reports or retrospective reviews of surgical series from single institutions.

Hoffman, et al., reviewed their experience with hydrosyringomyelia at the Hospital for Sick Children in Toronto between the period when CT myelography was introduced through 1985. There were 30 cases associated with myelomeningocele. Cerebrospinal fluid shunt function was confirmed in all patients. Twenty-two patients underwent posterior cervical decompression, opening of the fourth ventricle, and plugging of the obex; 16 patients improved clinically. Two patients were treated with posterior cervical decompression alone, and both improved. Syrinx shunts were placed in six patients, and four improved. No patient was made worse by treatment. Only clinical results were reported; postoperative imaging results were not described. Selection among treatment options was not discussed, but, overall, the authors endorsed posterior cervical decompression combined with plugging of the obex. Interestingly, even though there has been no negative experience with obex plugging published subsequently, my clear impression is that this procedure has fallen out of favor. Personal experiences and anecdotal communications suggest that obex plugging is frequently associated with protracted postoperative vomiting. The absence of commentary on this subject in the literature is probably an example of publication bias.

The largest experience with treatment of syringomyelia among patients with myelomeningocele was reported from Chicago Children’s Memorial Hospital by La Marca, et al., in 1997, and it deserves careful inspection because it illustrates well the challenges of clinical research in this area. In a retrospective review of 231 MR imaging studies obtained in children with myelomeningocele treated at a large, well-organized hospital-based program, the authors identified 112 patients with syringomyelia. The syringes were categorized as holocord or as segmental, and the segmental lesions were further divided into “high” and “low” categories based on the level of the involved segments. Syringes were further characterized as distended or not. Forty-five patients were judged to be symptomatic. Signs and symptoms were categorized as referable to the cervical, thoracic, or lumbar segments, or as mixed or nonspecific. Symptomatic patients underwent ventricular shunt insertion, posterior cervical decompression, syringopleural shunt insertion, and tethered cord release according to the judgments of the treating surgeons, and results varied. Based on this experience, the authors presented a complex algorithm recommending certain surgical interventions depending on which of the six imaging categories and three symptom categories best typify the patient’s presentation. Unfortunately, for purposes of clinical trial design, this algorithm reflects the complexity of the clinical situation and the attitudes of contemporary pediatric neurosurgeons toward it.

Another substantial experience has been reported by Caldarelli, et al. These authors discussed many of the same issues in categorization and treatment selection. Fourteen patients experienced symptoms related to spinal cord cavitation and required treatment: posterior cervical decompression in five patients, syringoperitoneal shunt insertion in five, ventricular shunt insertion in two, syringosubarachnoid shunt therapy in two, and tethered cord release in one patient. In all cases the cavitations were documented to be smaller on follow-up imaging, and symptoms in all patients improved or stabilized. There was no statement about duration of follow-up.

In other publications authors have described small clinical experiences with various treatment approaches. Stanley, et al., described performing posterior cervical

J. Neurosurg: Pediatrics / Volume 100 / February, 2004
decompression with obex plugging in five children who presented with upper-limb weakness, including two with intrinsic hand-muscle atrophy. In all five cases surgery “halted the progression of the disease,” but no patient was said to have improved. Craig, et al., described five adults with advanced neurological signs at diagnosis who underwent posterior cervical decompression and shunt placement. Only one patient experienced any functional improvement, and that patient died 10 weeks after surgery of bronchopneumonia related to general debilitation. Van Hall, et al., mentioned treatment of two children in whom a syringoperitoneal shunt was placed. They noted the obliteration of the subarachnoid space at the level of the syrinx by adhesions. One child was said to have improved clinically. Koyanagi, et al., performed decompression of syrinx cavities by placing syringosubarachnoid shunts in two patients and reported clinical improvement in one.

Summary of Treatments for Syringomyelia

There is evidence from case reports and retrospective institution-based surgical series that various surgical procedures can have favorable short-term imaging-based or clinical effects in selected cases of syringomyelia. I believe that publication bias in the existing literature has left certain published but possibly unreproducible results unchallenged, particularly with regard to plugging of the obex. There are no long-term follow-up data or multiinstitutional, prospective, or controlled studies. All of the existing treatment evidence is Level III or IV, and it supports only Grade C recommendations.

Recommendations

Although the randomized controlled trial is the desideratum of clinical knowledge, the problem of syringomyelia in the setting of myelomeningocele does not lend itself to this approach. Contemporary clinicians view syringomyelia as a collection of syndromes defined by particular clinical and imaging features and indicating particular surgical interventions. Rigorous testing of contemporary practices would require many focused trials or a comprehensive trial involving multiple layers of stratification. Recruitment of sufficient numbers of patients to permit meaningful scientific conclusions would require cooperation of many institutions over long periods of time. In view of the declining birth rate of infants with myelomeningocele, winning the resources to conduct such a project in a competitive funding environment seems unlikely.

Therapeutic questions might be approached more realistically by means of a multinstitutional cohort study. Patients would be recruited and undergo MR imaging based on prospective criteria established cooperatively by the participating centers, and syringomyelia would be treated according to a consensus-derived algorithm similar to the one proposed by LaMarca, et al. Follow-up study would require periodic neurological and functional assessment by an observer other than the surgeon using yet-to-be-developed-and-validated instruments. Periodic MR imaging surveillance would be required as well. Although a cohort study could not determine which of several treatments is best for certain indications, it could provide answers regarding such important issues as the following: the association between certain patterns of clinical deterioration and syringomyelia; the short-term clinical and imaging results and complications of contemporary treatments; the incidence, if any, of relapse after initially successful treatment and the temporal pattern of relapse; and the long-term functional outcomes.

A still more modest proposal might be to study the natural history of syringomyelia in myelomeningocele. In a prospective natural history study investigators could answer the following questions. 1) Are syringes present at birth? 2) If not, when do they develop? Do they develop in response to particular, identifiable clinical events? Can they be prevented? 3) What is the temporal relationship between the development of syringomyelia and the appearance of symptoms and signs, if any? 4) Are there correlations between imaging features (central or eccentric, segmental or holocord, thin or distended?) and clinical status?

To recruit sufficient patients in a reasonable period of time, such a study must be multiinstitutional. Ideally, patients must be identified and recruited before birth, and they must therefore be born to highly motivated and cooperative parents. Patients must undergo standardized periodic clinical assessments and imaging surveillance. Details of the management of associated clinical issues, hydrocephalus most importantly, must be carefully documented. An obvious structure recommends itself for this natural history study, namely, a continuation of the National Institute of Child Health and Development’s Management of Myelomeningocele Study.

References

Syringomyelia complicating myelomeningocele


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