Syringomyelia Following Spinal Cord Injury

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Key Points

Shunting of the syrinx cavity improves pain, motor function and sensory loss in some SCI patients post syringomyelia.

Untethering improves spasticity and motor and sensory loss post SCI-related syringomyelia.

Subarachnoid-subarachnoid bypass may improve motor and bladder functioning post SCI-related syringomyelia.

Cordectomy may improve motor and sensory function post SCI-related syringomyelia.

Cordectomy may improve quality of life post SCI-related syringomyelia.

Embryonic tissue transplantation may destroy syringomyelia cysts and improve sensory loss.

Further research is needed to determine the potential benefits of cellular therapy for the treatment of syringomyelia.
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Syringomyelia Following Spinal Cord Injury

1.0 Executive Summary

Post-traumatic syringomyelia refers to the formation of an intramedullary cyst filled with cerebrospinal fluid (CSF) within the spinal cord (Brodbelt & Stoodley, 2003). Though uncommon, its impact can be devastating following spinal cord injury (SCI). It can be seen as early as two months after injury, or many years later (Vernon, Silver, & Symon, 1983).

**What is the epidemiology of syringomyelia after spinal cord injury?**

Syringomyelia occurs in approximately 2% of individuals with SCI (Klekamp & Samii 2002). There is a 22% higher incidence of syringomyelia found at autopsy than those presenting clinically (Vannemreddy et al. 2002). No relationship has been reported between the level of SCI and the likelihood of developing syringomyelia, however, an increased risk of post-traumatic syringomyelia has been reported in complete SCI individuals (Vannemreddy et al. 2002; Kramer & Levine 1997).

**What is the pathophysiology and clinical presentation of syringomyelia after spinal cord injury?**

The pathophysiology of syringomyelia following SCI is not completely understood. The most supported theory is William’s “Cranial-Spinal Pressure Dissociation Theory” which involves formation of the cavity and its enlargement and extension (Williams et al. 1981). Most commonly, it is thought to be asymptomatic. When it expands or compresses surrounding nerve tracts, it can cause radicular pain, gait ataxia, sensory disturbance, dysesthesias and motor weakness (Brodbelt & Stoodley 2003; Klekamp & Samii 2002; Kramer & Levine 1997; Lyons et al. 1987). As syringomyelia progresses, reduction in sensation and increased spasticity may be seen (Carroll & Brackenridge 2005). Progression is usually slow in most patients, with the clinical presentation remaining static for many years (Mariani et al. 1991).

**How is syringomyelia diagnosed?**

- Magnetic Resonance Imaging (MRI) is currently the diagnostic test of choice for syringomyelia.
- Myelography Enhanced Computed Tomography (CT-myelography). A significant improvement over plain CT, as it is able to show swelling and fixation of the cord and localized CSF flow obstruction (Dworkin & Staas 1985; Klekamp & Samii 2002).
- Virtual Endocopy (VE) by Computer Tomography allows non-invasive exploration of the spinal canal in all directions and can provide information regarding the extent of stenosis, which plain CT cannot provide. Ultrasonography is useful in localizing syrinxes, determining the safest place to open the dura, and facilitating optimal shunt placement during surgery (Brodbelt & Stoodley 2003).
- Intraoperative Somatosensory Evoked Potentials have limited value in assessing for syringomyelia, however may be used during surgery to prevent neurological damage.
1.5 What are the management options for syringomyelia?

<table>
<thead>
<tr>
<th>Management Options</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Medications</strong></td>
<td>Used to manage presenting symptoms, but they do not treat the syringomyelia itself.</td>
</tr>
<tr>
<td><strong>Surgery</strong></td>
<td>Only recommended for patients with neurological deterioration or intractable pain (El Masry &amp; Biyani 1996; Klekamp &amp; Samii 2002). Commonly reported in the treatment of syringomyelia in SCI patients.</td>
</tr>
<tr>
<td><strong>Shunting</strong></td>
<td>Can be performed using syringoperitoneal, syringopleural, syringosubarachnoid, or ventriculoperitoneal shunts. Shunting improves pain, motor function and sensory loss in some SCI patients with syringomyelia (Karam et al. 2014; Ushewokenze et al. 2010; Schaan &amp; Jaksche 2001; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001; Hess &amp; Foo 2001; Hida et al. 1994). High rate of shunt failure has been observed.</td>
</tr>
<tr>
<td><strong>Untethering</strong></td>
<td>Used to prevent or revise neurological or orthopedic sequelae. Untethering improves motor and sensory loss (Falci et al. 2009; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001), and improves spasticity in more patients with syringomyelia than shunting (Lee et al. 2000; Lee et al. 2001).</td>
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<tr>
<td><strong>Subarachnoid–Subarachnoid Bypass (S-S Bypass)</strong></td>
<td>A new type of surgical technique for posttraumatic syringomyelia that may improve motor and bladder functioning (Hayashi et al. 2013).</td>
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<tr>
<td><strong>Corpectomy</strong></td>
<td>Used to manage spasticity, pain and improve neurological dysfunction; An invasive and irreversible procedure, it is only considered when other options have been exhausted (Gautschi et al. 2011).</td>
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<tr>
<td><strong>Neural Tissue Transplantation</strong></td>
<td>A novel treatment for syringomyelia that involves transplantation of neural tissue alone or in conjunction with surgical untethering or cyst shunting. Embryonic tissue transplantation along with drainage, untethering and shunting may obliterate syringomyelia cysts and improve sensory loss (Falci et al. 1997; Wirth III et al. 2001). However, further investigation is required.</td>
</tr>
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</table>

**Gaps in Literature:**

**Causes of Syringomyelia:** The exact incidence and etiology (tumor, infection, trauma, chiari malformation, etc.) is uncertain.

**Signs and Symptoms**

Symptoms of syringomyelia are variable and may include any of the following:
- Radicular pain, gait ataxia, sensory disturbance, dysesthesias and motor weakness, reduction in sensation, and increased spasticity. These differ from the classic symptoms seen in syringomyelia patients.
- Those that are not well studied include syringobulbia and death.

**Management**

Indications for each treatment modality are limited. Therefore, determining when to consider untethering, bypass, etc., can become a challenge. Furthermore, complications of treatment modalities are sparse in the literature.

**Prognosis**

To our knowledge, there is no published literature that specifically outlines the prognosis of syringomyelia following SCI, nor is there evidence suggesting recurrence risk after each treatment.
2.0 Introduction
Post-traumatic syringomyelia is a term used to describe the formation of an intramedullary cyst (syrinx) filled with cerebrospinal fluid (CSF) within the spinal cord (Brodbelt & Stoodley, 2003). Though uncommon, its impact can be devastating following spinal cord injury (SCI). It can be seen as early as two months after injury, or many years later (Vernon, Silver, & Symon, 1983). The typical clinical features of syringomyelia are motor and sensory deficits which correlate to the level of the syrinx (Davidson, Rogers & Stoodley, 2018).

2.1 Epidemiology
Syringomyelia occurs in approximately 2% of individuals with SCI (Klekamp & Samii 2002). No relationship has been reported between the level of SCI and the likelihood of developing syringomyelia. Incidence rates are similar in individuals with either tetraplegia or paraplegia (Brodbelt & Stoodley 2003; Klekamp & Samii 2002; Ko et al. 2012). However, an increased risk of post-traumatic syringomyelia has been reported in complete SCI individuals (Vannemreddy et al. 2002; Kramer & Levine 1997).

2.2 Pathophysiology
The pathophysiology of syringomyelia following SCI is not completely understood. The most supported theory is William’s “Cranial-Spinal Pressure Dissociation Theory” which involves formation of the cavity and its enlargement and extension (Williams et al. 1981). Initially, at the site of SCI, a cavity forms after liquefaction of cord tissue or hematoma (Biyani & El Masry 1994; Williams et al. 1981). The liquefaction and cyst formation at the site has been linked to microinfarcts and the release of cellular enzymes (Williams et al. 1981; Kao & Chang 1977). Cyst formation results in partial obstruction of cerebral spinal fluid movement, creating a pressure gradient between the intracranial space and spinal space (Sharma et al. 2006). The second phase, cyst enlargement and extension, is the result of this pressure gradient which has been linked to two mechanisms affecting fluid dynamics, ‘slosh’ and ‘suck’ (Biyani & El Masry 1994; Williams et al. 1981). The ‘slosh’ is due to increased epidural venous pressure and CSF movement which are triggered by everyday activities such as coughing and sneezing (Williams 1992). This pressure causes areas of structural weakness in the cord leading to proximal and distal extension of the syrinx. The second mechanism ‘suck’ is the result of a partial subarachnoid block. As the fluid is initially forced up due to increased epidural venous pressure, it returns slowly creating a pressure gradient across the partial subarachnoid block with negative pressure caudal to it (Biyani & El Masry 1994). This contributes to the syrinx formation and progression.

2.3 Clinical Presentation and Natural History
The classic symptoms of syringomyelia (i.e., suspended sensory loss, segmental weakness and burning) are often not present in individuals with SCI. Many individuals may lack symptoms in general or present with nonspecific symptoms that may be attributed to other complications of SCI such as spasticity, autonomic dysreflexia or neuropathic pain. Most commonly, symptoms include radicular pain, gait ataxia, sensory disturbance, dyesthesias or motor weakness.
As syringomyelia progresses, reduction in sensation and increased spasticity may be seen (Carroll & Brackenridge 2005). Progression is usually slow in most patients, with the clinical presentation remaining static for many years (Mariani et al. 1991).

### 3.0 Diagnosis and Monitoring

#### 3.1 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is currently the diagnostic test of choice for syringomyelia as it is able to detect fluid movement, syrinxes, and other abnormalities (Brodbelt & Stoodley 2003). MRI also has an important role in planning and monitoring outcomes of treatments. T1-weighted (T1W) and T2-weighted (T2W) images can be obtained from a MRI and allow for image contrast between different types of tissue (Enzmann 1991). Phase contrast with MRI can identify obstruction of the subarachnoid space and demonstrate normalization of CSF flow following surgery (as seen in Figure 2; Brodbelt & Stoodley 2003). However, MRI is limited in its ability to differentiate posttraumatic syringomyelia from myelomalacia or tumor-associated syringomyelia (Biyani & El Masry 1994).

#### 3.2 Myelography Enhanced Computed Tomography

Myelography-enhanced computed tomography (CT-myelography) of the spinal cord is a significant improvement over plain CT in the diagnosis of syringomyelia. Images from plain CT are considered unreliable due to imaging distortions of the surrounding bone (Klekamp & Samii 2002). CT-myelography is able to show swelling and fixation of the cord and localized CSF flow obstruction (Dworkin & Staas 1985; Klekamp & Samii 2002). As water soluble contrast accumulates in the cyst, CT-myelography can show the syrinx itself (Aubin et al. 1981). However, 10-50% of syrinxes may still be missed using this tool; therefore, MRI remains the diagnostic tool of choice (Brodbelt & Stoodley 2003).

#### 3.3 Virtual Endoscopy by Computer Tomography

Improvements in CT technology have resulted in better three-dimensional imaging. Advanced computer graphics hardware and software have enabled the visualization of organs both inside and out. Virtual endoscopy (VE) is “a realistic 3D intraluminal simulation of tubular structures that is generated by post-processing of CT data sets” (Kotani et al. 2012, p. E752). Using this technology, surgeons can noninvasively explore the spinal canal in all directions. VE can provide information regarding the extent of stenosis, which plain CT cannot provide. It is useful for diagnosis, preoperative planning, and postoperative assessing.
3.4 Ultrasonography
Ultrasonography is usually confined to the intraoperative setting. It is useful in localizing syringes, determining the safest place to open the dura, and facilitating optimal shunt placement during surgery (Brodbelt & Stoodley 2003).

3.5 Intraoperative Somatosensory Evoked Potentials
Since the spinal cord is usually already significantly damaged, intraoperative somatosensory evoked potentials (SSEP) are of limited value in assessing for syringomyelia. However, it may be used during surgery to prevent neurological damage if action potentials can be obtained.

4.0 Management
Medications can be used to manage presenting symptoms but they do not treat the syringomyelia itself. Surgery is the only intervention which directly treats and resolves the syringomyelia. Surgery is only recommended for patients with neurological deterioration or intractable pain (El Masry & Biyani 1996; Klekamp & Samii 2002), although its use is commonly reported in the treatment of syringomyelia in SCI patients.

4.1 Shunting
Shunting of the syrinx cavity can be performed using syringoperitoneal, syringopleural, syringosubarachnoid, or ventriculoperitoneal shunts. Most shunting procedures also involve laminectomies and duraplasties prior to the insertion of shunts (Figure 3).

Table 1 Shunting

<table>
<thead>
<tr>
<th>Author Year Country Research Design Score Total Sample Size</th>
<th>Methods</th>
<th>Outcome</th>
</tr>
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<tbody>
<tr>
<td>Schaan &amp; Jaksche 2001 Germany Cohort N=30</td>
<td>Population: Gender: males=21, females=9; Level of severity: complete=24, incomplete=6. Intervention: Patients with syringomyelia were divided into 3 groups: Group 1 (n=18) received single or multiple shunting procedures; Group 2 (n=5) received shunting procedures before surgical creation of a pseudomeningocele; Group 3 (n=7) was treated only with the surgical pseudomeningocele. Outcome Measures: Sensory and motor deficit, Pain, Syringobulbia.</td>
<td>1. There were no significant differences in outcomes between groups. 2. Prior to shunting (n=18) 15 had sensory deficits, 13 had motor deficits, 14 had pain and two had syringobulbia. Post-surgery: a. Sensory deficits improved in five, deteriorated in two, and were unchanged in eight patients. b. Motor deficits improved in five, deteriorated in two and were unchanged in four patients. c. Pain improved in five, deteriorated in four, and was unchanged in five patients. d. Syringobulbia improved in one and deteriorated in the second patient. 3. Prior to shunting and pseudomeningocele (n=5) five had sensory and motor deficits, one had pain and one had syringobulbia. Post-surgery: a. Sensory deficits improved in four and deteriorated in one patient. b. Motor deficits improved in three.</td>
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<tr>
<td>Author Year</td>
<td>Country</td>
<td>Research Design</td>
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<tr>
<td>Davidson, Rogers &amp; Stoodley, 2018</td>
<td>Australia</td>
<td>Pre-Post</td>
</tr>
<tr>
<td>Tassigny et al. 2017</td>
<td>Belgium</td>
<td>Pre-Post</td>
</tr>
<tr>
<td>Karam et al. 2014</td>
<td>Canada</td>
<td>Pre-Post</td>
</tr>
<tr>
<td>Author Year</td>
<td>Country</td>
<td>Research Design</td>
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<tr>
<td>Ushewokunze et al. 2010 UK</td>
<td>Pre-Post</td>
<td>N=40</td>
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<tr>
<td>Hess &amp; Foo 2001 USA</td>
<td>Case Series</td>
<td>N=8</td>
</tr>
<tr>
<td>Lee et al. 2001 USA</td>
<td>Case Series</td>
<td>N=45</td>
</tr>
<tr>
<td>Lee et al. 2000 USA</td>
<td>Case Series</td>
<td>N=34</td>
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<tr>
<td>Author Year</td>
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<tr>
<td>Falci et al. 1999</td>
<td>USA</td>
<td>Case Series</td>
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<tr>
<td>Ronen et al. 1999</td>
<td>Israel</td>
<td>Case Control</td>
</tr>
<tr>
<td>Hida et al. 1994</td>
<td>Japan</td>
<td>Case Series</td>
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</tbody>
</table>

**Methods**

- posttraumatic syringomyelia were assessed. Patients underwent laminectomies and a syringosubarachnoid shunt was inserted. Patients were divided into three groups: Group 1 underwent untethering only, Group 2 underwent shunting only, and Group 3 underwent both untethering and shunting. Patients were followed up to assess treatment efficacy.

**Outcome Measures:** Improvement in symptoms, Complications.

**Population:** Mean age: 26 yr; Gender: males=49, females=10; Level of severity: AIS A=53, B=1, C=4, D=1.

**Intervention:** All patients underwent spinal untethering and if a spinal cyst was present a lumbo-peritoneal shunt tube was placed along the length of the cyst.

**Outcome Measures:** Pinprick, Motor and light touch scores, MRI findings, Somatosensory evoked potentials.

1. Participants with no previous surgery showed a significant increase in light touch (+2.38), pinprick (+3.88) and motor scores (+1.47) post-surgery.
2. Participants who had previous surgery had a decrease in touch, pinprick and motor score, although it was minimal (0.7, 0.8, and 0.5, respectively).
3. At 2wk post-surgery, MRI showed decreased cyst size or complete collapse.
4. Somatosensory evoked potentials were improved in amplitude compared to baseline; latency of 2 milliseconds or greater was observed in 27 patients.

**Population:** Mean age: 31.3 yr; Gender: males=10, females=0; Level of injury: C=5, L=4; Level of severity: incomplete=5, complete=5.

**Intervention:** Charts of patients with syringomyelia were reviewed. Patients were divided into two groups: patients receiving rehabilitation only and patients receiving rehabilitation and shunting.

**Outcome Measures:** Functional and neurological outcome.

1. Four out of five patients in the shunt surgery and rehabilitation group showed functional and neurological deterioration; the fifth patient remained unchanged.
2. Patients in the rehabilitation only group remained unchanged except for one who showed significant functional improvement without any change in neurological status.

**Population:** Mean age: 48 yr; Gender: males=10, females=4; Level of injury: C=5, T=5, L=4.

**Intervention:** Charts of patients who underwent syringosubarachnoid (n=6), syringoperitoneal (n=4), and ventriculoperitoneal (n=1) shunts were assessed.

**Outcome Measures:** Neurological, motor, Sensory functioning, Shunt malfunction.

1. Neurological amelioration was obtained in all patients.
2. Of the nine patients with motor function difficulty, eight improved.
3. Sensory disturbance and relief of local pain or numbness improved in all patients.
4. Malfunction was reported in three of four syringoperitoneal shunts and in the one ventriculoperitoneal shunt.
Discussion
In all of the studies, no shunting procedure was found to be superior to another. Schaan and Jaksche (2001) in a cohort study assessed the efficacy of syringomyelia treatment in three groups of patients: Group One received various shunts only, Group Two received shunting followed by surgical creation of a pseudomeningocele, and Group Three was treated with the pseudomeningocele only. The study found improvement in sensory and motor deficits, pain and syringobulbia in all three groups. However, more patients experienced greater pain post-surgery in the shunting only group than the other two groups. It should be noted that although groups did improve on some of the outcome measures, none of the groups were significantly different from each other.

Falci et al. (1999) demonstrated that untethering and shunt tube placement among individuals without prior surgery can significantly improve light touch, pinprick and motor scores. Two case series (Lee et al. 2001; Lee et al. 2000) further examined untethering and shunting treatment in individuals with syringomyelia. In the study by Lee et al. (2001), patients were divided into three groups: untethering only, shunting only, and untethering and shunting. Improvement in motor and sensory functioning was observed in all three groups, although the groups did not significantly differ from each other. In the first group, untethering only, improvement in spasticity was more common; while the shunting only group found gait improvement to be the most common. These results are also supported by Lee et al. (2000) earlier case series which found the same outcome measures were improved by the same corresponding intervention. Furthermore, shunting alone has been reported to significantly improve pain (Hess & Foo 2001; Hida et al. 1994; Davidson, Rogers & Stoodley, 2018), strength (Hess & Foo 2001), motor function (Hida et al. 1994; Davidson et al., 2018) and sensation (Hess & Foo 2001; Hida et al. 1994) in patients with syringomyelia, although, a high rate of shunt failure (36-50%) has been reported (Hess & Foo, 2001; Hida et al. 1994).

One case control study (Ronen et al. 1999) reviewed charts of patients receiving either rehabilitation only or rehabilitation and shunting for syringomyelia. The study found 80% of patients in the shunting and rehabilitation group experienced functional and neurological deterioration, while patients in the rehabilitation group remained either unchanged or improved. One must be careful when drawing conclusions from such a study because allocation to either group was dictated by receiving the treatment, which presumably was given to those patients already deteriorating or those were considered at a higher risk of deterioration.

Ushewokunze et al. (2010) studied the adverse events after laminectomy and shunting and reported a reduction in syrinx size among 21 of 40 patients and a stabilization of symptoms among 27 of 40. However, symptoms deteriorated for 13 individuals including pain, increased neurological deficits, infection and CSF leakage. In 17 individuals, a second surgical procedure was required to improve deteriorating symptoms.

Only one Pre-Post Study examined the use of a myringotomy tube (Tassigny et al., 2017). Of the 17 participants in the study, only one experienced clinically worse progression of the syrinx. Additionally, between days 1-3 post-surgery 15 patients experienced shrinkage of the syrinx, with eight of those being complete (Tassigny et al., 2017).

A Pre-Post study examining just shunting (Davidson et al., 2018) found that shunting alone was enough to reduce the size of the syrinx in up to 90% of patients. Although the majority of patients improved on clinical symptoms there were no significant differences between groups for quality of life. Finally, a study by Karam et al. (2014) revealed that patients who received both shunting and duraplasty were less likely to require reoperations (3/11 patients) compared with
patients who received a shunt only with 10 of 16 requiring revisions and reoperations. However, this contrast was not statistically significant. Overall, 14 patients (52%) experienced an improvement in symptoms, 10 (37%) remained stable whilst three (11%) reported a progression of symptoms without improvement. In addition, a reduction in syrinx size was reported which correlated significantly with clinical improvement as measured by Odom Score. Only one patient experienced complications post-surgery with pain and dysphagia reported; however, it was later revealed the patient had developed another syrinx larger than before. The patients received another shunt and duraplasty which resulted in improvements reported at three-month follow-up.

Conclusions

There is level 2 evidence (from one cohort, four pre-post, and five case series studies; Karam et al. 2014; Ushewokenze et al. 2010; Schaan & Jaksche 2001; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001; Hess & Foo 2001; Hida et al. 1994; Tassigny et al. 2017; Davidson et al. 2018) that shunting improves pain, motor function and sensory loss in some SCI patients with syringomyelia; however, a high rate of shunt failure has been observed; these findings are tempered by level 4 evidence (from one pre-post study; Karam et al. 2014) that reported minimal clinical improvement post shunting with or without duraplasty.

Shunting of the syrinx cavity improves pain, motor function and sensory loss in some SCI patients post syringomyelia.

4.2 Untethering

Spinal cord tethering is commonly seen in patients with syringomyelia. A tethered spinal cord occurs when scar tissue forms and holds the spinal cord to its surrounding soft tissue membrane and dura. It has significant effects on spinal cord movement, CSF flow and extracellular fluid flow resulting in mobility issues and intramedullary pressure changes when exerting certain movements (Klekamp & Samii 2002). Untethering of the spinal cord is used to prevent or revise neurological or orthopedic sequelae.

Table 2 Untethering

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Country</th>
<th>Research Design</th>
<th>Score</th>
<th>Total Sample Size</th>
<th>Methods</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falci et al. 2009 USA Pre-Post N=362</td>
<td>Population: Mean age: 40.5 yr; Level of injury: C6=163, C6-T1=83, T1=116; Level of severity: AIS A=229, B=36, C=41, D=54, E=2. Intervention: Surgical treatment for spinal cord untethering. Outcome Measures: Asia Impairment Scale (AIS) sensory and motor scores, Sensory and motor changes, Subjective report of changes post-surgery.</td>
<td>1. Sixty percent of the patients found an improvement in spasticity, 77% found an improvement in hyperhidrosis and 47% reported an improvement in neuropathic pain. 2. Most patients (86.5%) required only one surgery. 3. Progressive myelopathy regarding sensory and motor functions was arrested for an average of 3.3-3.4 yr post-surgery. 4. 89% of patients reported an arrest in loss of sensory and/or motor function post-surgery. 5. Return of function was reported in 46% of</td>
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<tr>
<td>Author Year</td>
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<td>Lee et al. 2001 USA Case Series N=45</td>
<td></td>
<td>Population: Mean age: 45.6 yr; Gender: males=30, females=15. Intervention: Records of patients who underwent surgical treatment for posttraumatic syringomyelia were assessed. Patients were divided into three groups: Group 1 underwent untethering only, Group 2 underwent shunting only, and Group 3 underwent both untethering and shunting. Patients were followed up to assess treatment efficacy. Outcome Measures: Improvement in symptoms, Magnetic Resonance Imaging (MRI), Complications.</td>
<td>1. There was no significant difference in outcomes between groups. 2. Patients in the surgical untethering group: a. Demonstrated improvement in motor and spasticity symptoms in the majority of patients (60% and 58%, respectively). b. Experienced 1 treatment failure and 2 complications. c. Revealed cyst re-accumulation at 1 yr follow-up. 3. The shunt only group experienced one complication and three treatment failures; 60% of patients in this group experienced improvement in gait followed by sensory (57%) and motor (54%). 4. Among those who underwent both untethering and shunting, 33% had clinical recurrence, one experienced CSF leak, and 50% showed improvement in motor symptoms.</td>
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<tr>
<td>Lee et al. 2000 USA Case Series N=34</td>
<td></td>
<td>Population: Mean age: 43.2 yr; Gender: males=23, females=11. Intervention: Records of patients who underwent surgical treatment for posttraumatic syringomyelia were assessed. Patients underwent laminectomies and a syringosubarachnoid shunt was inserted. Patients were divided into three groups: Group 1 underwent untethering only, Group 2 underwent shunting only, and Group 3 underwent both untethering and shunting. Patients were followed up to assess treatment efficacy. Outcome Measures: Improvement in symptoms, Complications.</td>
<td>1. At follow-up (&gt;1 yr), 26 patients had resolution of one or more of their pre-operative symptoms; two patients experienced deterioration of motor function. 2. A decrease in spasticity was the most common improvement in patients who underwent untethering only (67%), followed by motor functioning (57%) and sensory loss (50%); this group experienced one treatment failure and two complications. 3. Improvement in gait was seen most frequently in the shunt only procedure group (60%), followed by motor (50%) and sensory loss (50%); in this group, two treatment failures and two complications occurred. 4. Patients who underwent untethering and shunt procedures did not experience clinical recurrence; motor (67%) and gait (50%) improved in patients in this group.</td>
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<tr>
<td>Falci et al. 1999 USA Case Series N=59</td>
<td></td>
<td>Population: Mean age: 26 yr; Gender: males=49, females=10; Level of severity: AIS A=53, B=1, C=4, D=1. Intervention: All patients underwent spinal untethering and if a spinal cyst was present a lumbo-peritoneal shunt tube was placed along the length of the cyst. Outcome Measures: Pinprick, Motor and light touch scores, Magnetic Resonance Imaging (MRI) findings.</td>
<td>1. Participants with no previous surgery showed a significant increase in light touch (+2.38), pinprick (+3.88) and motor scores (+1.47) post-surgery. 2. Participants who had previous surgery had a decrease in touch, pinprick and motor score, although it was minimal (0.7, 0.8, and 0.5, respectively). 3. At 2 wk post-surgery, MRI showed decreased cyst size or complete collapse. 4. Somatosensory evoked potentials were improved in amplitude compared to the patients.</td>
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</table>
Discussion

In a pre-post trial, Falci et al. (2009) reported that spinal cord untethering resulted in improvement in neuropathic pain, sensory and motor functions. Falci et al. (1999) found untethering and shunt tube placement resulted in a significant improvement in light touch, pinprick and motor scores in SCI patients without previous syringomyelia surgery. Two case series (Lee et al. 2001; Lee et al. 2000) assessed the result of untethering only, shunting only, and untethering and shunting in a group of SCI individuals with syringomyelia. Both studies found that more patients in the untethering only group had improved spasticity than patients in the other groups. Motor function and sensory loss improvement was common in all three groups. However, the shunting group only demonstrated more improvement in gait than the untethering group.

Conclusions

There is level 4 evidence (from one pre-post and three case series studies; Falci et al. 2009; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001) that untethering improves motor and sensory loss.

There is level 4 evidence (from two case series studies; Lee et al. 2000; Lee et al. 2001) that untethering improves spasticity in more patients with syringomyelia than shunting.

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Country</th>
<th>Research Design</th>
<th>Score</th>
<th>Methods</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hayashi et al. 2013</td>
<td>Population: Mean age: 47.3 yr; Gender: males=19, females=1; Level</td>
<td></td>
<td></td>
<td>Untethering improves spasticity and motor and sensory loss post SCI-related syringomyelia.</td>
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</tbody>
</table>

4.3 Subarachnoid–Subarachnoid Bypass

A new type of surgical technique for posttraumatic syringomyelia has been described in the literature, subarachnoid-subarachnoid bypass (S-S Bypass). Hayashi et al. (2013) hypothesized that reconstruction of the subarachnoid channels could re-establish CSF flow and therefore correct the underlying issue causing syrinx formation. In general, the S-S Bypass technique is accomplished by surgical laminectomy at the level of trauma, followed by a midline dural opening made under a microscope. One or two silicone tubes are inserted into the cephalic and caudal ends of the normal subarachnoid space; after a watertight dural closure, Bypass tubes are laid in the subdural space (Hayashi, 2013).

Table 3 Subarachnoid-Subarachnoid Bypass

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Country</th>
<th>Research Design</th>
<th>Score</th>
<th>Total Sample Size</th>
<th>Methods</th>
<th>Outcome</th>
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</thead>
<tbody>
<tr>
<td>Hayashi et al. 2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Somatosensory evoked potentials.</td>
<td>baseline; latency of 2 milliseconds or greater was observed in 27 patients.</td>
</tr>
</tbody>
</table>
**Methods**

of injury: thoracic=11, lumbar=5, cervical=4; Level of severity: complete=11, incomplete=9.

**Intervention:** All patients underwent a laminectomy at the level of trauma with ventricular drainage tubes inserted into the cephalic and caudal ends of the subarachnoid space. Bypass tubes were also inserted into the subdural space.

**Outcome Measures:** Frankel Score (neurologic status), ASIA motor score, Klekamp system (bladder function), Syrinx length.

**Outcome**

four showed deterioration of symptoms. Of the four who reported worsening symptoms, two improved after additional shunting but one reported no change.

2. There was a significant reduction in mean syrinx length from pre-surgery to post-surgery (p<.01).

3. A significant correlation was found between clinical outcome and change in the syrinx size whereby those who syrinx was reduced experienced clinical improvement (p=.01).

4. No significant correlation was found between preoperative and postoperative scores for either the ASIA Motor Score (59.6 versus 60.8 respectively) or Klekamp system for bladder function (1.1 versus 1.0 respectively).

**Discussion**

A single pre-post study has assessed the effectiveness of S-S Bypass in 20 individuals (mean age=47.3 years, 19 males) with SCI-related syringomyelia (Hayashi et al. 2013). The mean time since SCI was 126 months (range 2-336 months) and they were followed up, on average, for 48.2 months (range 12-93 months). Post-surgery, 12 patients showed improvements, four remained stable, and four showed signs of deterioration. Three of the four patients who demonstrated deterioration underwent a shunt replacement; two improved and one remained unchanged. There was no significant correlation between ASIA scores at baseline and follow-up. Finally, no patient experienced a CSF leak that needed treatment (Hayashi et al. 2013). The authors conclude that S-S Bypass is not only an effective method in treating syringomyelia but that it may be associated with better clinical results than those of other surgical interventions (e.g., shunts, cordectomy). Hayashi et al. (2013) state that S-S Bypass can be conducted without myelotomy therefore reducing the risk of neurological damage and does not usually require performing arachnoid lysis which avoids the possibility of scarring. Although there is a risk of re-scarring or re-tethering, the bypass tubes prevent the obstruction of CSF flow caused by re-scarring (Hayashi et al. 2013). However, a potential methodological concern of this study was the use of a subjective grading approach to patient improvement, stabilization and deterioration. Further investigation from multiple studies is required to make conclusions as to its clinical effectiveness.

**Conclusions**

There is level 4 evidence (from one pre-post study; Hayashi et al. 2013) that subarachnoid-subarachnoid bypass may improve motor and bladder functioning post SCI-related syringomyelia.
4.4 Cordectomy

Cordectomy has been shown to be a useful procedure in the surgical treatment of syringomyelia. It can be used to manage spasticity, pain and improve neurological dysfunction. However, since it is an invasive procedure and irreversible, it is only considered when other options have been exhausted (Gautschi et al. 2011).

Table 4 Cordectomy

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Country</th>
<th>Research Design Score Total Sample Size</th>
<th>Methods</th>
<th>Outcome</th>
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<tbody>
<tr>
<td>Gautschi et al. 2011 Switzerland Pre-Post N=17</td>
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<td>Population: Median age: 48.3 yr; Gender: males=15, females=2.</td>
<td>1. Overall EQ scale improved from 42 points to 67 points (p=0.006) postoperatively.</td>
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<td>Intervention: Patients received a spinal cordectomy.</td>
<td>2. The mental health score on the SF-36 improved significantly (p=0.01), whereas physical health score improved from 34.1 to 55.3 post-surgery (p=0.057).</td>
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<td>Outcome Measures: Quality of life using the EuroQol (EQ), Short Form-36 (SF-36).</td>
<td>3. The majority of patients (16/17) reported that they would undergo the operation again.</td>
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<tr>
<td>Ewelt et al. 2010 Switzerland Pre-Post N=15</td>
<td></td>
<td></td>
<td>Population: Mean age: 52 yr; Level of severity: AIS: A=7, B=8.</td>
<td>1. ASIA Scores: eight stabilized, four had improved motor and sensory scores, and one reported a progressive deterioration.</td>
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<tr>
<td></td>
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<td>Intervention: Patients received a spinal cordectomy.</td>
<td>2. Pain: 10 patients stabilized and two improved.</td>
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<td>Outcome Measures: ASIA motor and sensory function, Visual Analogue Scale (VAS), Adverse events, Spasticity.</td>
<td>3. Spasticity: nine patients stabilized, two improved, and four deteriorated.</td>
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<td>4. No complications relating to surgery were reported.</td>
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</table>

Discussion

Two pre-post studies examined the spinal cordectomy procedure on individuals with syringomyelia post SCI. Ewelt et al. (2010) found that cordectomy resulted in stabilization and improvement of motor and sensory function in 14 out of 15 patients. The study also reported improvement in pain and spasticity following the procedure. No significant adverse events were reported. Gautschi et al. (2010) reported a significant improvement in the quality of life of individuals who underwent the cordectomy procedure and high levels of subjective satisfaction.

Conclusions

There is level 4 evidence (from one pre-post study; Ewelt et al. 2010) that cordectomy improves motor and sensory function post SCI-related syringomyelia.

There is level 4 evidence (from one pre-post study; Gautschi et al. 2011) that cordectomy improves quality of life of individuals post SCI-related syringomyelia.

Cordectomy may improve motor and sensory function post SCI-related syringomyelia.

Cordectomy may improve quality of life post SCI-related syringomyelia.
4.5 Neural Tissue Transplantation

A novel treatment for syringomyelia involves transplantation of neural tissue alone or in conjunction with surgical untethering or cyst shunting. Embryonic spinal cord grafts have been shown to help repair structure and function of the spinal cord in experimental studies with an 80-90% survival rate (Houle & Reier 1988; Reier et al. 1988; Akesson et al. 1998). These grafts are used to fill the syrinx cavity and minimize cystic deformations in patients with progressive posttraumatic syringomyelia (Falci et al. 1997).

Two case reports (Falci et al. 1997; Wirth III et al. 2001), examined the use of embryonic tissue transplantation in the treatment of syringomyelia in patients post SCI. The studies involved untethering, cyst drainage and implantation of embryonic fetal tissue of SCI patients. Both studies reported collapse of cyst in the transplantation region and improvement in sensation. Improvement in spasticity was also observed, although it was short lived. Wirth III et al. (2001) demonstrated improvement in bladder functioning post-surgery, while Falci et al. (1997) showed significant improvement in deafferentation pain. At seven-month follow-up, MRI images showed no reoccurrence of the cyst in the transplantation region; however, improvement of secondary complications were not maintained (Falci et al. 1997). Further investigation using studies with more subjects is required to make conclusions as to its clinical effectiveness.

Conclusions

There is level 5 evidence (from two case reports; Falci et al. 1997; Wirth III et al. 2001) that embryonic tissue transplantation along with drainage, untethering and shunting may obliterate syringomyelia cysts and improve sensory loss.

Embryonic tissue transplantation may destroy syringomyelia cysts and improve sensory loss.

4.6 Cellular Therapies

Cellular therapy is a relatively new treatment option, which contributes to significant advancements in technology and genetic research (Vaquero, Hassan, Fernandez, Rodriguez & Zurita, 2017). Cell transplantation with mesenchymal stromal cells via injection into the site of the syrinx shows potential in the future treatment of syringomyelia without surgery (Vaquero et al. 2017).

Table 5 Cellular Therapies

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Country</th>
<th>Research Design</th>
<th>Total Sample Size</th>
<th>Methods</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaquero et al., 2018</td>
<td>Spain</td>
<td>Pre-Post N=6</td>
<td>Population: Mean age: 39 yr; Gender: Males=6; Injury etiology: SCI-trauma=6; Mean time since injury: 13.7 yr; Level of severity: AISA-A=3, AISA-B=2, AISA-D=1; Lesion location: D5=2, D3=1, D4=1, D8=1, L1=1. Intervention: Cell therapy medicament (NC1, PEI number 12-141), developed by the Spanish</td>
<td>1. No genome alterations were detected during the cell expansion process. 2. Pin prick scores on the ASIA measure improved (p=0.06), this effect was only observed at 6 mo follow-up. 3. Scores on the IANR-SCIFRS (spinal cord function) increased at 3 mo follow-up (p=0.06), and 6 mo follow-up (p=0.06). 4. There were no significant differences in VAS score post-injection (p=0.25).</td>
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<tr>
<td>Author Year Country Research Design Total Sample Size</td>
<td>Methods</td>
<td>Outcome</td>
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<td>Agency of Medicament and Health Products. The solution was injected into the syrinx over the course of one month. <strong>Outcome Measures:</strong> Alteration to genome of expanded cells, ASIA, SCI Functional Rating Scale of the International Association of Neurorestoratology (IANR-SCIFRS), Visual Analog Scale (VAS), Penn and modified Ashworth scale (MAS), Geffner scale, and neurogenic bowel dysfunction scale (NBD).</td>
<td>although patients self-reported a decrease in neuropathic pain. 5. There were no significant differences in levels of spasticity or spasms experienced by patients post-injection (MAS, p=0.50). 6. The Geffner scale (bladder dysfunction) showed no significant differences post-injection (p=0.25). 7. The NBD scale showed no significant differences post-injection (p=0.12), although four patients observed an improvement.</td>
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**Discussion**

To our knowledge, only one study has examined the use of cellular therapies for the treatment of syringomyelia. Vaquero et al. (2018) had a small patient sample of six, however they were able to observe strong improvements in spinal cord function at three and six months post-injection. Unfortunately, in terms of outcomes measuring bladder and bowel dysfunction no significant differences were reported. More studies are required on the use of cellular therapy as a potential non-surgical treatment for syringomyelia before any substantial conclusions can be drawn.

**Conclusions**

*There is level 4 evidence (from one pre-post study; Vaquero et al., 2018a) that mesenchymal stromal cell therapy may be effective in improving spinal cord function post-SCI.*

Further research is needed to determine the potential benefits of cellular therapy for the treatment of syringomyelia.

**5.0 Summary**
There is level 2 evidence (from one cohort, four pre-post, and five case series studies; Karam et al. 2014; Ushewokenze et al. 2010; Schaan & Jaksche 2001; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001; Hess & Foo 2001; Hida et al. 1994; Tassigny et al. 2017; Davidson et al. 2018) that shunting improves pain, motor function and sensory loss in some SCI patients with syringomyelia; however, a high rate of shunt failure has been observed; these findings are tempered by level 4 evidence (from one pre-post study; Karam et al. 2014) that reported minimal clinical improvement post shunting with or without duraplasty.

There is level 4 evidence (from one pre-post and three case series studies; Falci et al. 2009; Falci et al. 1999; Lee et al. 2000; Lee et al. 2001) that untethering improves motor and sensory loss.

There is level 4 evidence (from two case series studies; Lee et al. 2000; Lee et al. 2001) that untethering improves spasticity in more patients with syringomyelia than shunting.

There is level 4 evidence (from one pre-post study; Hayashi et al. 2013) that subarachnoid-subarachnoid bypass may improve motor and bladder functioning post SCI-related syringomyelia.

There is level 4 evidence (from one pre-post study; Ewelt et al. 2010) that cordectomy improves motor and sensory function post SCI-related syringomyelia.

There is level 4 evidence (from one pre-post study; Gautschi et al. 2011) that cordectomy improves quality of life of individuals post SCI-related syringomyelia.

There is level 5 evidence (from two case reports; Falci et al. 1997; Wirth III et al. 2001) that embryonic tissue transplantation along with drainage, untethering and shunting may obliterate syringomyelia cysts and improve sensory loss.

There is level 4 evidence (from one pre-post study; Vaquero et al., 2018a) that mesenchymal stromal cell therapy may be effective in improving spinal cord function post-SCI.
References


### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CSF</td>
<td>Cerebrospinal Fluid</td>
</tr>
<tr>
<td>CT-myelography</td>
<td>Myelography-enhanced computed tomography</td>
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<tr>
<td>EQ</td>
<td>European Quality of Life</td>
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<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
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<tr>
<td>SCI</td>
<td>Spinal Cord Injury</td>
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<tr>
<td>SF-36</td>
<td>Short Form-36</td>
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<tr>
<td>S-S Bypass</td>
<td>Subarachnoid-subarachnoid bypass</td>
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<tr>
<td>SSEP</td>
<td>Intraoperative somatosensory evoked potentials</td>
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<tr>
<td>VE</td>
<td>Virtual Endoscopy</td>
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