Autologous cervical fascia duraplasty in 123 children and adults with Chiari malformation type I: surgical technique and complications

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OBJECT Techniques for combined extradural and intradural decompression with expansile duraplasty for Chiari malformation type I (CM-I) have been well described, with various allogenic and autologous materials used for duraplasty. However, the approach and surgical technique used for duraplasty in our treatment of CM-I and developed by the senior author in the 1990s has not been described.

METHODS A prospective database was initiated in March 2003 to denote the use of cervical fascia for duraplasty and incorporate an ongoing detailed record of complications during the surgical treatment of children and adults with CM-I with and without syringomyelia. A total of 389 surgeries for CM-I were performed on 379 patients from March 2003 to June 2016. A total of 123 posterior procedures were performed on 123 patients in which both a posterior fossa extradural and intradural decompression with duraplasty (extra-intradural) was performed. In this paper the authors describe the surgical technique for harvesting and using cervical fascia for duraplasty in the surgical treatment of CM-I and analyze and discuss complications from a prospective database spanning 2003–2016.

RESULTS The authors found that cervical fascia can be harvested in patients of all ages (2–61 years old) without difficulty, and it provides a good substitute for dura in creating an expansile duraplasty in patients with CM-I. Cervical fascia is an elastic-like material with a consistency that allows for a strong watertight closure. Harvesting the cervical fascia graft does not require any further extension of the incision superiorly or inferiorly to obtain the graft. Complications were uncommon in this study of 123 children and adults. The risk of any type of complication (aseptic meningitis, CSF leak, pseudomeningocele, infection, development of hydrocephalus, and need for ventriculoperitoneal shunt) for the 78 patients in the pediatric age group was 0%. The risk of complication in the adult group was 6.7% (1 patient with aseptic meningitis and 2 patients with CSF leak).

CONCLUSIONS Autologous cervical fascia is easy to obtain in patients of all ages and provides an effective material for duraplasty in the treatment of CM-I. Complications from the combination of both an extradural and intradural decompression with autologous cervical fascia duraplasty are uncommon.

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KEYWORDS Chiari I malformation; tonsillar herniation; tonsillar ectopia; duraplasty; intradural; extradural; syringomyelia; pericranium; allograft; surgical technique

CHIARI malformation type I (CM-I)^{3,9–11} is a condition characterized by the inferior displacement of the cerebellar tonsils through the foramen magnum. The pathophysiology of CM-I tonsillar herniation and CM-I-associated syringomyelia is unclear, but evidence suggests a combination of posterior fossa extradural^{5,6,20,28,31,32,35,36,40,42} and intradural pathology¹⁵ that occurs in development and creates a partial blockage of CSF flow

through the foramen of Magendie and foramen magnum. This pathology leads to the pulsatile impaction of the cerebellar tonsils into the foramen magnum.⁸

Successful treatment of CM-I and CM-I-associated syringomyelia without craniocervical junction (CVJ) osseoligamentous abnormalities has been achieved with posterior fossa decompression.⁴¹ The degree of decompression required^{16,23,27} varies across individuals due to

ABBREVIATIONS CJV = craniocervical junction; CM-I = Chiari malformation type I.

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the heterogeneity in the pathophysiology of CM-I.⁴⁰ Some patients only require a posterior fossa extradural decompression to achieve adequate decompression.^{23,24} Other patients, however, will continue to be symptomatic and/or will have persistent syringomyelia despite an extradural decompression.^{16,23,27} These patients require a combination of both a posterior fossa extradural and intradural decompression with expansile duraplasty to achieve adequate decompression. The intradural decompression may or may not include any of the following depending on the degree of the tonsillar herniation and impaction: lysis of adhesions, opening of foramen of Magendie, and tonsillar reduction.^{29,38} The combination of extradural and intradural decompression with expansile duraplasty aims to treat all aspects of the pathophysiology of CM-I with or without syringomyelia. Although opening the dura potentially provides a more complete decompression compared with an extradural decompression alone, the risk for CSF complication is increased.^{16,25,26} In fact, authors of some studies have expressed concerns about opening the dura given the sizeable rates of CSF complications and have utilized a posterior fossa extradural decompression as a first-line treatment in all symptomatic CM-I patients with or without syringomyelia.^{22,23}

Techniques for the combined extradural and intradural decompression with expansile duraplasty for CM-I have been well described with various allogenic and autologous materials used for duraplasty. However, the approach and technique developed in the 1990s by the senior author (A.H.M.) has not been described. In this paper we describe our posterior fossa extradural and intradural decompression with cervical fascia duraplasty in the surgical

treatment of CM-I in children and adults, with and without syringomyelia. We describe in detail harvesting cervical fascia for duraplasty in patients of all ages. We analyze and discuss complications using this technique from a prospective database spanning 2003–2016.

Methods

Much of the following methods first appeared in our previously published study.¹⁵

Patients

The senior author (A.H.M.) initiated a prospective database of all CVJ abnormalities,¹⁴ including CM-I,²⁹ in 1978. In March 2003, we modified the database to denote the use of cervical fascia for duraplasty and incorporate an ongoing detailed record of complications. A total of 389 surgeries for CM-I were performed on 379 patients from March 2003 to June 2016 (Fig. 1). A total of 123 posterior procedures were performed on 123 patients in which both a posterior fossa extradural and intradural decompression with duraplasty (extra-intradural) was performed. One hundred nine of these surgeries were first-time intradural procedures, 6 were repeat intradural decompressions (first surgery was performed at another institution), and 10 had associated osseoligamentous abnormalities requiring occipitocervical fusion at the time of duraplasty. A 1-year follow-up was required for inclusion. No patients presented with signs/symptoms of hydrocephalus. All surgeries were performed by the senior author (A.H.M.) from March 2003 to June 2016 and by the first author (B.J.D.) and senior author (A.H.M.) from July 2015 to June 2016. The University of Iowa IRB approved this study.

FIG. 1. Flow diagram illustrating the total number of CM-I surgeries and patients and breakdown per type of surgery from March 2003 to June 2016 in our prospective database. A total of 123 posterior procedures using autologous cervical fascia for duraplasty were performed on 123 patients in which both an extradural and intradural decompression (extra-intradural) was performed. OC = occipitocervical. Figure is available in color online only.

CM-I Treatment Algorithm and Indications for Intradural Decompression and Duraplasty

Important to this study is the selection criteria for performing an intradural decompression and duraplasty following the standard extradural decompression for CM-I. The authors utilized a tailored treatment strategy for each patient with CM-I with and without syringomyelia. All patients underwent preoperative evaluation and if deemed symptomatic, a posterior decompression was offered. Symptomatic patients included patients who presented with Valsalva-induced occipital headaches, bulbar signs/symptoms, cerebellar signs/symptoms, cranial nerve deficits, or spinal cord signs/symptoms. Intraoperative ultrasonography was utilized through the different stages of the extradural decompression to assess for effective decompression and sufficient subarachnoid space and CSF flow around the tonsils. The presence of CSF behind the tonsils or tonsillar ascent was each a criterion for effective extradural decompression. Although intraoperative ultrasonography is used on all patients, in most patients with CM-I and syringomyelia the authors performed a posterior extra-intradural decompression due to data suggesting that patients with syringomyelia have a significantly greater prevalence of arachnoid veils obstructing the foramen of Magendie.^{15,29,43}

Surgical Technique

Step 1: Posterior Extradural Decompression and Intraoperative Ultrasound Assessment

All posterior extra-intradural decompressions for CM-I with or without syringomyelia are performed similarly. Prior to intraoperative assessment by ultrasound, a posterior extradural decompression is performed. A posterior occipitocervical incision is made and a subperiosteal dissection performed to expose the occiput, foramen magnum, and C1 lamina. A high-speed electric drill and rongeurs are used to remove approximately 25–30 mm of the posterior foramen magnum. The occiput is removed superiorly by approximately 30 mm to the inferior nuchal line. The posterior 25–30 mm of the superior two-thirds of the C1 lamina is removed and the occipitocervical epidural compressive ligament is excised. Ultrasound is performed to assess the adequacy of the extradural decompression and to determine whether to proceed with intradural decompression and duraplasty (see indications above).

Step 2: Harvesting Cervical Fascia Autograft for Duraplasty

The edge of the cervical fascia in the midline is isolated with Allis clamps (Figs. 2 and 3, Video 1).

VIDEO 1. Clip showing harvest of autologous cervical fascia for duraplasty. This video is an operative illustration of the step-by-step technique for obtaining autologous cervical fascia for duraplasty in the treatment of CM-I. Copyright Brian J. Dlouhy. Published with permission. Click here to view.

Church scissors are used to conduct a suprafascial dissection and expose 3 cm of cervical fascia laterally and 4 cm superiorly and inferiorly. A rake or combination of skin hooks can be used to hold the skin and subcutaneous fat outward. Saline is injected into the subfascial plane to

FIG. 2. Intraoperative photographs of harvesting autologous cervical fascia in a 14-year-old girl with CM-I and syringomyelia for use as a dural substitute for duraplasty after extradural and intradural posterior decompression. **A:** Proposed preoperative occipitocervical incision. **B:** Allis clamps attached to the cervical fascia on the right with suprafascial dissection to expose 3 cm of cervical fascia (asterisk). **C:** Dissection below the cervical fascia and above the cervical musculature with no. 11 and no. 15 blades. **D:** Inset from panel C showing the isolated cervical fascia that will be cut and set aside in moist Telfa pads until used for duraplasty. Figure is available in color online only.

assist with dissection from the underlying muscle. A no. 15 blade is used to dissect the fascia from the underlying cervical musculature. Church scissors are used to remove the cervical fascia graft. A 3 × 2-cm graft is typically obtained. Hemostasis of the underlying musculature is

FIG. 3. Intraoperative photographs of the step-by-step approach for harvesting autologous cervical fascia for duraplasty in a 29-year-old man with CM-I and syringomyelia (top of each panel is superior and bottom of each panel is inferior; asterisk indicates cervical fascia). **A:** Allis clamps attached to the edge of the cervical fascia on the right. **B:** Church scissors are used to conduct a suprafascial dissection (arrow) and expose 3 cm of cervical fascia laterally. **C:** Complete exposure of cervical fascia. Skin hooks can be used to hold the skin and subcutaneous fat in place. **D and E:** A no. 15 blade is used to dissect the fascia from the underlying cervical musculature. **F and G:** Church scissors are used to remove the cervical fascia. A 3 × 2-cm graft is typically obtained. **H and I:** Hemostasis of the underlying musculature is obtained and interrupted closure is performed with polyglycolic acid sutures, thereby allowing a tight fascial approximation with the left-sided fascia when closing. Figure is available in color online only.

obtained and interrupted closure is performed with polyglycolic acid (Vicryl) sutures, thereby allowing a tight fascial approximation with the opposite-sided fascia during closure. The cervical fascia graft can be trimmed to the appropriate size and any extraneous fat or muscle can be removed if present.

Step 3: Posterior Intradural Decompression With Cervical Fascia Duraplasty

Using a surgical microscope under high-power magnification, the posterior fossa dura is opened starting at the superolateral quadrant on the right and proceeding down to the midline at the foramen magnum and then along the dorsal axis of the cervical canal toward the lamina of C1 in a curvilinear-like fashion (Fig. 4). Care is taken to leave the arachnoid intact during dural incision. Stay sutures hold apart the exposure. Hemostasis in the venous sinuses is secured with titanium clips.

Upon completion of the dural opening, the arachnoid is inspected and divided in the midline and held apart temporarily and attached to the dural edges with titanium clips. Arachnoid adhesions are lysed and the foramen of Magendie (opening of fourth ventricle) is explored and any adhesions and arachnoid veils are cauterized and lysed.

Cerebellar tonsillar reduction is performed through low-power bipolar pia-arachnoid electric coagulation of the cerebellar tonsils such that the tonsils ascend upward and outward. This opens the roof of the fourth ventricle and exposes the egress of the fourth ventricle. The integrity of the pia mater is maintained to avoid potential adhesion, scarring, and recurrence. Modified cisterna magna reconstruction is performed with placement of a patulous elliptical cervical fascia dural graft previously harvested from the patient. Typically, the side of the fascia not adjacent to the cervical musculature should face the intradural contents when suturing the graft. Cervical fascia is elastic and pliable and when sutured, the fascia fills in the suture holes, allowing a watertight closure. Additionally, the fascia will billow in and out with the CSF pulsations, allowing for even more expansion without requiring a large duraplasty. Tisseel is layered over the duraplasty incision and a piece of Gelfoam is placed over the exposed dura to prevent muscular adherence to the dura. The wound is closed meticulously in a multilayered muscular and fascial closure to ensure musculoligamentous stability.

Results

Demographics

A total of 123 patients underwent posterior fossa extradural decompression with cervical fascia duraplasty (Fig. 1). The mean age of patients was 17.6 years (range 2–61 years; Table 1). Seventy-eight patients (63.4%) were pediatric (< 18 years old) and 45 patients (36.6%) were adults (≥ 18 years old). A total of 81 females and 42 males underwent surgery. The mean tonsillar herniation was 15.2 mm (range 4.5–26.4 mm). Cervicomedullary compression with cervicomedullary buckle was observed in 90 patients (73.2%). Syringomyelia occurred in 89 patients (72.4%). No hydrocephalus was observed in any of the pa-

tients preoperatively. Associated CVJ abnormalities were observed in 10 patients (8.1%). Six surgeries (4.8%) were repeat intradural procedures in which the first surgery was performed at another institution. Follow-up was at least 1 year from surgery (mean 4.8 years).

Complications

Complications were assessed in the immediate postoperative period; at 3, 6, and 12 months postoperatively; and for the entirety of the follow-up period for each of the 123 patients (Table 1). No intraoperative complications occurred with graft harvest or graft placement in any of the patients. No postoperative complications occurred in the 78 patients in the pediatric age group (< 18 years old). Only 3 CSF complications were observed in the 123 patients, all of which occurred in the adult group. Aseptic meningitis, defined as severe nonbacterial meningitis that resulted in postoperative headache, fevers, prolonged vomiting, and/or readmission for these symptoms, occurred in 1 adult patient. CSF leak occurred in 2 adult patients, both of which occurred in 2005. One patient required reexploration and a small leak was noted at the edge and the end of the autologous cervical fascial graft and the native dura. A single stitch was placed here and the patient did well postoperatively. The other leak was treated with a lumbar drain for 5 days, which was effective in eliminating the CSF leak, and the patient tolerated this without worsening symptoms or recurrent symptoms in the future.

The only radiographic pseudomeningocele or symptoms of a pseudomeningocele were the 2 patients described above who presented with a CSF leak. No superficial or deep infections occurred. No patients developed hydrocephalus on imaging or with signs/symptoms. Therefore, no patients required ventriculoperitoneal shunting for hydrocephalus. Additionally, no patients required ventriculoperitoneal shunting for any reason, including persistent syringomyelia, CSF leak, or pseudomeningocele.

Four adults and no pediatric patients required readmission within the 3-month postoperative period. These included the 2 patients who developed a pseudomeningocele and CSF leak requiring treatment as described above, the adult patient who developed aseptic meningitis, and a fourth patient who was admitted for migraine headache management. One adult patient and 1 pediatric patient required a future repeat intradural reoperation for increase in syrinx size, resulting in increased symptoms. On reexploration, no complications were observed from the graft—it was intact without scarring—and more aggressive intradural lysis of adhesions was performed. This procedure resulted in improvement in symptoms and decrease in the syrinx size on follow-up.

Discussion

Key Results and Interpretation

This is the first study to describe the surgical technique and use of an autologous cervical fascia duraplasty in the treatment of CM-I in patients of all ages (children and adults) with and without syringomyelia. We found that cervical fascia can be harvested in patients of all ages

FIG. 4. A 13-year-old girl with CM-I and syringomyelia who underwent extradural and intradural decompression with cervical fascia duraplasty. **A:** Suboccipital craniectomy from the inferior nuchal line to the foramen magnum, superior two-thirds C1 laminectomy, and excision of occipitocervical epidural compressive band. *Dashed line* illustrates proposed dural opening. Ultrasound is used at this point to assess for adequate decompression. If not adequate, the autologous cervical fascia is harvested and the dura opened. **B:** Dura opened along proposed *dashed line* (panel A) and held back with stay sutures. Adhesions were lysed, the foramen of Magendie opened, and the tonsils reduced with pia-arachnoid coagulation. **C–F:** The cervical fascia graft (CfG) is sutured to the native dura in a patulous but watertight fashion. **G:** Preoperative sagittal T2-weighted MR image demonstrating the tonsillar herniation, cervicomedullary kink, and large cervical syrinx. **H:** Three-year postoperative sagittal T2-weighted MR image revealing good decompression of the cervicomedullary junction with CSF surrounding the tonsils, brainstem, and upper cervical spinal cord. Ascent of the cervicomedullary junction and complete resolution of the cervical syrinx is demonstrated. Oc = occipital bone. Figure is available in color online only.

TABLE 1. Demographics and complications associated with cervical fascia duraplasty after extradural and intradural decompression for CM-I in 123 children and adults

Variable	All Patients (n = 123)	Pediatric (<18 yrs; n = 78)	Adult (≥18 yrs; n = 45)
Demographics			
Mean age, yrs (range)	17.6 (2–61)	10.4 (2–17)	30.1 (18–61)
Male gender, n (%)	42 (34.1)	30 (38.5)	12 (26.7)
Mean tonsillar herniation, mm (range)	15.2 (4.5–26.4)	15.9 (4.5–26.0)	14.0 (5.0–26.4)
Cervicomedullary kink/buckle, n (%)	90 (73.2)	60 (76.9)	30 (66.7)
Syringomyelia, n (%)	89 (72.4)	59 (75.6)	30 (66.7)
Hydrocephalus, n (%)	0 (0)	0 (0)	0 (0)
Associated CVJ osseoligamentous abnormality, n (%)	10 (8.1)	6 (7.7)	4 (8.9)
Repeat CM-I decompression w/ duraplasty, n (%)	6 (4.9)	6 (7.7)	0 (0)
Mean total follow-up, yrs (range)	4.8 (1–13.1)	4.8 (1–12.9)	4.8 (1–13.1)
Postop complications, n (%)			
Aseptic meningitis	1 (0.8)	0 (0)	1 (2.2)
CSF leak*	2 (1.6)	0 (0)	2 (4.4)
Pseudomeningocele*	2 (1.6)	0 (0)	2 (4.4)
Infection	0 (0)	0 (0)	0 (0)
Development of hydrocephalus	0 (0)	0 (0)	0 (0)
Need for ventriculoperitoneal shunt	0 (0)	0 (0)	0 (0)
Need for reoperation due to other complication†	1 (0.8)	0 (0)	1 (2.2)
Need for readmission	4 (3.25)	0 (0)	4 (8.9)
Need for reoperation for CM-I/syrinx in future unrelated to complications	2 (1.6)	1 (1.3)	1 (2.2)

* The only radiographic pseudomeningocele or symptoms of a pseudomeningocele were the 2 patients who presented with a CSF leak.

† One adult patient required readmission and reoperation for a subcutaneous fluid collection associated with the use of bone morphogenetic protein; this complication was described and reported in Lindley TE, Dahdaleh NS, Menezes AH, et al: Complications associated with recombinant human bone morphogenetic protein use in pediatric craniocervical arthrodesis. *J Neurosurg Pediatr* 7:468–474, 2011.

(2–61 years old) without difficulty, and it provides a good substitute for dura in creating an expansile duraplasty. It is elastic and billows in and out with CSF pulsations, and its consistency allows obliteration of suture holes for a strong watertight closure. Harvesting the cervical fascia graft does not require any further extension of the incision superiorly or inferiorly to obtain the graft. Complications were uncommon in this prospective study of 123 children and adults.

Complications

Postoperative complications associated with intradural exploration and duraplasty for the surgical treatment of CM-I vary significantly in the literature. Studies have found the risk of complications to be between 3% and 40% and consist of aseptic meningitis, pseudomeningocele, CSF leak, postoperative hydrocephalus,¹⁸ wound infection, and meningitis.^{13,16,21,33} CSF complications specifically have been reported to occur in 3%–19% of reported series.^{16,21,25,26} In this study we found the complication risk profile was very small using a cervical fascia duraplasty. The risk of any type of complication for the 78 patients in the pediatric age group was 0%, and the risk of complication in the adult group was 6.7% (1 patient with aseptic meningitis and 2 patients with CSF leak). Similarly, others have also demonstrated small rates of complications with the combination of extradural and intradural CM-I decompression with duraplasty.²¹

Autologous and Allogenic Materials Used in Duraplasty

The types of autologous, allogenic, and synthetic materials used for duraplasty in CM-I are extensive.^{1,34} These materials include autologous and allogenic pericranium,^{4,39,45} autologous and allogenic fascia lata,² autologous ligamentum nuchae, lyophilized cadaveric dura,⁴⁵ acellular human dermis allograft (AlloDerm; Allergan, Inc.),^{12,13} bovine pericardium (DuraGuard; Baxter, Inc.), fetal bovine tissue (Durepair; Medtronic, Inc.), processed bovine collagen matrix (DuraGen; Integra, Inc., and DuraMatrix; Stryker, Inc.),¹³ synthetic Gore-Tex, expanded polytetrafluoroethylene,^{4,30,37} autologous posterior atlantooccipital membrane,⁴⁴ autologous splenius capitis muscle flap,¹⁷ and porcine small intestinal submucosa (Durasis; Cook Medical).⁷ A survey of pediatric neurosurgeons in July 1998 by the AANS revealed wide variation in preferred material for duraplasty.¹⁹

Others have proposed criteria for an optimal dura mater graft. Theoretically, the ideal graft would provide watertight dural closure without inflammatory reaction against the leptomeninges or cortex; induce no adhesions to the brain tissue or arachnoid; provide protection against external bacteria; be readily and easily available, durable, flexible, elastic, easily prepared, inexpensive, easily sterilized and handled, and easily shaped; and be known to be chemically inert and nontoxic.⁴⁵ Only a few studies have compared one graft or multiple grafts against each other.¹ However, these studies are hindered by many limitations.

Therefore, no study has shown superiority of either autologous or allogenic grafts for duraplasty in CM-I.

Autologous cervical fascia meets many of the criteria for an optimal dura mater graft and harvesting autologous cervical fascia does not require extension of the incision or a separate incision. The most common autologous material used for duraplasty reported in the literature is the pericranium. However, most techniques for harvesting pericranium require extension of the incision superiorly beyond the need for adequate exposure for the CM-I posterior fossa decompression. Although theoretical, an additional advantage of autologous cervical fascia is that it is unlikely to induce bone development (a risk more associated with younger children with CM-I), unlike other materials, such as pericranium, which could potentially induce bone growth and result in future compression and symptom recurrence.

Limitations

Although this study was prospective in nature, it was not a randomized study. Therefore, there is a selection bias of patients with CM-I who underwent intradural exploration and duraplasty. For most patients with syringomyelia, an extra-intradural decompression is performed to ensure egress from the foramen of Magendie. As discussed, we individualize the treatment strategy using intraoperative ultrasonography to determine the need for greater decompression through intradural exploration, tonsillar reduction, and duraplasty. Therefore, not all patients undergo intradural exploration and duraplasty. However, with this individualized strategy, it appears the risk of complication with an intradural procedure and autologous cervical fascia graft is quite minimal.

Conclusions

Autologous cervical fascia is easy to obtain in patients of all ages and provides an effective material for duraplasty in the treatment of CM-I. Complications from the combination of both an extradural and intradural decompression with cervical fascia duraplasty are uncommon.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Dlouhy. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Dlouhy. Administrative/technical/material support: Menezes. Study supervision: both authors.

Supplemental Information

Videos

Video 1. <https://vimeo.com/266120726>.

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