Understanding the connection:
Noonan Syndrome, Chiari malformation and TCS

From Symptom to Treatment

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Background

- Increasing recognition of neurological manifestations in Noonan syndrome
- Importance of identifying treatable causes of neurological disability
- Emerging understanding of connective tissue involvement

Objectives

- Recognize neurological manifestations of Noonan syndrome
- Understand the pathophysiological relationship between Noonan syndrome and Chiari malformation and Tethered cord
- Appreciate the role of connective tissue abnormalities and overlapping genetics
- Discuss current diagnostic and treatment strategies

Noonan Syndrome_***Facts _Link to the Nervous System***

Noonan=The most common RASopathy (autosomal dominant)

- PTPN11 (~50%)
- SOS1
- RAF1
- KRAS
- RIT1

Incidence

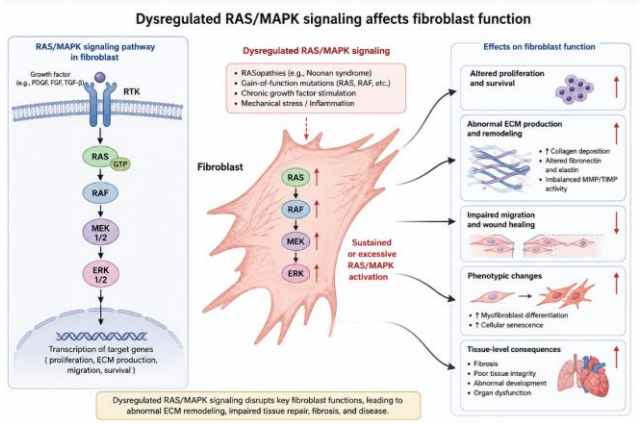
- ≈1:1,000–2,500 births

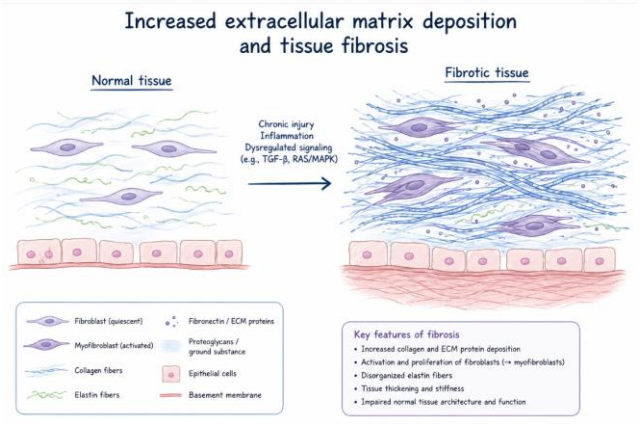
Clinical features/phenotype

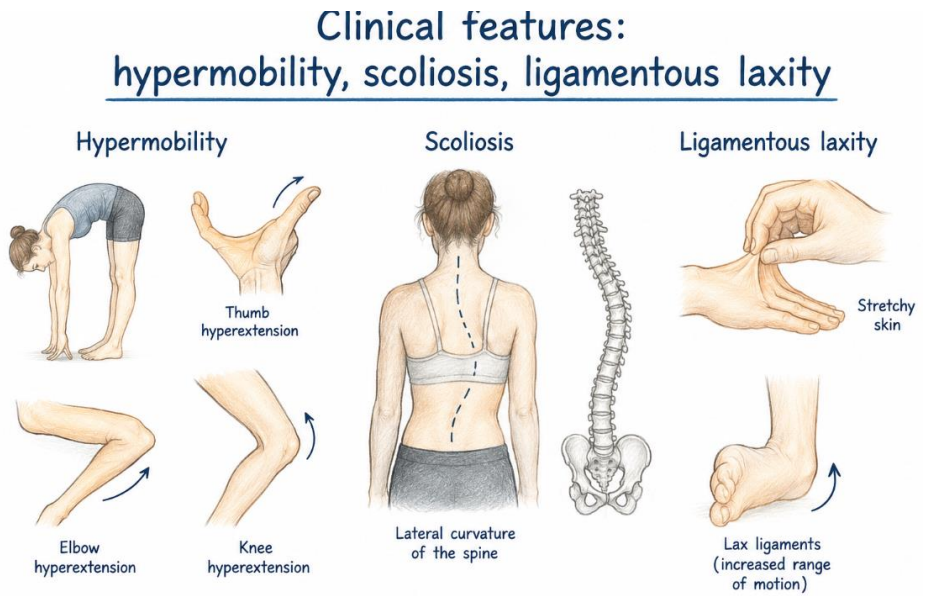
- Short stature
- Congenital heart disease
- Webbed neck
- Chest deformities
- Joint hypermobility/Scoliosis
- Craniofacial anomalies
- Developmental delay

- GENETIC LINK :the most important intracellular pathways regulating cell growth, differentiation, migration

- *BIODYNAMIC PHENOTYPE LINK:*
  The nervous tissue is mechanically influenced by connective tissue and skeletal integrity







NOONAN Syndrome_Evidence for altered connective tissue biology

- Dysregulated RAS/MAPK signaling affects fibroblast function
- Increased extracellular matrix deposition and tissue fibrosis
- Abnormal craniofacial and skeletal development
- Clinical features: hypermobility, scoliosis, ligamentous laxity

Noonan syndrome and Chiari I malformation

Traditional explanation

Small posterior fossa due to altered mesodermal development and Craniospinal disproportion

↓

Cerebellar tonsillar herniation

Review > Am J Med Genet A. 2024 Oct;194(10):e63776. doi: 10.1002/ajmg.a.63776. Epub 2024 Jun 7.

Noonan syndrome and type 1 Chiari malformation: Possible association

Megan Samuels [1], Hope Northrup [2]

Affiliations + expand

PMID: 38847235 DOI: 10.1002/ajmg.a.63776

Abstract

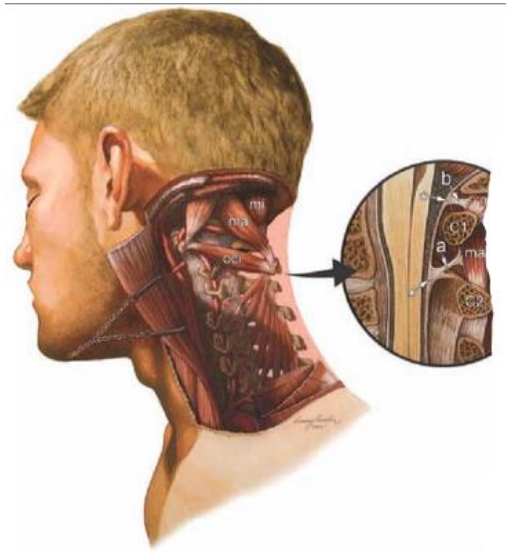
Noonan syndrome (NS) is mostly an autosomal dominant genetic disorder that affects between 1 in 1000 and 1 in 2500 people. Type 1 Chiari malformations (CM1) have an estimated prevalence of <1 in 1000 people. Though NS typically spares the posterior fossa, there have been 11 past instances of patients with NS having a concurrent CM1 that have been published in the literature. Each of these 11 cases occurred sporadically, in an isolated individual with no published family history of CM1. This case report presents a three generational family with four members having both NS and concurrent CM1. All affected family members share a pathogenic variant in PTPN11. A literature review was performed to identify and compile data regarding all past published cases of NS and CM1 occurring concurrently. Since 1982, a dozen case reports have detailed NS with concurrent CM1. Where molecular genetic data was presented, seven had a variant in PTPN11, and only one had a variant in another gene. The clustering of NS with CM1 within a single family that shares the same genotype, along with the exclusion of both NS and CM1 in other family members, may indicate that CM1 is a part of the NS phenotype.

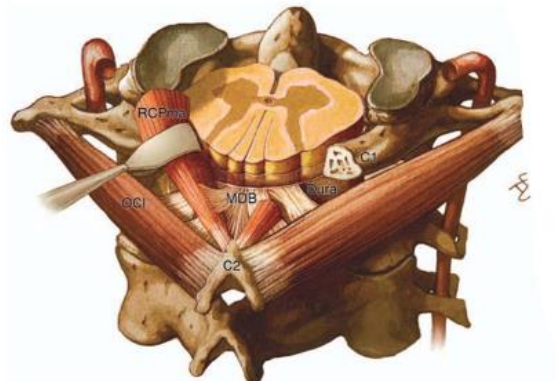
Published evidence linking Noonan syndrome and Chiari I malformation

- First report: **Holder-Espinasse & Winter, 2003**
- Updated case review: **Witters L, Vanvolsem S, Achahbar S, et al. 2025**
- Familial **PTPN11** cases suggesting a genetic association (“CM1 phenotype”): **Samuels & Northrup, 2024**

Connective Tissue Association

Zheng, N., Chung, B.S., Li, YL. *et al*. The myodural bridge complex defined as a new functional structure. *Surg Radiol Anat* **42,** 143–153 (2020).





Myodural Bridges in Chiari Patients

- Connective tissue bridging suboccipital musculature to posterior dura mater
- Attach to dura mater via the posterior atlanto-occipital membrane-spinal dura complex

Hack and Hallgren (1995)a *et al.*, 2012
Pimenta *et al.* (2012)
Xu *et al.* (2016)

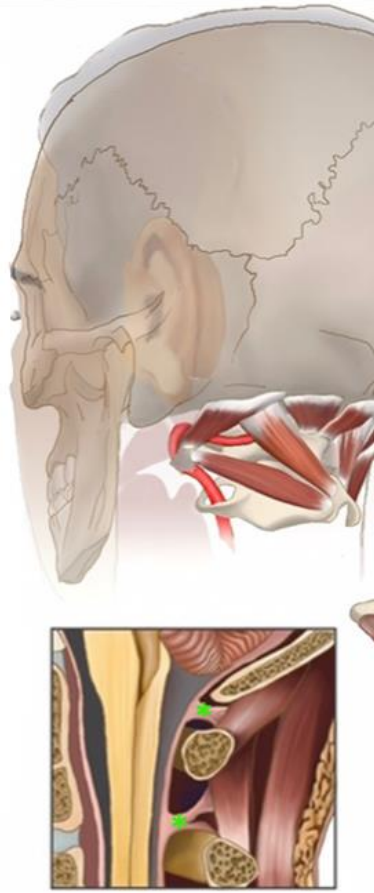
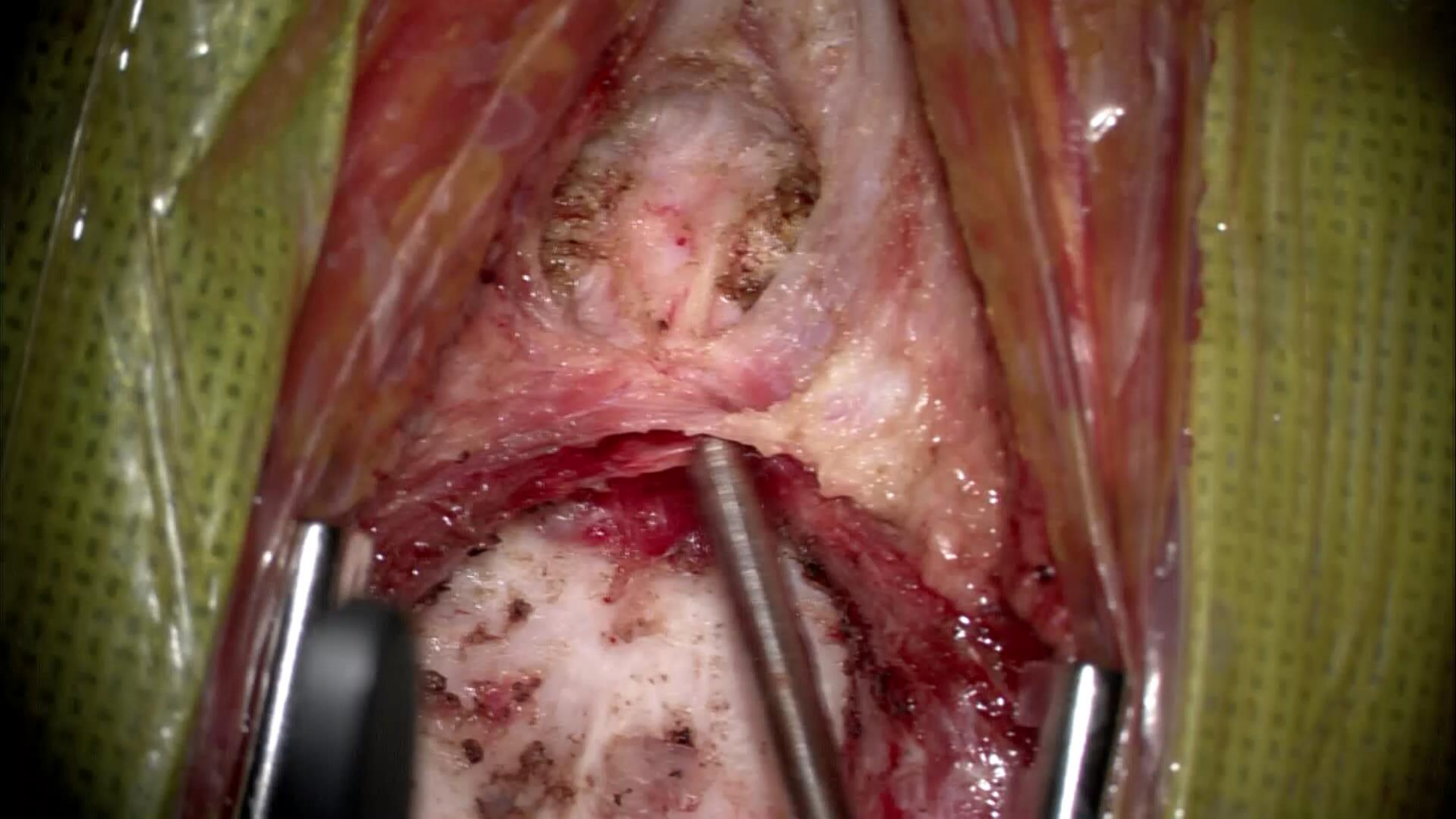
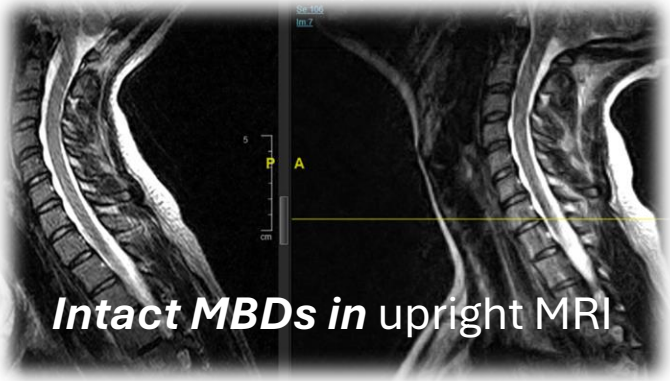
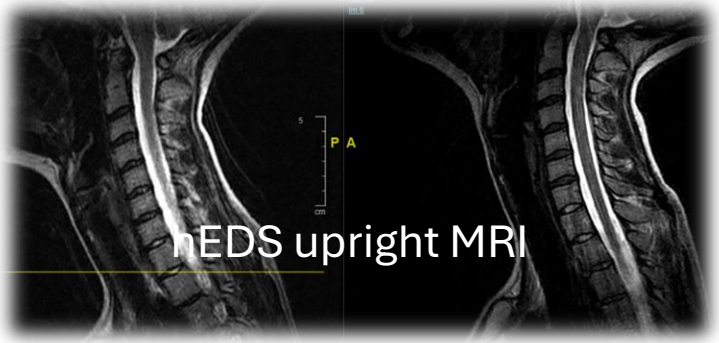


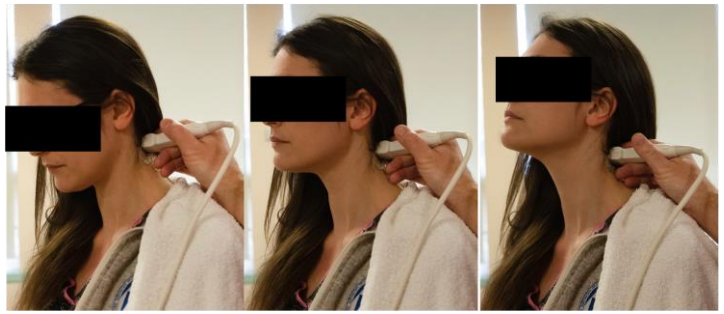
Figure 1. The suspensive myodural bridge comple
tion of the craniocervical junction with magnified s
are seen connecting the cisterna magna dura to the
tration by Kendall Lane, BFA, Department of Medi
Brown University).



HEDS/HSD and Chiari: Unstable MYODURAL BRIDGE COMPLEX





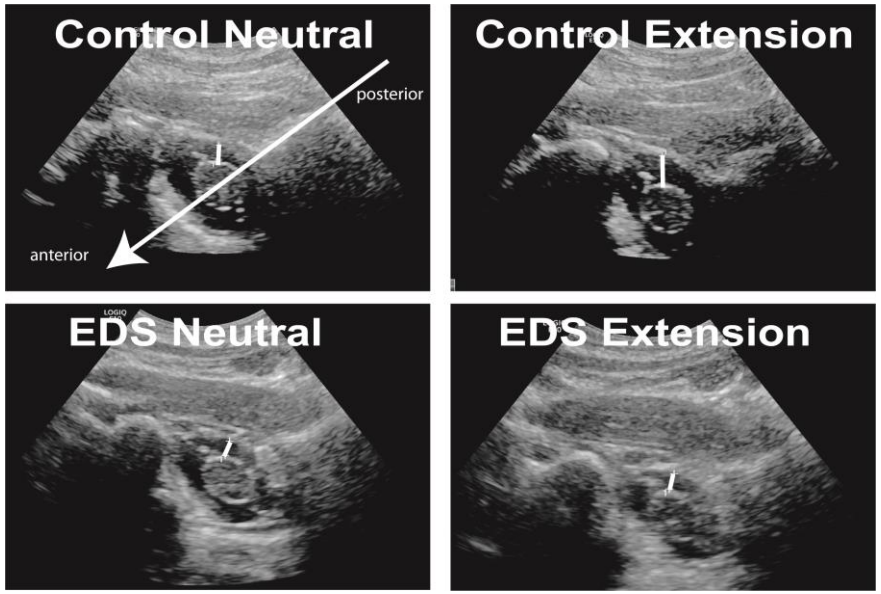


In Vivo Ultrasound Imaging of the Spinal Cord and Subarachnoid Space at the C1-C2 Level in Healthy Adult Subjects

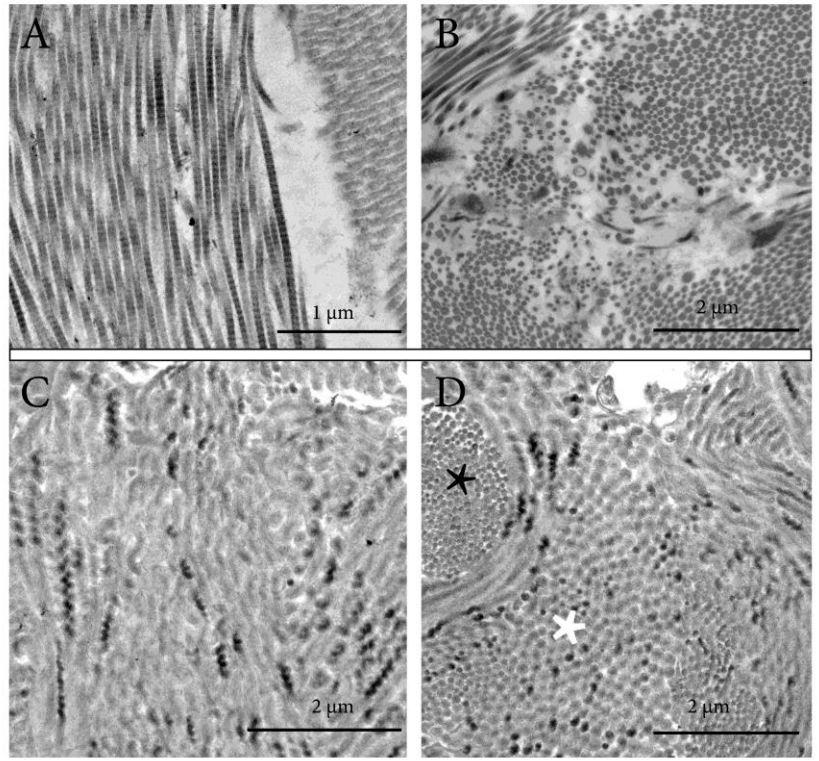
Beland, Michael D. MD[*,†]; McElroy, Abigail W. DVM[†,‡]; Brinker, Thomas MD[§]; Gokaslan, Ziya L. MD[†,‡]; Klinge, Petra M. MD[†,‡]

Author Information

Ultrasound Quarterly 38(1):p 49-52, March 2022. | **DOI:** 10.1097/RUQ.0000000000000542



Collagen Ultrastructure



Northeastern University

METHODS AND PROCEDURES

Ultrasound

Results from the following groups will be compared.

1. Healthy volunteers
2. Asymptomatic Chiari patients
3. Symptomatic Chiari patients (n=15, funded)
4. Posterior fossa pathology patients (tumor, stroke etc) (n=5, funded)

Subjects will be enrolled for a short (30-60 minute) ultrasonographic examination of the myodural bridges. Examinations will be conducted in the RIH Radiology department under the supervision of Dr. Ghada Issa.

The atlanto-axial interspace will be imaged in the following settings:

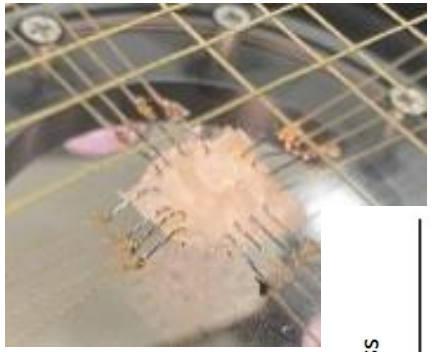
1. Neutral
2. Flexion at 45deg
3. Extension at 30deg
4. During Valsalva maneuver
5. During a cough

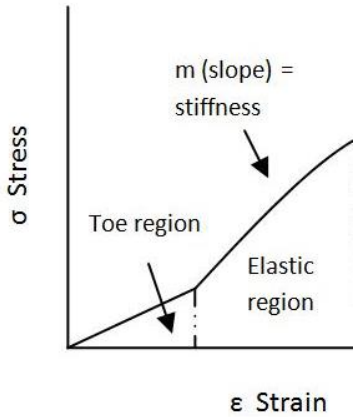
A goniometer will be used to measure the head/neck angle.

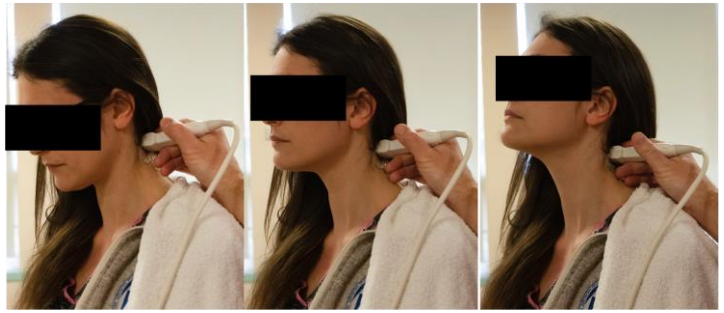
Measurements will be taken consisting of the width of the subarachnoid space from the posterior edge of the spinal cord to the posterior dura mater at the level of the bifurcation of the myodural bridges. Three measurements of the dorsal and ventral subarachnoid space will be taken at each position to ensure repeatability.

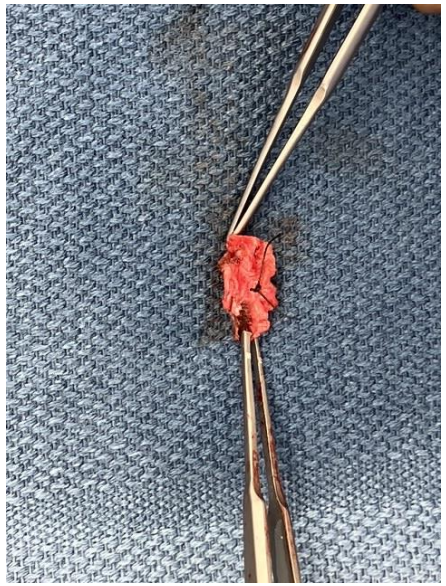
In addition, the following image and videos will be saved for post-processing analysis, in an axial or cross-sectional view of C1-C2:

1. Still image
2. Video at rest
3. Video of 5 repeat coughs
4. Video of Valsalva maneuver 5-10 seconds









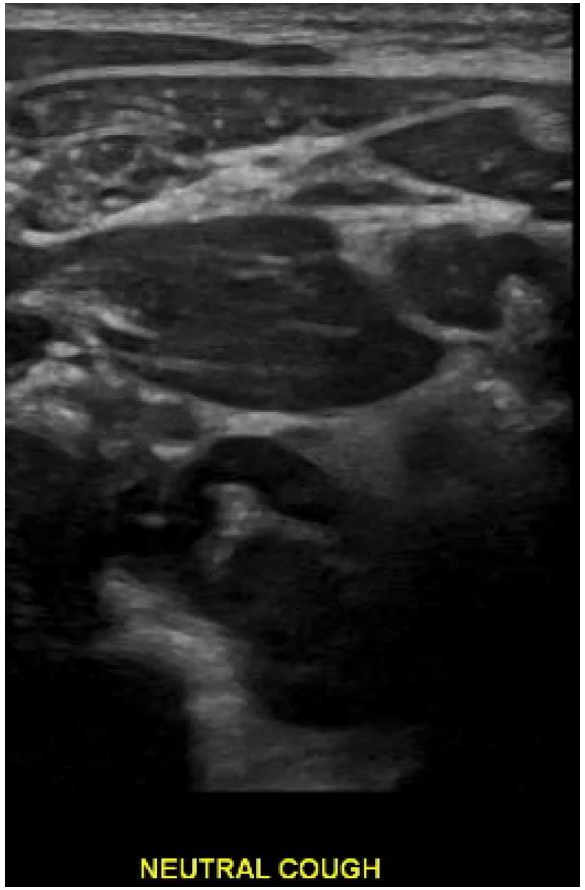
Craniocervical Ultrasound of Myodural Bridges: Control vs. Chiari

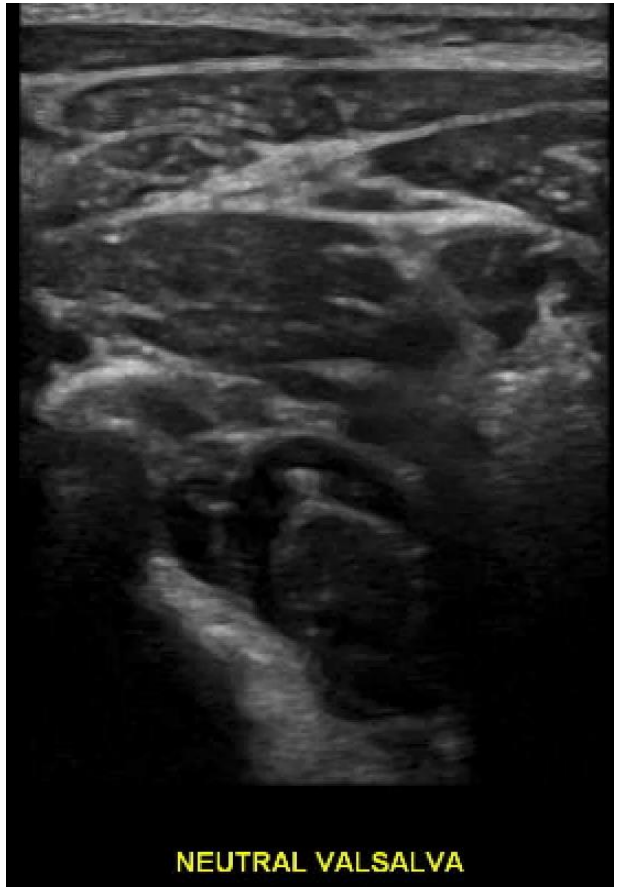
CONTROL

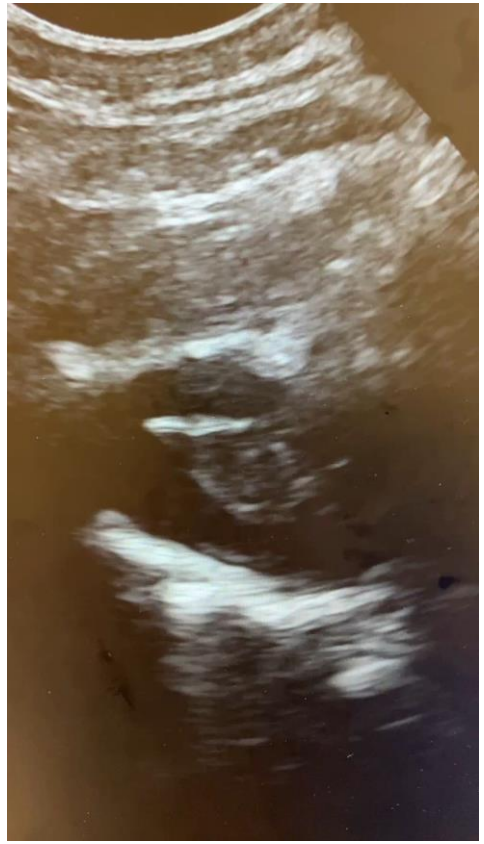
CHIARI

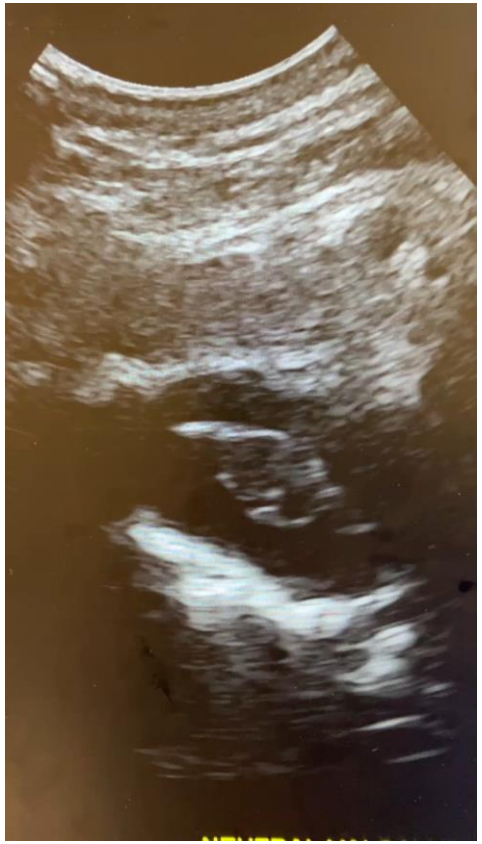
COUGH

Valsalva









JNS SPINE

CLINICAL ARTICLE

J Neurosurg Spine 35:18–24, 2021

Abnormal spinal cord motion at the craniocervical junction in hypermobile Ehlers-Danlos patients

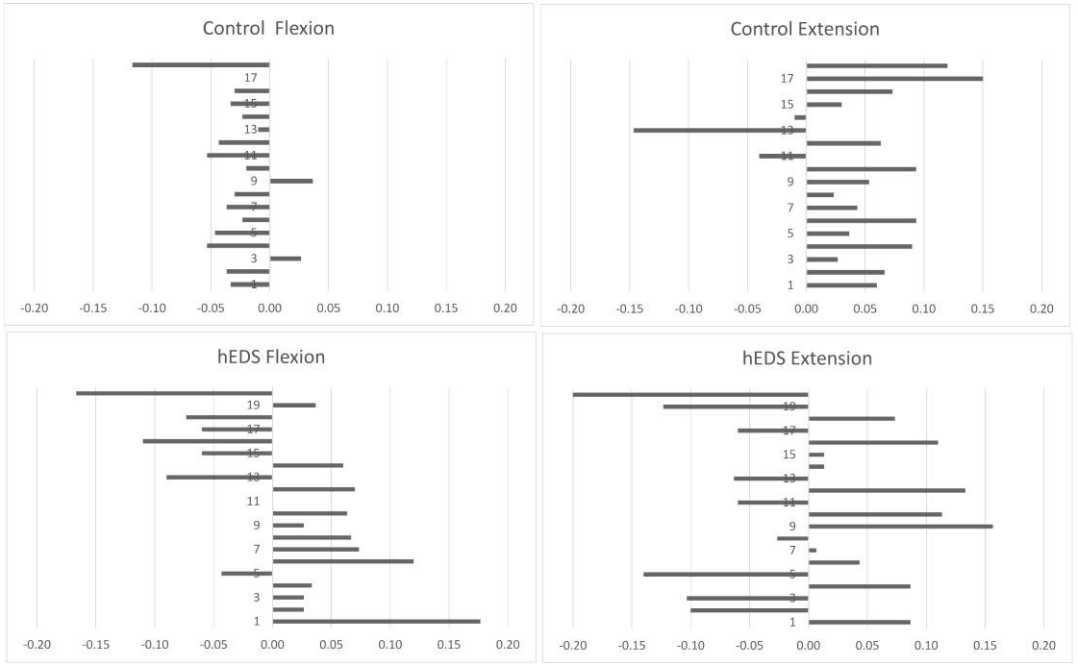
*Petra M. Klinge, MD,[1] Abigail McElroy, DVM,[1] John E. Donahue, MD,[2] Thomas Brinker, MD,[3] Ziya L. Gokaslan, MD,[1] and Michael D. Beland, MD[4]

Departments of [1]Neurosurgery, [2]Neuropathology, and [4]Radiology, Rhode Island Hospital, The Warren Alpert Medical School of Brown University, Providence, Rhode Island; and [3]Department of Neurosurgery, Medical School Hannover, Germany

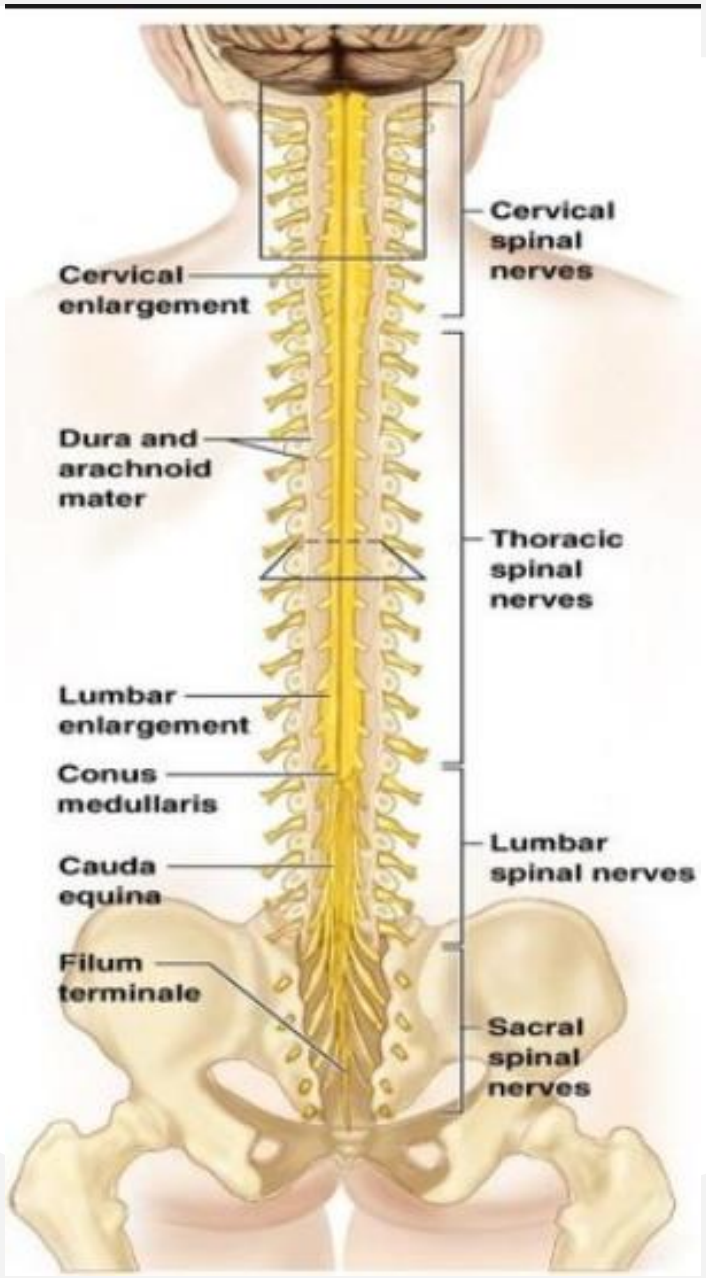
TABLE 1. Grading of the collagen ultrastructure of MDBs in patients with Chiari malformation, with and without EDS

Patient No.	Age (yrs)/Sex	Fibril Disorganization or Loss of Longitudinal Orientation	Loss of D-Period	Variation in Fibril Diameter on Cross Sections
Group w/ EDS				
1	21/F	++	++	–
2	18/F	–	–	+
3	37/F	++	++	–
4	48/F	++	++	–
5	41/F	–	–	++
6	25/F	++	++	–
7	35/F	++	++	+
8	18/F	++	++	–
Group w/o EDS				
1	19/F	+	–	–
2	26/F	+	+	++
3	47/F	–	–	++
4	42/M	–	+	+
5	25/M	–	–	–
6	14/F	–	–	–
7	23/F	–	–	–
8	38/F	–	–	+

– = not present in any samples; + = mild but focal appearance; ++ = severe appearance, with more than 50% of TEM captures displaying collagen changes.



! Chiari represents a disorder of the entire craniospinal axis rather than an isolated posterior fossa abnormality


Cervical spinal nerves
Cervical enlargement
Dura and arachnoid mater
Thoracic spinal nerves
Lumbar enlargement
Conus medullaris
Lumbar spinal nerves
Cauda equina
Filum terminale
Sacral spinal nerves

Tethered Cord Syndrome_not that well established

Definition

- Pathological longitudinal tension on the spinal cord.

Can occur

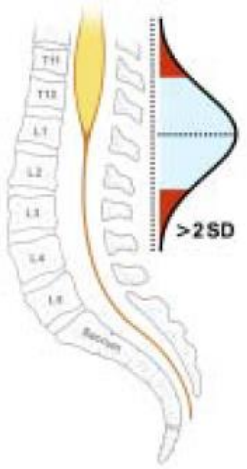
- Classical (low conus)

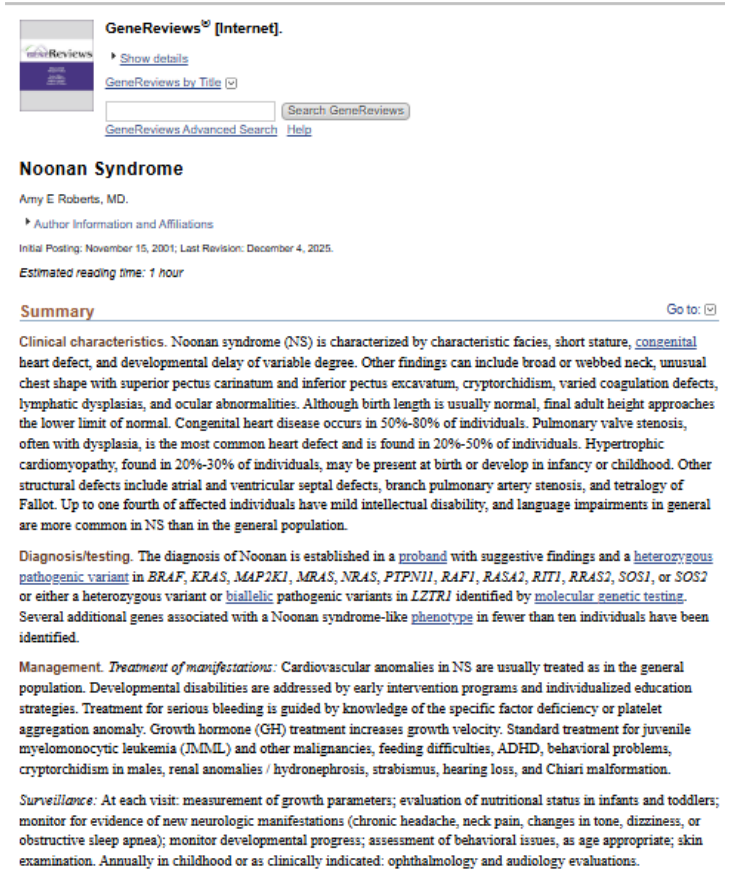
or

- Occult (normal conus)

Symptoms

- Low back pain
- Leg fatigue
- Sensory disturbances
- Bladder dysfunction
- Bowel dysfunction
- Progressive neurological decline





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Noonan Syndrome

Amy E Roberts, MD.

Author Information and Affiliations

Initial Posting: November 15, 2001; Last Revision: December 4, 2025.

Estimated reading time: 1 hour

Summary Go to:

Clinical characteristics. Noonan syndrome (NS) is characterized by characteristic facies, short stature, congenital heart defect, and developmental delay of variable degree. Other findings can include broad or webbed neck, unusual chest shape with superior pectus carinatum and inferior pectus excavatum, cryptorchidism, varied coagulation defects, lymphatic dysplasias, and ocular abnormalities. Although birth length is usually normal, final adult height approaches the lower limit of normal. Congenital heart disease occurs in 50%-80% of individuals. Pulmonary valve stenosis, often with dysplasia, is the most common heart defect and is found in 20%-50% of individuals. Hypertrophic cardiomyopathy, found in 20%-30% of individuals, may be present at birth or develop in infancy or childhood. Other structural defects include atrial and ventricular septal defects, branch pulmonary artery stenosis, and tetralogy of Fallot. Up to one fourth of affected individuals have mild intellectual disability, and language impairments in general are more common in NS than in the general population.

Diagnosis/testing. The diagnosis of Noonan is established in a proband with suggestive findings and a heterozygous pathogenic variant in *BRAF*, *KRAS*, *MAP2K1*, *MRAS*, *NRAS*, *PTPN11*, *RAF1*, *RASA2*, *RIT1*, *RRAS2*, *SOS1*, or *SOS2* or either a heterozygous variant or biallelic pathogenic variants in *LZTR1* identified by molecular genetic testing. Several additional genes associated with a Noonan syndrome-like phenotype in fewer than ten individuals have been identified.

Management. *Treatment of manifestations:* Cardiovascular anomalies in NS are usually treated as in the general population. Developmental disabilities are addressed by early intervention programs and individualized education strategies. Treatment for serious bleeding is guided by knowledge of the specific factor deficiency or platelet aggregation anomaly. Growth hormone (GH) treatment increases growth velocity. Standard treatment for juvenile myelomonocytic leukemia (JMML) and other malignancies, feeding difficulties, ADHD, behavioral problems, cryptorchidism in males, renal anomalies / hydronephrosis, strabismus, hearing loss, and Chiari malformation.

Surveillance: At each visit: measurement of growth parameters; evaluation of nutritional status in infants and toddlers; monitor for evidence of new neurologic manifestations (chronic headache, neck pain, changes in tone, dizziness, or obstructive sleep apnea); monitor developmental progress; assessment of behavioral issues, as age appropriate; skin examination. Annually in childhood or as clinically indicated: ophthalmology and audiology evaluations.

There is currently no established association between Noonan syndrome and tethered cord syndrome in the peer-reviewed literature.

› Am J Med Genet A. 2023 May;191(5):1222-1226. doi: 10.1002/ajmg.a.63128. Epub 2023 Feb 1.

Tethered cord syndrome in KBG syndrome

Sonia Hills [1], Alisa Pugacheva [2], Patricia Weltin [3], Annette Maughan [4], Sarah U Morton [1 5], Henry A Feldman [5 6], Petra M Klinge [7], Pankaj B Agrawal [1 5 8 9]

Affiliations + expand

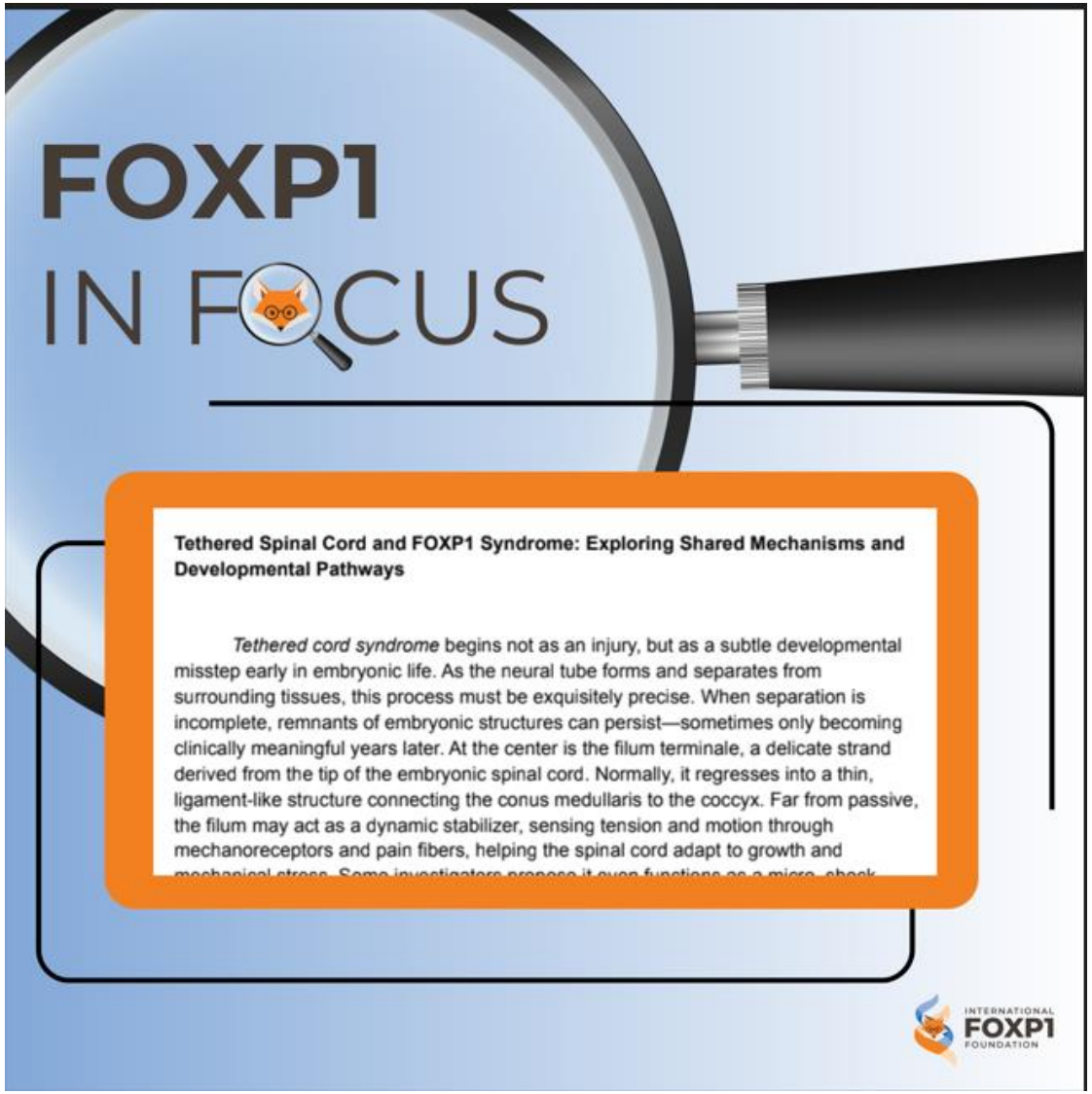
PMID: 36722669 DOI: 10.1002/ajmg.a.63128

Abstract

Tethered cord syndrome (TCS) is characterized by leg pain and weakness, bladder and bowel dysfunction, orthopedic malformations such as scoliosis, and motor deficits caused by the fixation of the spinal cord to surrounding tissues. TCS is surgically treatable and often found in conjunction with other syndromic conditions. KBG syndrome is caused by variants in the ANKRD11 gene and is characterized by short stature, developmental delay, macrodontia, and a triangular face. The current study explores the prevalence of TCS in pediatric KBG patients and their associated signs and symptoms. Patients with KBG were surveyed for signs and symptoms associated with TCS and asked if they had been diagnosed with the syndrome. We found a high proportion of patients diagnosed with (11%) or being investigated for TCS (24%), emphasizing the need to further characterize the comorbid syndromes. No signs or symptoms clearly emerged as indicative of TCS in KBG patients, but some the prevalence of some signs and symptoms varied by sex. Male KBG patients with diagnosed TCS were more likely to have coordination issues and global delay/brain fog than their female counterparts. Understanding the presentation of TCS in KBG patients is critical for timely diagnosis and treatment.

Keywords: ANKRD11; KBG syndrome; tethered cord syndrome.

Overlap between the genetic architecture of Tethered cord syndrome and molecular pathways implicated in rare genetic syndromes is supported by emerging literature demonstrates. Genes governing cell migration, neural tube formation, and secondary neurulation appear particularly relevant. These include MNX1, HOX patterning genes, and Sonic hedgehog (SHH) signaling, as well as regulators of planar cell polarity and extracellular matrix integrity. Collectively, these pathways orchestrate caudal spinal development—the precise embryologic region from which tethering abnormalities arise. HOX genes are central to vertebral identity, neural tube regionalization, and mesodermal patterning, providing a plausible mechanistic bridge between syndromic developmental programs and distal spinal cord anomalies. Disruption within these coordinated signaling networks may alter both neural and connective tissue architecture, predisposing to pathological tethering. This framework is relevant to FOXP1. FOXP1 is expressed in developing spinal motor neurons and interneurons, where it regulates neuronal identity, motor column patterning, and axonal organization, partly through interaction with HOX pathways. Although overt structural malformations are infrequently reported, FOXP1 dysfunction mechanistically intersects with developmental processes critical to caudal spinal cord formation.



…however, filum terminale depends on normal connective tissue architecture and viscoelastic properties ***as shown in hEDS***

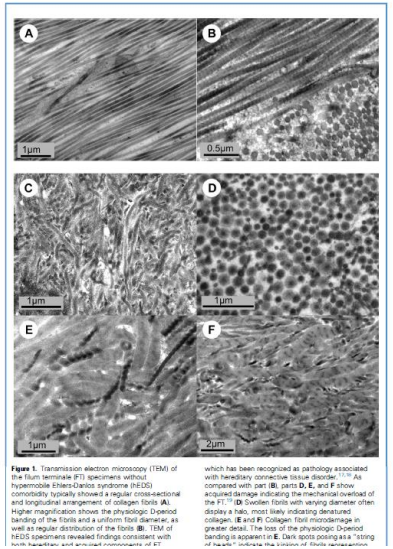


Table 1. Transmission Electron Microscopy Findings of the Filum Terminale

	hEDS-TCS (n = 78)	TCS (n = 10)	Chi-Square with Bonferroni Correction
Congenital collagen abnormalities			
Fibril disorganization	69.6%	10.0%	$P < 0.001$
Variation in fibril diameter in cross section	40.5%	11.1%	$P < 0.001$
Acquired collagen microdamage			
Kinking fibrils	63.3%	30.0%	$P < 0.05$
Loss of D-period banding	68.4%	30.0%	$P < 0.01$

The filum ultrastructure of the EDS-TCS and typical TCS cases was evaluated in longitudinal and cross sections. Markers of EDS collagen structural abnormalities such as fibril disorganization and variation in fibril diameter in cross section were assessed as well as markers of collagen microdamage such as kinking fibrils and loss of D-period banding.

hEDS, hypermobile Ehlers-Danlos syndrome; TCS, tethered cord syndrome.

- **RASopathy → abnormal extracellular matrix/connective tissue biology → altered matrix biology could theoretically influence filum filum biomechanics**

› World Neurosurg. 2022 Jun:162:e492-e502. doi: 10.1016/j.wneu.2022.03.038. Epub 2022 Mar 17.

Diseased Filum Terminale as a Cause of Tethered Cord Syndrome in Ehlers–Danlos Syndrome: Histopathology, Biomechanics, Clinical Presentation, and Outcome of Filum Excision

Petra M Klinge [1], Vikas Srivastava [2], Abigail McElroy [3], Owen P Leary [3], Zahra Ahmed [2], John E Donahue [4], Thomas Brinker [5], Philippe De Vloo [6], Ziya L Gokaslan [3]

Affiliations + expand

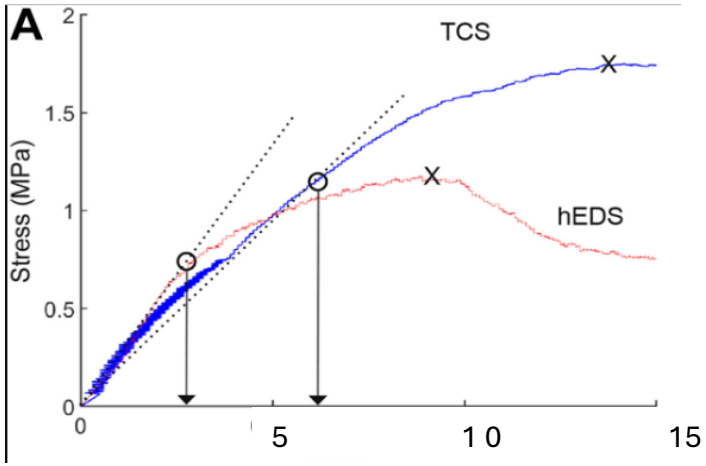
PMID: 35307588 DOI: 10.1016/j.wneu.2022.03.038

Free article

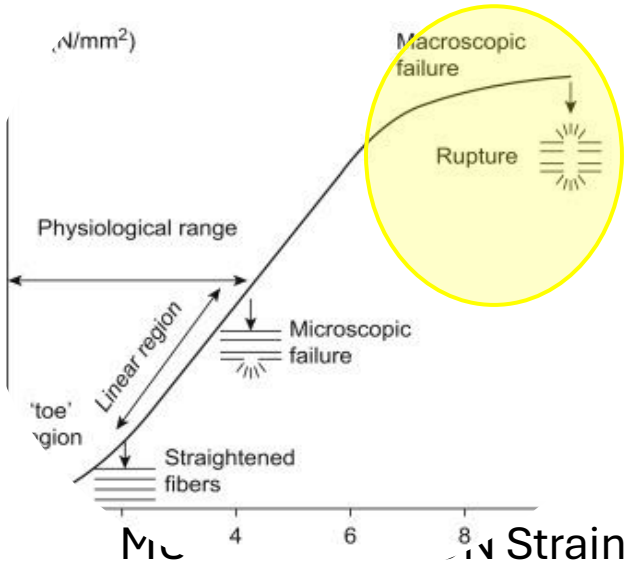
Biomechanics of the FT

FT Stress-Strain-tests shows **elastic properties similar to muscle tendons** with loss of elasticity (equals loss of shock buffering capacity)

- around a 6% strain (relative elongation): ***those relative elongation in humans are reached with just "physiological" spine movements***



FILUM TERMINALE Strain



Strain

Diseased Filum Terminale as a Cause of Tethered Cord Syndrome in Ehlers-Danlos Syndrome: Histopathology, Biomechanics, Clinical Presentation, and Outcome of Filum Excision. Petra M Klinge, Vikas Srivastava , Abigail McElroy et al. World Neurosurg, 2022 Jun:162:e492-e502

(Wang: Mechanobiology of tendons, Journal of Biomechanics 39, 2006)

Many patients have BOTH

Chiari	Tethered Cord
Headache	Low back pain
Neck pain	Leg pain
Balance	Weakness
Brain fog	Fatigue
Sleep problems	Bladder dysfunction

- Conceptual model
  - Abnormal connective tissue
  - ↓
  - Reduced elasticity
  - ↓
  - Increased longitudinal spinal tension
  - ↓
  - Chiari
  - Tethered cord
  - ↓
  - Progressive neurological dysfunction
- Emerging evidence supports viewing these as disorders of the same mechanical system.

Compromised Craniospinal Anchoring

Compromised Cranio-Spinal Suspension in Chiari Malformation Type 1: A Potential Role as Secondary Pathophysiology

Belinda Shao [1,*], Jonathan A Poggi [1], Natalie Amaral-Nieves [1], Daniel Wojcik [1], Kevin L Ma [1], Owen P Leary [1], Petra M Klinge [1]

Editor: Palma Ciaramitaro[1]

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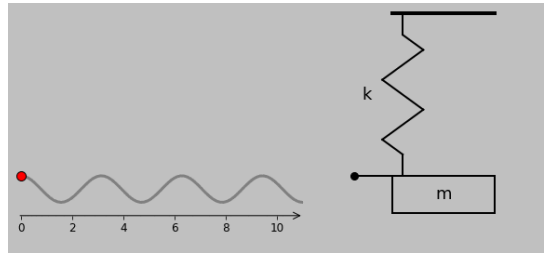
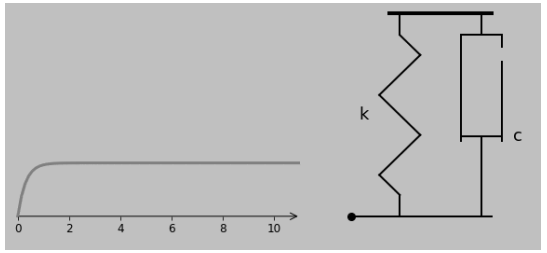
Abstract

In Chiari Malformation Type I (CM1), low-lying tonsils obstruct the cisterna magna at the foramen magnum, thereby compromising the essential juncture between the cranial and spinal compartments. The anatomical obstruction of the cisterna magna inhibits bi-directional CSF flow as well as CSF pulse pressure equilibration between the intracranial compartment and the intraspinal compartment in response to instances of increased intracranial pressure. Less understood, however, are the roles of the spinal cord suspension structures at the craniocervical junction which lend viscoelastic support to the spinal cord and tonsils, as well as maintain the anatomical integrity of the cisterna magna and the dura. These include extradural ligaments including the myodural bridges (MDBs), as well as intradural dentate ligaments and the arachnoid framework. We propose that when these elements are disrupted by the cisterna magna obstruction, tonsillar pathology, and altered CSF dynamics, there may arise a secondary pathophysiology of compromised and dysfunctional cranio-spinal suspension in CM1. We present intraoperative images and videos captured during surgical exposure of the craniocervical junction in CM1 to illustrate this proposal.

Keywords: Chiari Malformation Type I, cisterna magna, myodural bridges, dentate ligaments, craniocervical junction, arachnoid adhesions, spinal cord suspension, viscoelasticity

- ✓ The brain and spine is elastically suspended by extra- and intradural tissues and the cranial and spinal nerve roots **(SPRING).**
- ✓ The brain and spine represent the mass which is floating within CSF and is permanently moving, driven by cardiac and respiratory forces, and by spine movements **(MASS).**
- ✓ The movement of brain and spine within the dural sac is dampened by the CSF of the spinal compartment **(DAMPER).**

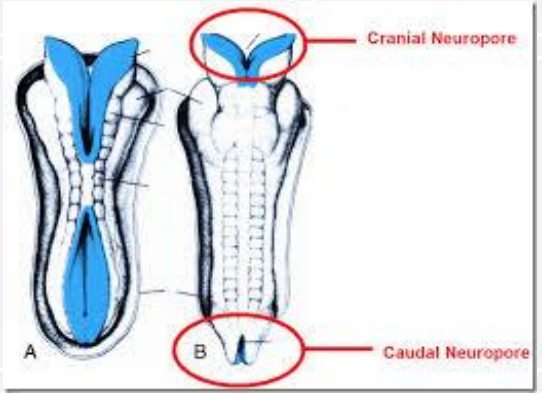




Emerging (Genetic&Biodynamic) Concept

Category	Candidate genes	Why they matter
Secondary neurulation	TBXT (Brachyury), VANGL1/2, CELSR1, SCRIB, FUZ, PTK7	Formation and regression of the caudal cell mass and neural tube closure
RAS/MAPK pathway	PTPN11, SOS1, RAF1, KRAS, RIT1, SHOC2	Developmental maturation, neural crest, connective tissue remodeling

➢Around 6 weeks of gestation:
Caudal extension of the spinal cord and "more" neural tube formation
_ ***"Secondary neurulation"***



➢Around 9 to10 weeks of gestation:
Cell necrosis causes a decrease in the size of the caudal neural tube and will form the Filum Terminale _
Retrogressive differentiation

❑ Rather than isolated anomalies…

Think of **A dynamic craniospinal disorder**

Where connective tissue evokes neural tension and alters CSF dynamics

and the developmental anatomy all interact.

❑ Possible Genetic overlap between Noonan Genes and Genese involved in TC ("retrogressive differentiation")

Persistent RAS/MAPK activation (particularly through **PTPN11**) could theoretically interfere with:

terminal differentiation,

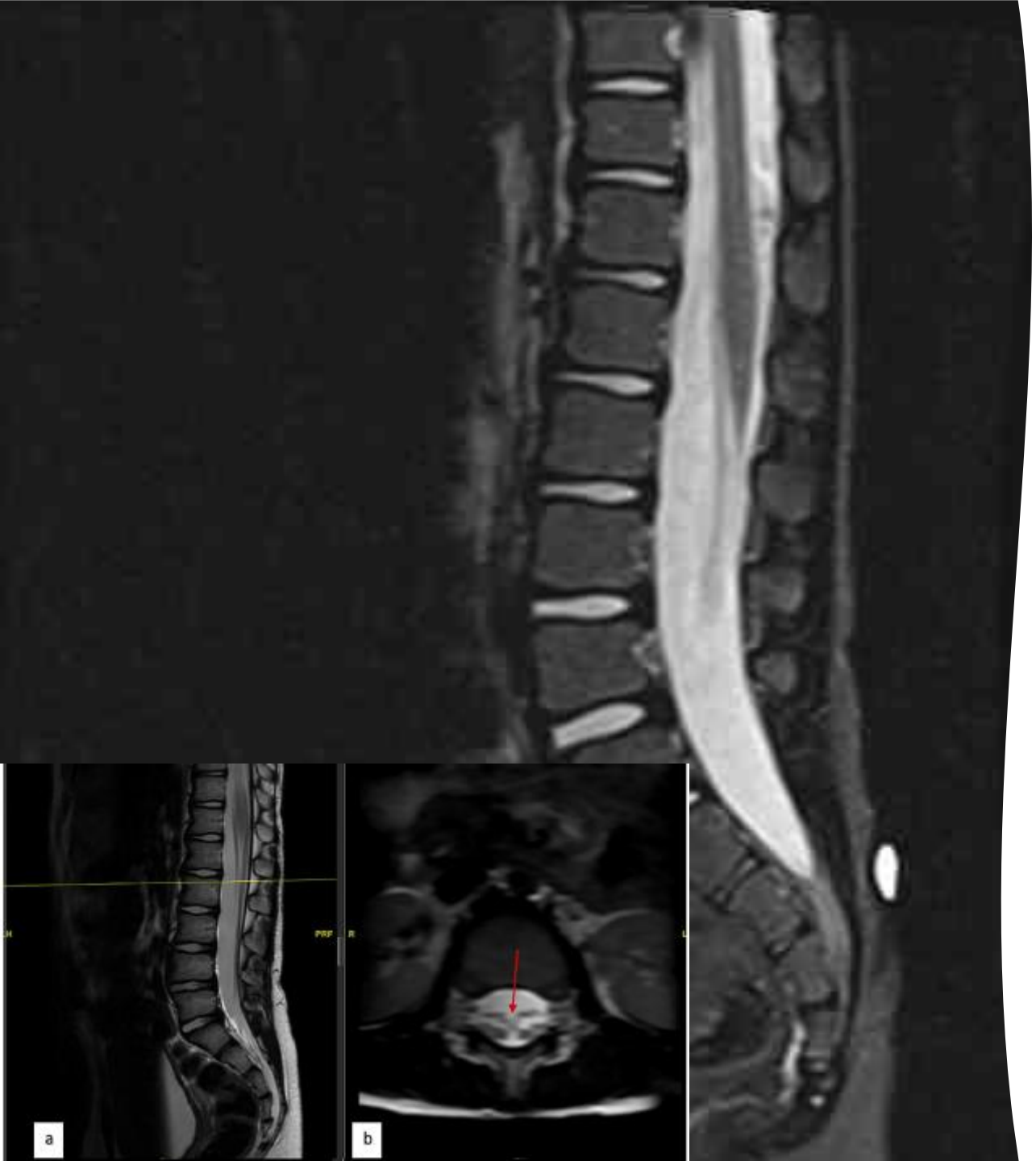
regression/remodeling,

collagen and elastin organization,

fibroblast maturation,

mechanotransduction

That could result in persistence of a more immature, cellular, less compliant filum rather than a normally involuted elastic ligament.



Evaluation

- ❑ History AND EXAMINATION
  - ❑ Neurological examination
- ❑ MRI
  - ❑ Brain
  - ❑ Cervical
  - ❑ Thoracic
  - ❑ Lumbar
  - ❑ Assess
  - ❑ Syrinx
  - ❑ Filum terminale
  - ❑ Conus
  - ❑ Scoliosis
  - ❑ Craniocervical junction
- ❑ Consider
  - ❑ Urodynamics
  - ❑ Neuropsychological evaluation
  - ❑ Sleep study

Biomarker for TC (occult and classic) in Pediatric and Adults Patients

Fluctuating back and non-dermatomal leg PAINS AND WEAKNESS (“aches”, “fatigue”, “soreness”, “tightness”)

“hard to locate and often more in one leg”

NEUROLOGICAL findings LE _often asymmetric and found in the symptomatic leg :

- **Increased LE ankle tone**
- **Foot clonus**
- **Hyperreflexia 4+ and extended reflex zone**
- ***Occasional* LE weakness on MOTOR scale max. 3/5 to 4/5**

= “upper motor neuron dysfunction”, aka “ Spascticity”

J Neurosurg Spine. 2024 Mar 15;40(6):758-766. doi: 10.3171/2024.1.SPINE231191. Print 2024 Jun 1.

Clinical criteria for filum terminale resection in occult tethered cord syndrome

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Affiliations + expand

PMID: 38489815 DOI: 10.3171/2024.1.SPINE231191

Abstract

Objective: Tethered cord syndrome (TCS) comprises three symptom categories: back/leg pain, bowel/bladder, and neurological complaints. MRI typically reveals a low-lying conus medullaris, filum terminale (FT) pathology, or lumbosacral abnormalities. FT resection is established in TCS but not in radiologically occult TCS (OTCS). This study aims to identify patients with OTCS who are likely to benefit from FT resection.

Methods: The authors recruited 149 patients with OTCS (31 pediatric, 118 adult) treated with FT resection-including only cases with progressive TCS, negative spine MRI, and no concurrent neurological/urological conditions. A comprehensive questionnaire collected patient self-reported symptoms and clinical findings at the preoperative and at 3- and 12-month follow-up examinations. Based on questionnaire data, the authors extracted a 15-item symptoms and findings scale to represent the three TCS symptom categories, assigning 1 point for each item present.

Results: OTCS presents without radicular/segmental sensorimotor findings, but with leg/back pain and conus dysfunction, in addition to leg fatigue and spasticity; the latter indicating an upper motoneuron pathology. The 15-item scale showed clinical improvement in 89% of patients at the 3-month follow-up and 68% at the 12-month follow-up. Multivariate analysis of the scale revealed that it accurately predicts outcome of FT resection in 82% of cases. Patients with a preoperative score exceeding 6 points are most likely to benefit from surgery.

Conclusions: By applying the study's inclusion criteria and incorporating the novel 15-item scale, surgeons can effectively select candidates for FT resection in patients with OTCS. The observed outcomes in these selected patients are comparable to those achieved in degenerative spine surgery.

Keywords: congenital; lumbar; occult tethered cord syndrome; outcome assessment; pain; sacral; symptom scale.

TABLE 2. Prevalence of symptoms on the 15 item-scale

Category or Sx	No. of Patients (%)
Neurological scale	
Increased muscle tone legs*	42 (28)
Hyperreflexia legs*	98 (66)
Foot clonus*	83 (56)
Fatigue legs	127 (85)
Paresthesia legs	84 (56)
Pain scale	
Leg	132 (89)
Sacral	62 (42)
Low-back	119 (80)
Cramps in leg & back	84 (56)
Fluctuating pain Sxs	42 (28)
Bowel & bladder scale	
Urinary leakage	85 (57)
Urinary urgency	87 (58)
Urinary frequency	78 (52)
Urinary hesitation	72 (48)
Bowel Sxs	92 (62)

* Objective clinical findings.

Novel TCS/OTCS 15-item scale of most prevalent SP&SX

Klinge et al.

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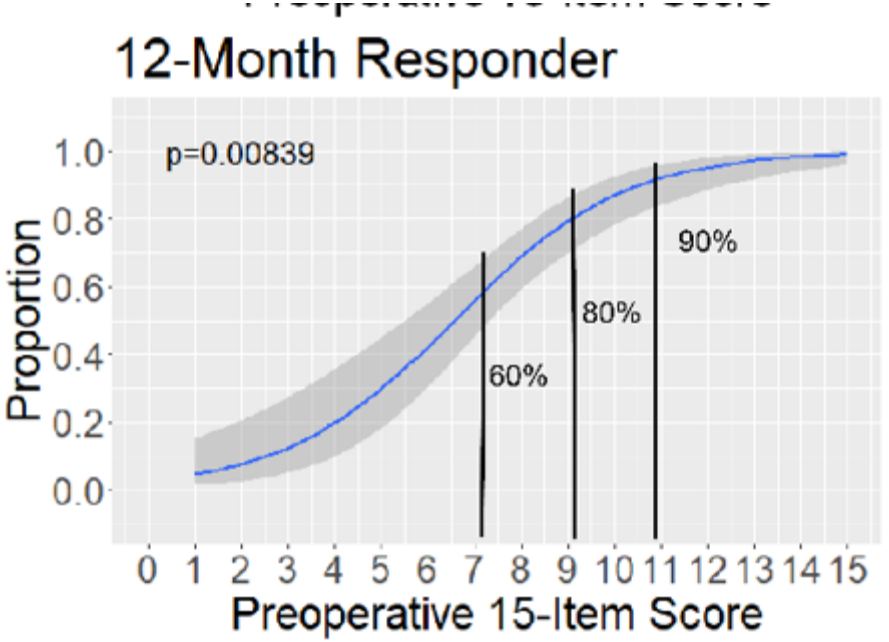
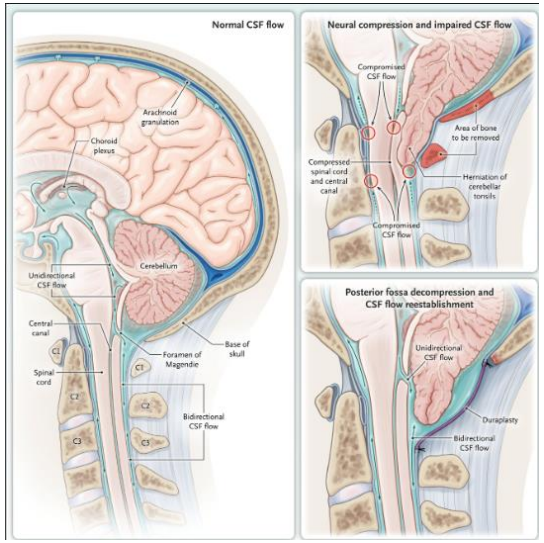
* Objective clinical findings.

A preop score > 6 is associated with benefit from surgery



Treatment



- Chiari

→ Posterior fossa decompression

- Tethered cord

→ Filum sectioning / spinal cord detethering

Associated disorders require individualized management

- Hydrocephalus
- Syringomyelia
- Craniocervical instability

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Expansile duraplasty and obex exploration compared with bone-only decompression for Chiari malformation type I in children: retrospective review of outcomes and complications

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Abstract

OBJECTIVE—While a select population of pediatric patients with Chiari malformation type I (CM-I) remain asymptomatic, some patients present with tussive headaches, neurological deficits, progressive scoliosis, and other debilitating symptoms that necessitate surgical intervention. Surgery entails a variety of strategies to restore normal CSF flow, including increasing the posterior fossa volume via bone decompression only, or bone decompression with duraplasty, with or without obex exploration. The indications for duraplasty and obex exploration following bone decompression remain controversial. The objective of this study was to describe an institutional series of pediatric patients undergoing surgery for CM-I, performed by a single neurosurgeon. For patients presenting with a syrinx, the authors compared outcomes following bone-only decompression with duraplasty only and with duraplasty including obex exploration. Clinical outcomes evaluated included resolution of syrinx, scoliosis, presenting symptoms, and surgical complications.

METHODS—A retrospective review was conducted of the medical records of 276 consecutive pediatric patients with CM-I operated on at a single institution between 2001 and 2015 by the senior author. Imaging findings of tonsillar descent, associated syrinx (syringomyelia or syringobulbia), basilar invagination, and clinical assessment of CM-I–attributable symptoms and scoliosis were recorded. In patients presenting with a syrinx, clinical outcomes, including syrinx

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Author Contributions
Conception and design: Wang, Ene, Ellenbogen. Acquisition of data: Wang, Ene, Collins, Bonow, McGrath. Analysis and interpretation of data: Wang, Ene, Barber, Ellenbogen. Drafting the article: Wang, Ene, Durfy. Critically revising the article: Wang, Ene, Bonow, Durfy, Barber, Ellenbogen. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Wang. Statistical analysis: Wang, Ene, Barber. Administrative/technical/material support: Durfy. Study supervision: Wang, Ellenbogen.
*C.I.E. and A.C.W. contributed equally to this work.

Disclosures
Dr. McGrath reports being a patent holder for and having ownership in EigenHealth, Inc.

Surgical approach ***FILUM REMOVAL***

“When Kids Lead the Way”

HOW I DO IT

Microsurgical approach for resection of the filum terminale internum in tethered cord syndrome—a case demonstration of technical nuances and vignettes

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Received: 27 February 2023 / Accepted: 19 March 2023

Abstract

Background In tethered cord syndrome due to filum terminale pathology, the surgical approach to achieve detethering of the spinal cord may vary. Traditionally, sectioning the filum through a laminectomy at the lumbosacral level is performed.

Method A microsurgical technique at a higher level to approach the filum below the conus tip is performed. This allows for removal of the entire distal portion of the filum through a limited interlaminar approach and dural opening.

Conclusion We propose a technique to transect the filum terminale below the conus tip and extract the distal filum by releasing it from its intradural attachments to minimize any remnants of the filum terminale.

Keywords Filum terminale pathology · Lumbosacral level · Tethered cord syndrome

Introduction

Traditionally, sectioning the filum through a laminectomy at the lumbosacral level is performed for detethering in patients with tethered cord syndrome (TCS) [5, 9]. Some surgeons would resect a small portion of the filum for histopathological evaluation. The rationale for a lower surgical approach to the filum is to avoid being in the vicinity of the conus medullaris. Furthermore, the increased width of the thecal sac and the loss of cauda equina density in the lumbosacral space facilitate filum isolation and sectioning.

The procedure has been proposed as fairly straightforward with minimal surgical risks; however, the main challenges remain the fairly high rate of retethering of up to 8% in some studies, particularly in a thickened filum, where the residual filum may re-attach to the dura proximal to the surgical site [6, 10, 11].

The authors perform a microsurgical technique at a higher level to approach the filum below the conus tip. This minimizes any residual filum and allows for removal of the entire distal portion of the filum terminale through a limited interlaminar approach and small dural opening. We discuss ways to optimize the surgical technique and limit short- and long-term complications, such as cerebrospinal fluid (CSF) leak, pseudomeningocele, and adhesive arachnoiditis.

Relevant surgical anatomy

The conus medullaris-filum terminale transition zone typically lies at the lumbar 1–2 disc space. The conus medullaris marks the end of the spinal cord proper and the beginning of the cauda equina nerve roots. The filum terminale usually consists of fibrovascular tissue that extends from the conus medullaris and attaches to the end of the thecal sac [1]. The conus-filum interface may be determined on a preoperative magnetic resonance image (MRI) of the lumbar spine which to facilitate allows for surgical planning of the target levels for laminotomy and, therefore, filum resection. Identifying this level will guide the surgical approach and point of resection of the filum (Fig. 1).

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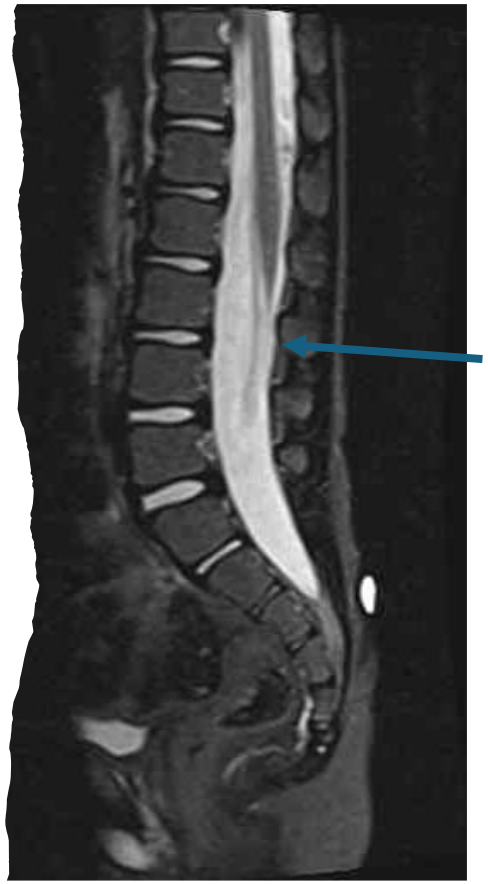
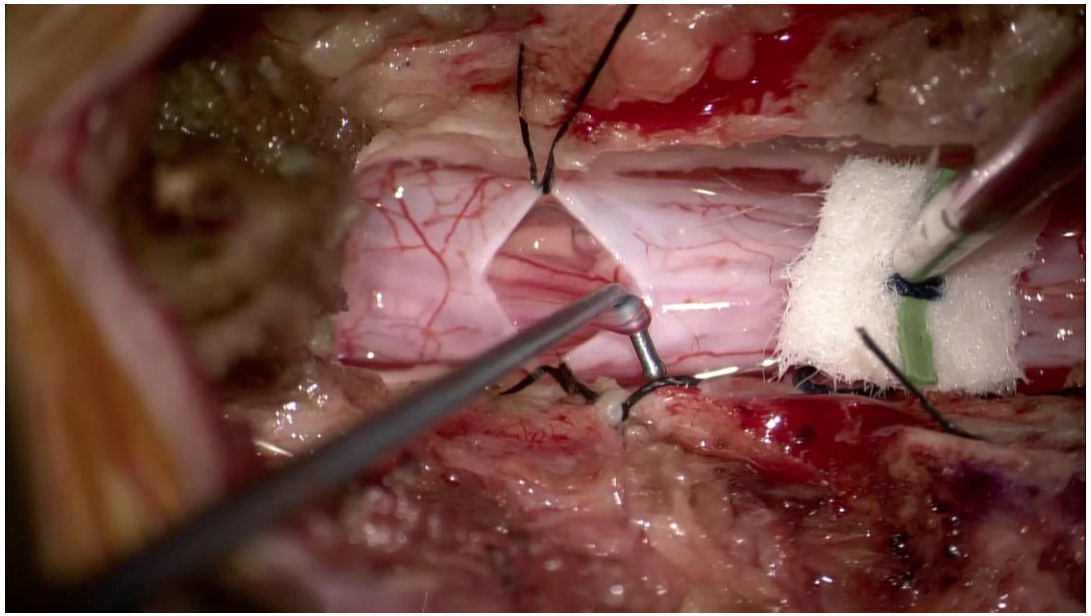
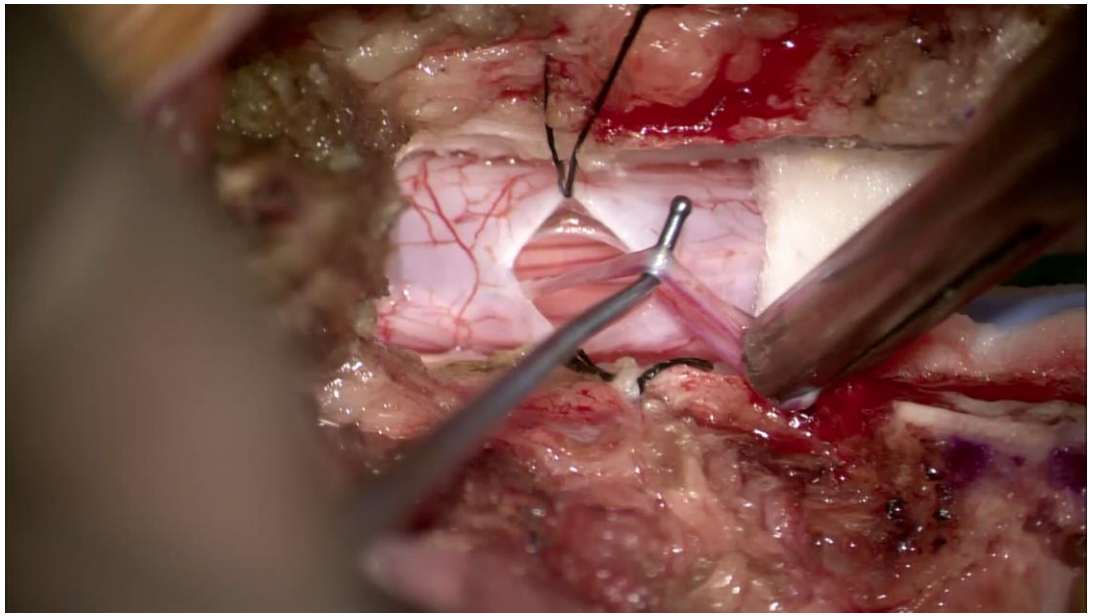


[Microsurgical approach for resection of the filum terminale internum in tethered cord syndrome—a case demonstration of technical nuances and vignettes | SpringerLink]





FILUM REMOVAL ***in both kids and adults***
improves 3 months 15-item scale outcome

Table 4 Logistic GLM modeling of Responders

Term	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.01590	0.18466	5.501	3.77e-08 ***
Filum removal	0.48639	0.21708	2.241	0.0251 *
EDS	0.38190	0.23189	1.647	0.0996 .
OTCS	0.01216	0.23810	0.051	0.9593

Table 4
Probability of being a responder

FT removal	Eds	OTCS	prob	SE
0	0	0	0.734	0.0360
1	0	0	0.818	0.0282
0	1	0	0.802	0.0370
1	1	0	0.868	0.0278
0	0	1	0.737	0.0496
1	0	1	0.820	0.0379
0	1	1	0.804	0.0352
1	1	1	0.869	0.0262

Future Directions

- ❑Better phenotyping of neurological co-morbidities
- ❑Genotype–phenotype relationships
- ❑Advanced MRI biomarkers
- ❑Prospective outcome studies
- ❑Role of connective tissue biology
- ❑Personalized surgical decision making

Take-Home Messages

- ❑Noonan syndrome is increasingly recognized as having important neurological manifestations.
- ❑Chiari malformation and tethered cord syndrome may coexist through shared developmental/genetic and connective tissue mechanisms.
- ❑Clinical evaluation remains more important than MRI alone.
- ❑Early recognition allows effective treatment and improved quality of life as shown with beneficial outcome.
- ❑**Both conditions have livelong implications (adult-onset!)**

CENTER FOR SURGICAL TREATMENT OF THE DEVELOPING BRAIN AND SPINE

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Director, Neurosurgery Pain Program

Overview

Welcome to the Center for Surgical Treatment of the Developing Brain and Spine, where we offer comprehensive surgical management for congenital disorders of the brain, spinal cord, and nervous system for both adult and pediatric patients. Our dedicated team is committed to providing the highest level of care for your neurologic condition throughout your life.

"The center will treat a variety of CSF disorders across all ages"

– Petra M. Klinge, MD, PhD