A 17-year-old presents with a distal sensorimotor polyneuropathy

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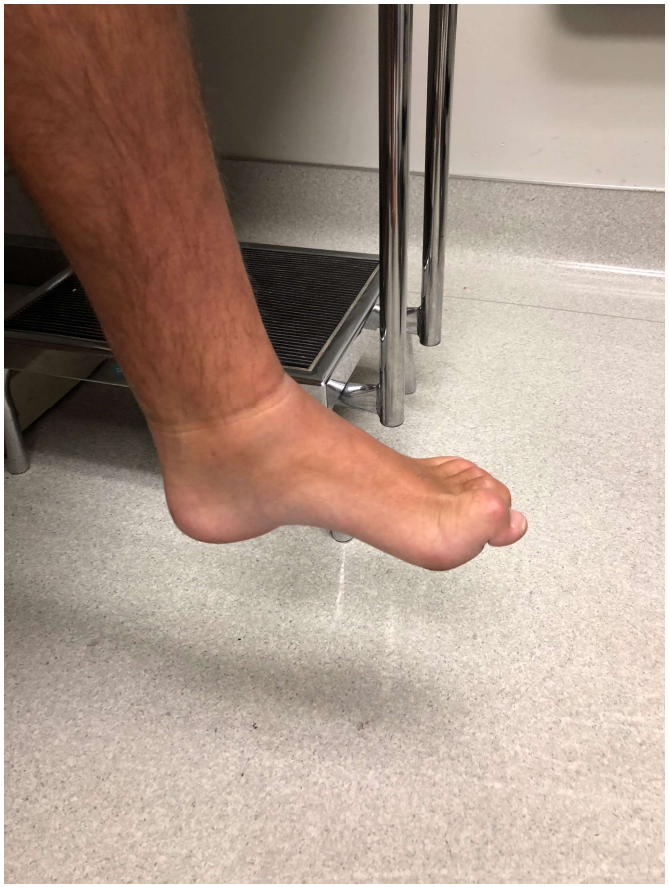
No conflicts of interest to disclose.

Clinical Presentation

- This patient is a 17-year-old right-handed male with a history of high arched feet, curled toes, and toe walking.
- The family noted toe walking and slower running than his peers starting at 5 years of age.
- At age 13, he started tripping more and developed pain in his feet on ambulation. He underwent bilateral Achilles tendon lengthening surgeries.
- Persistent walking difficulties prompted a new referral to orthopedic surgery.
- During the initial visit, he reported his toes catch frequently, resulting in near falls, and uses railing for assistance when climbing stairs. He also reported muscle cramps in both hands.
- He denied tingling-like sensations, but did report numbness and pain in his feet in cold weather.
- He mentioned difficulty maintaining an erection.

Review of Systems
Family History
Social History

Physical Examination



Physical and Neurological Examination

Neurological Examination: Motor

Normal bulk and tone. Distal weakness in the lower extremities with 2/5 strength on dorsiflexion and 4/5 strength on plantar flexion bilaterally

Neurological Examination: Sensation

Light touch: intact throughout

Pinprick: decreased in a length dependent manner; mild hyperesthesia up to the ankles

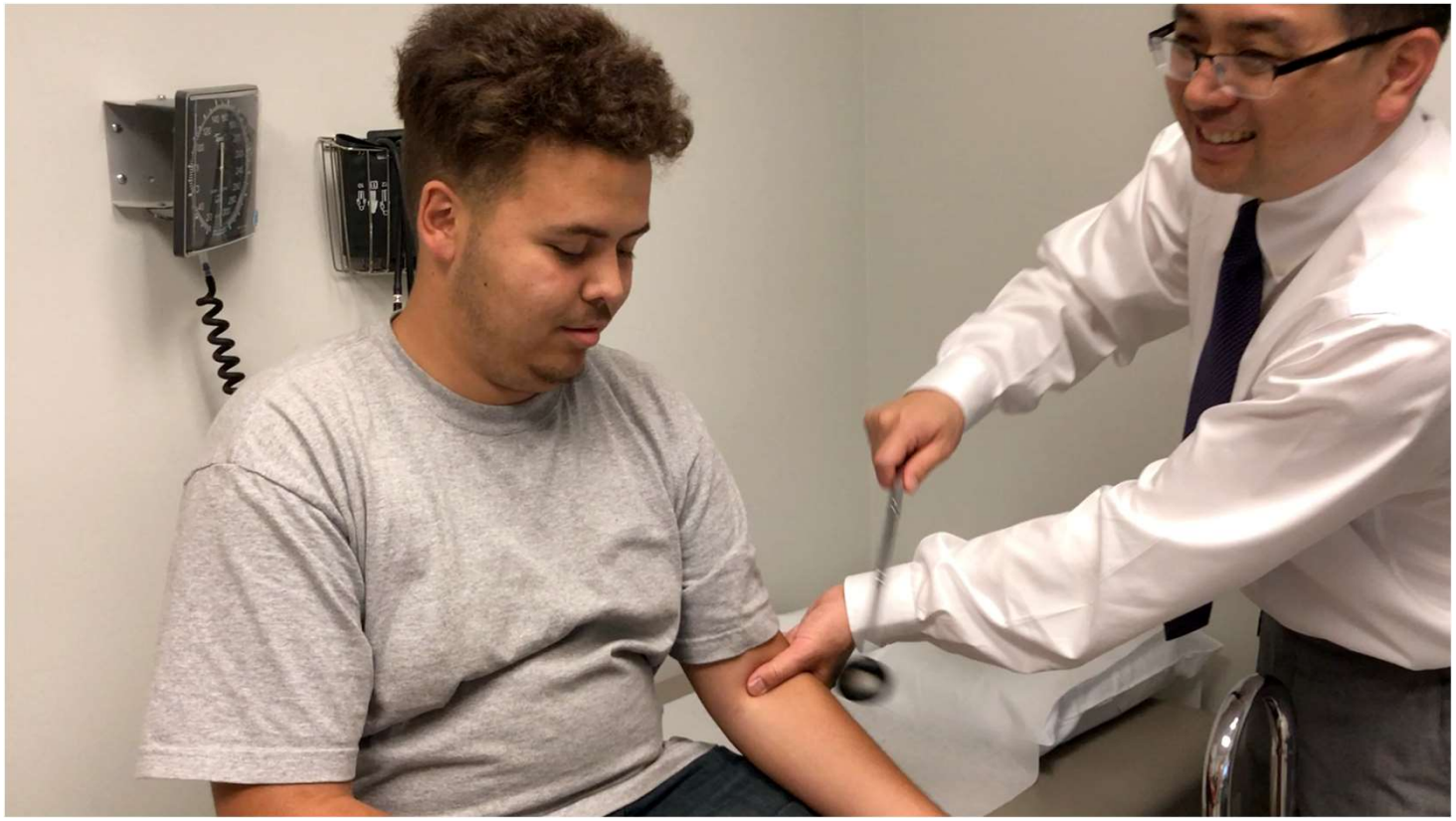
Temperature: intact to cold and warm water

Vibration: decreased at the toes and ankles

Proprioception: impaired at the toes, normal at the ankles

Romberg's: Present

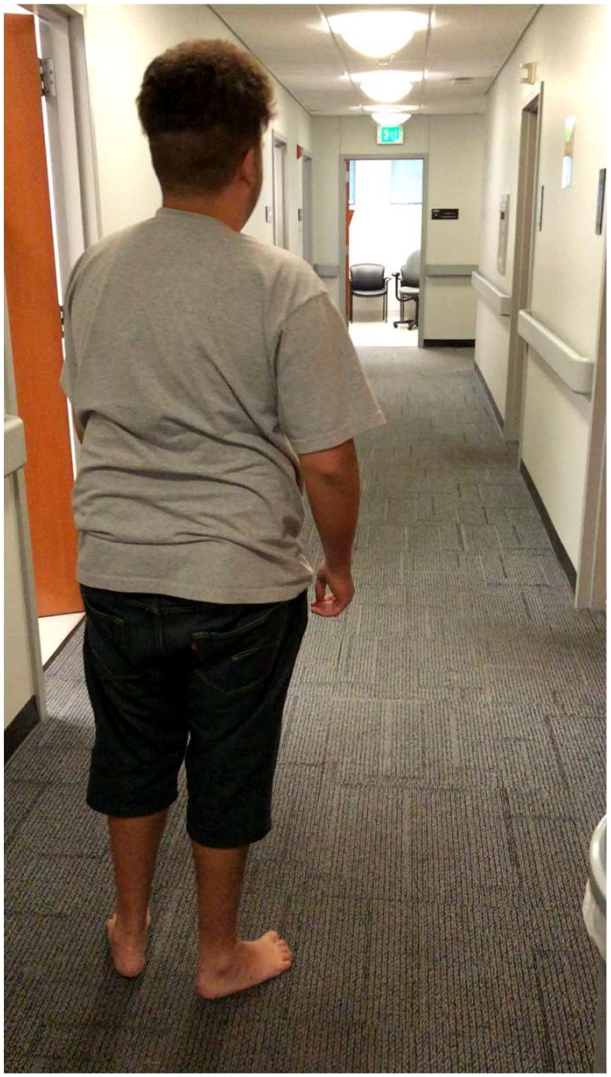
Neurological Examination: Reflexes



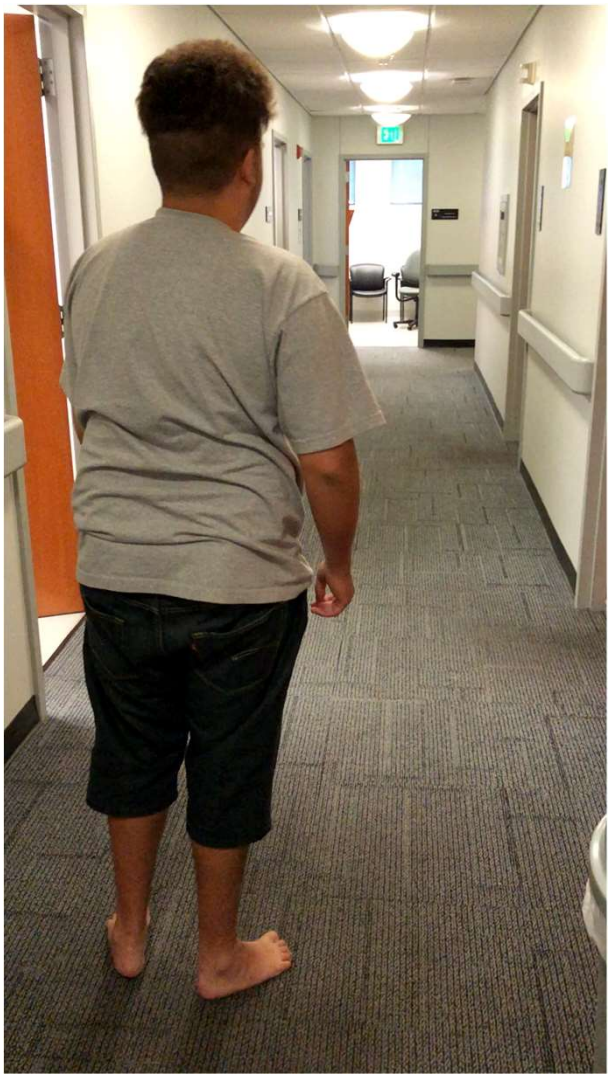
Neurological Examination: Coordination

- No dysmetria on finger to nose

Neurological Examination: Gait



Neurological Examination: Gait



Neurological Examination: Functional Assessment

Physical and Neurological Examination

- General examination: **Bilateral pes cavus and hammer toes**.

- Neurological examination
  - Mental status: Normal
  - Cranial Nerves: Normal
  - **Motor:** Distal weakness of the lower extremities with 2/5 strength on dorsiflexion and 4/5 strength on plantar flexion bilaterally
  - **Sensory:** Length dependent sensory deficits involving all modalities
  - **Reflexes:** Areflexia
  - Coordination: Normal
  - **Gait:** Steppage gait with normal stride. Difficulty with heel, toe, tandem walk

Discussion

Electrodiagnostic Findings

Sensory NCSs

Site	Onset (ms)	Peak (ms)	O-P Amp (μV)	Site	Dist (cm)	Vel (m/s)
Right Median Anti Sensory (2nd Digit)						
Wrist	2.6	3.6	36.9	2nd Digit	13.0	50
Right Ulnar Anti Sensory (5th Digit)						
Wrist	2.1	3.0	29.0	5th Digit	11.0	52

Motor NCSs

Site	Onset (ms)	O-P Amp (mV)	Site1	Site2	Dist (cm)	Vel (m/s)
Right Median Motor (Abd Poll Brev)						
Wrist	4.9	8.5	Elbow	Wrist	23.0	51
Elbow	9.4	8.2				
Right Peroneal Motor (Ext Dig Brev)						
Ankle	NR	NR				
Right Tibial Motor (Abd Hall Brev)						
Ankle	9.1	1.0	Knee	Ankle		
Right Ulnar Motor (Abductor Digit Minimi)						
Wrist	3.0	7.7	B Elbow	Wrist	22.5	52
B Elbow	7.3	7.6	A Elbow	B Elbow	9.0	50
A Elbow	9.1	7.6				

EMG

Side	Muscle	Nerve	Root	Ins Act	Fibs/PSW	Fasc	Other	Amp	Dur	Poly	Recrt
Right	AntTibialis	Dp Br Peron	L4-5	Incr	2+	None	None	Nml	Nml	Nml	Nml

Electrodiagnostic Findings: Summary

- Prior Nerve conduction studies at a different facility: **absent sensory responses and reduced motor amplitudes in the lower extremities**.

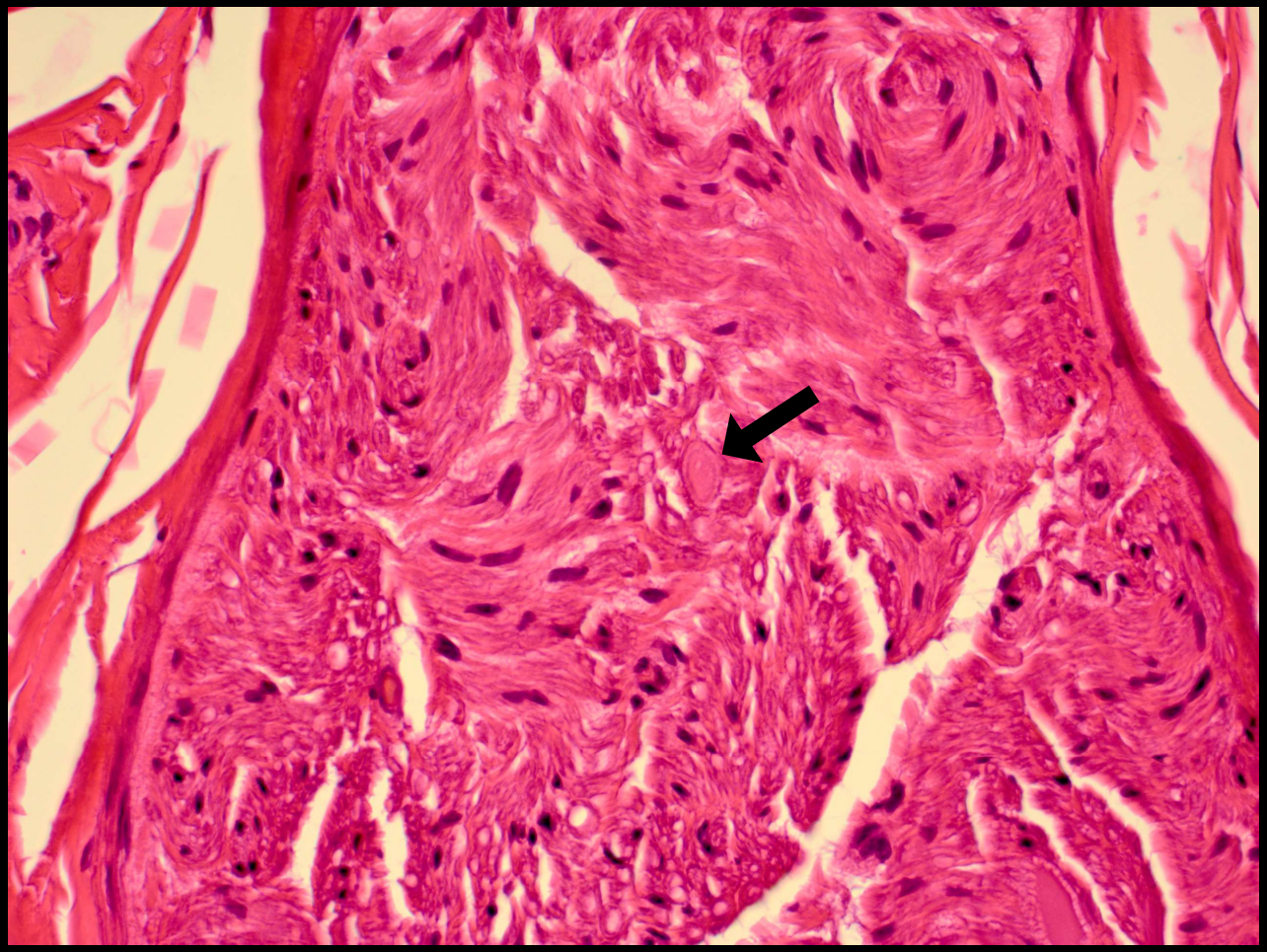
- Our EMG/NCS: **absent or reduced motor responses in the lower extremities with normal motor and sensory responses in the upper extremities**

A diagnostic test was performed.

17-year-old with a distal sensorimotor polyneuropathy

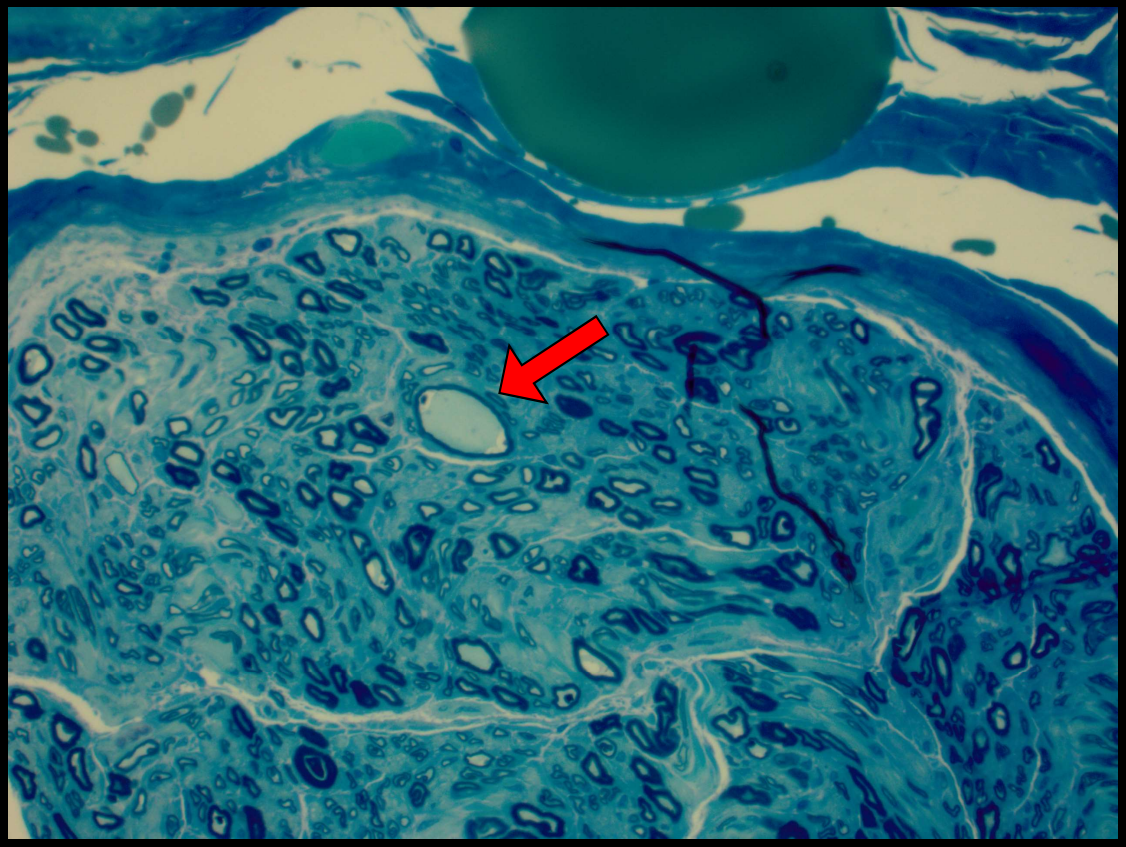
Genetic testing for *PMP22* and *GJB1* was negative

Sural Nerve Biopsy

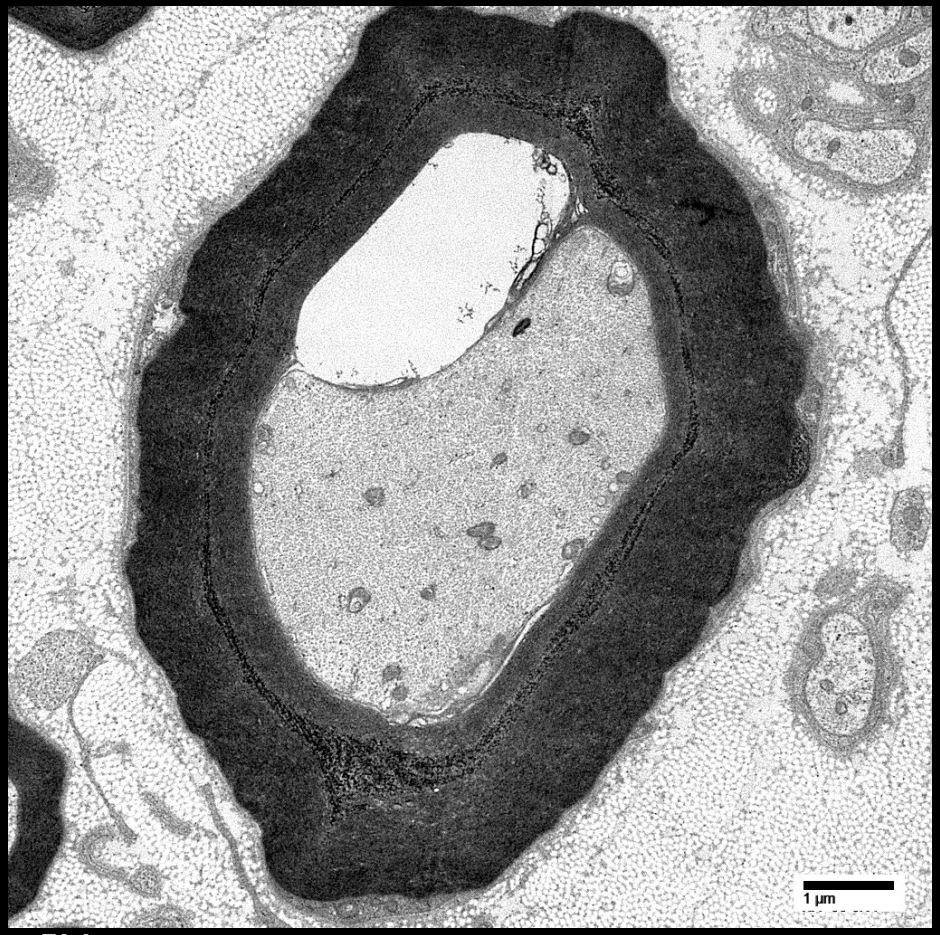


H&E

Sural Nerve Biopsy: Electron Microscopy (EM)

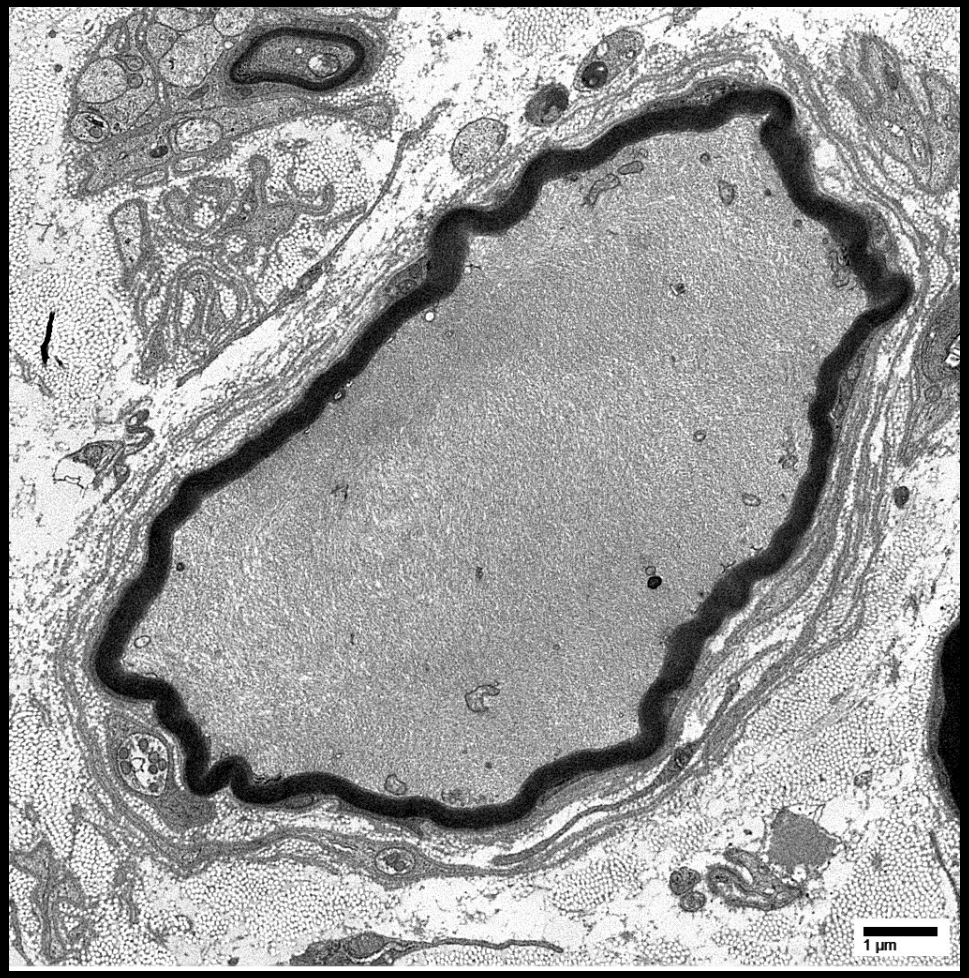


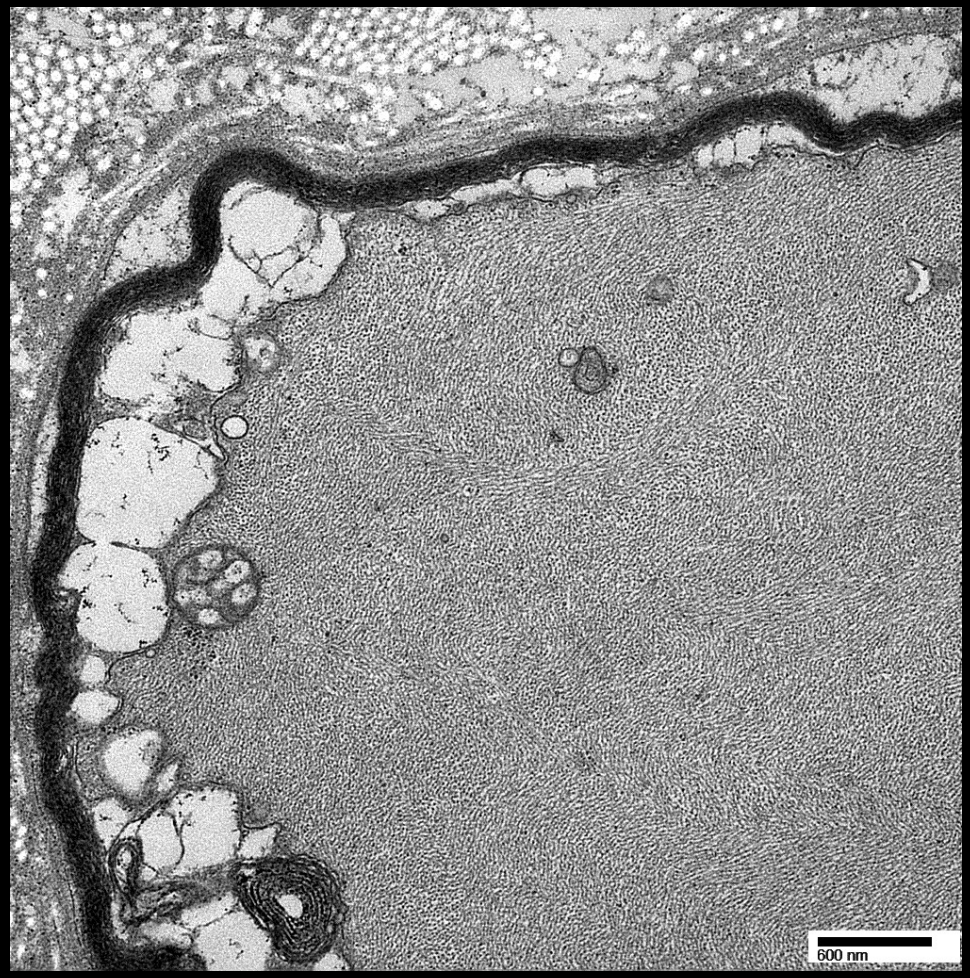
Methylene Blue



EM

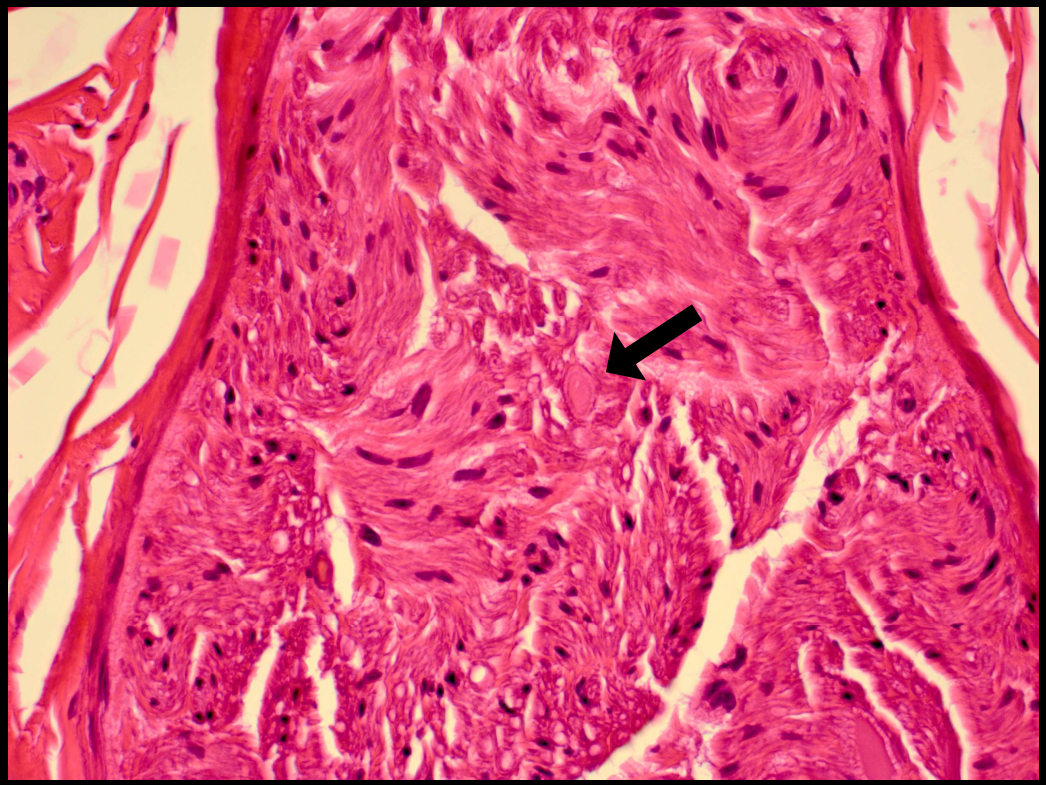
Sural Nerve Biopsy: Electron Microscopy



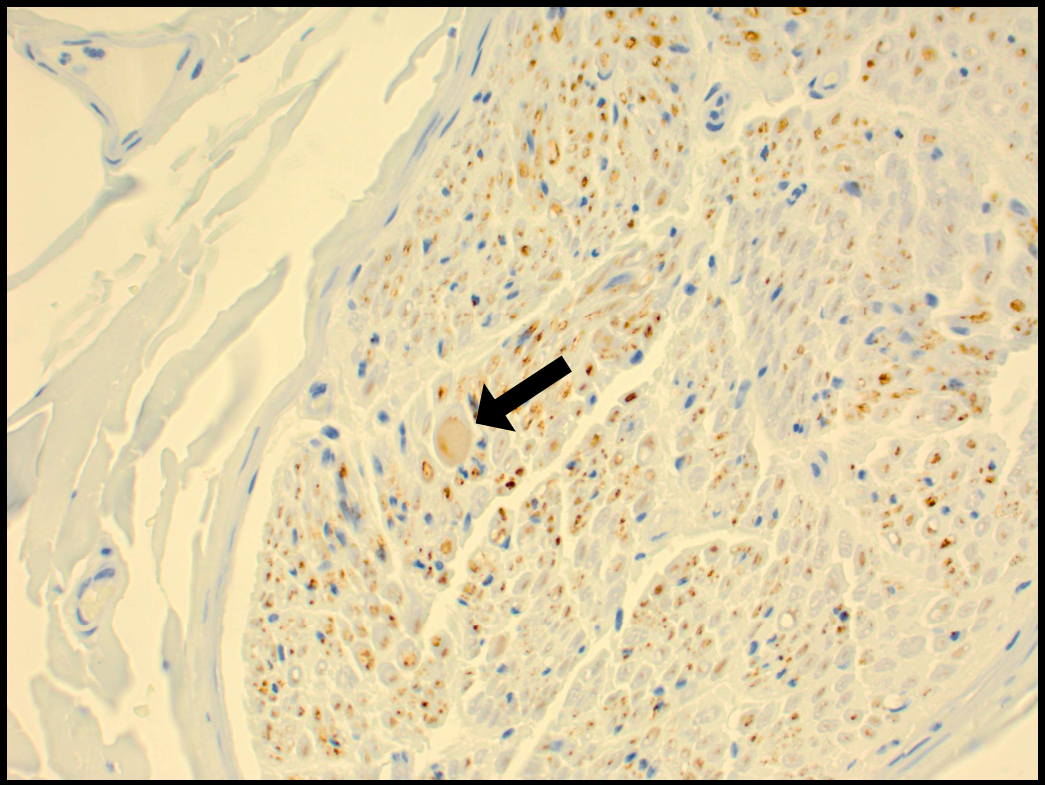


Sural Nerve Biopsy

H&E



Neurofilament



Genetic Testing

- Two VUS in the *GAN* (gigaxonin) gene:
  - c.1506G>T (p.Trp502Cys) (maternal)
  - c.944C>T (p.Pro315Leu) (paternal)

- c.944C>T has been previously reported by Bruno et. al. 2004 and Houlden et. al. 2007

- c.1506G>T has not been reported.

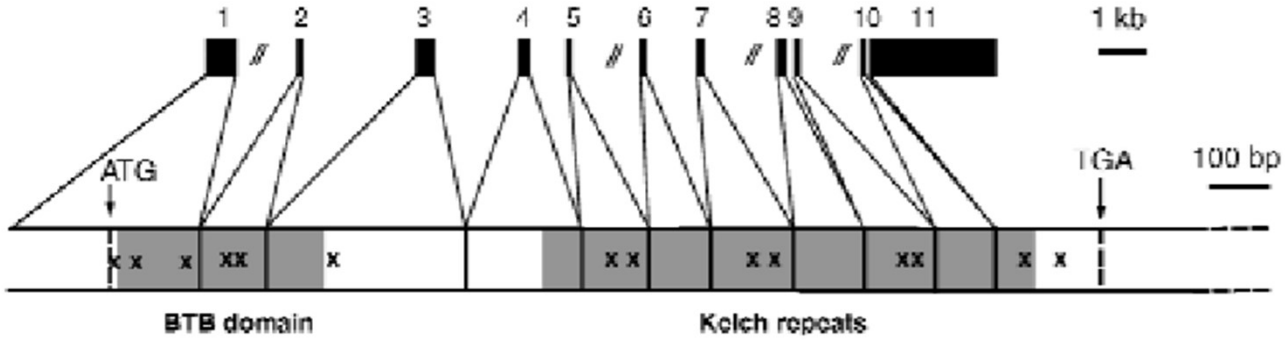
Giant Axonal Neuropathy (GAN)

- In its classic form, it is a severe autosomal recessive disease that affects both the peripheral and central nervous system
- First Described in 1972
- Very rare
- Only about 50 families have been described in the medical literature
- Likely underdiagnosed

Giant Axonal Neuropathy (GAN)

- The gigaxonin gene *GAN* was identified as the mutated gene in giant axonal neuropathy in 2000 (Bomont et. al. Nat Genet). Located in chromosome 16q24

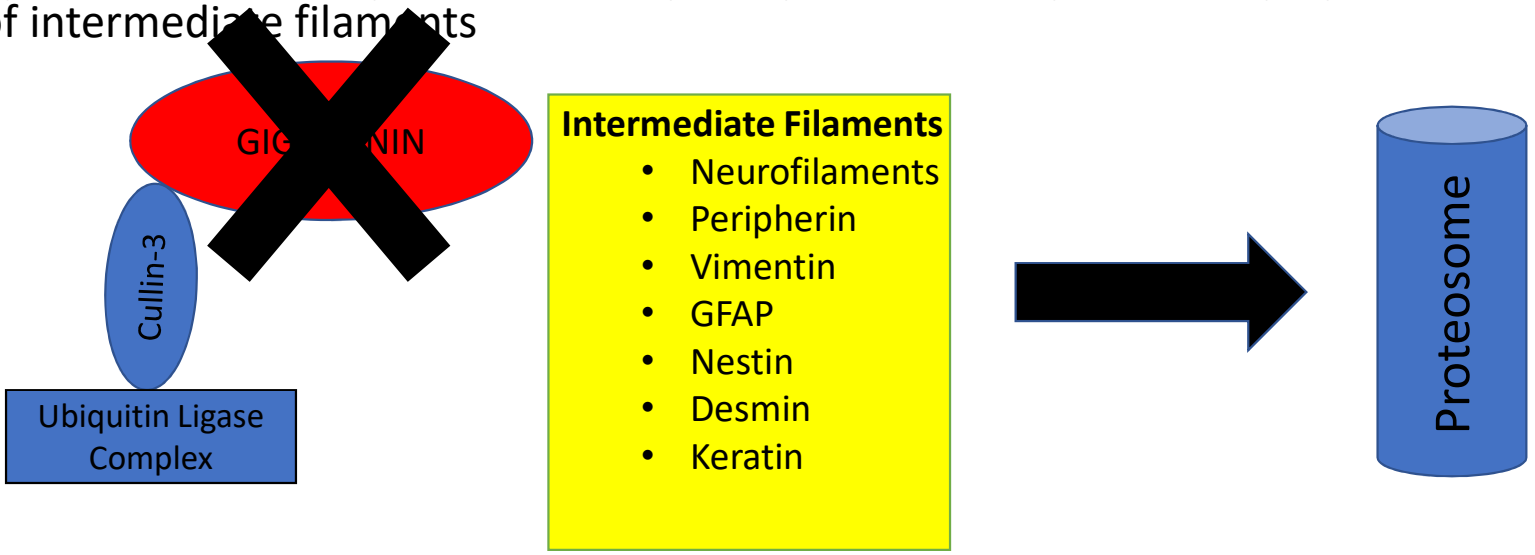
- Composed of an amino-terminal BTB (for Broad-Complex, Tramtrack and Bric a brac) domain followed by six Kelch repeats



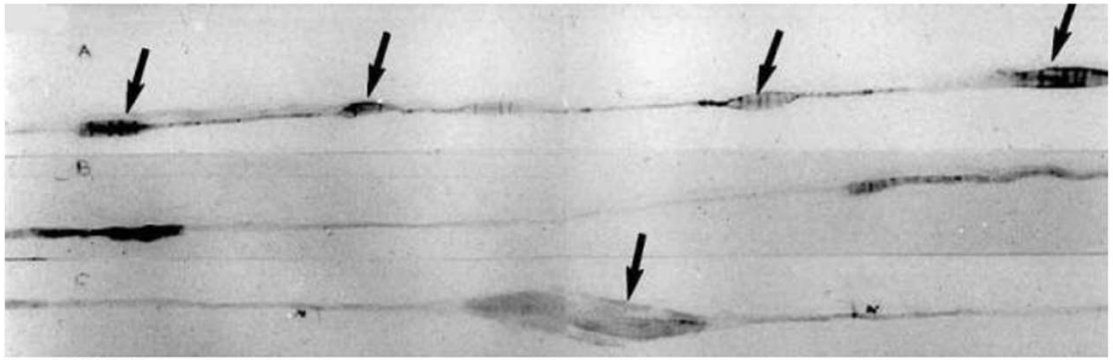
- More than 40 different mutations have been reported.

Giant Axonal Neuropathy (GAN)

- E3-ligase adaptor that works as part of the ubiquitin-proteasome system and plays a role in the breakdown of intermediate filaments



- Loss of GAN causes accumulation of intermediate filaments-> axonal accumulation and axonal swelling



From Pr P Landrieu

Teased axons with focal swellings (Arrows).

Source. https://neuromuscular.wustl.edu

Giant Axonal Neuropathy (GAN)

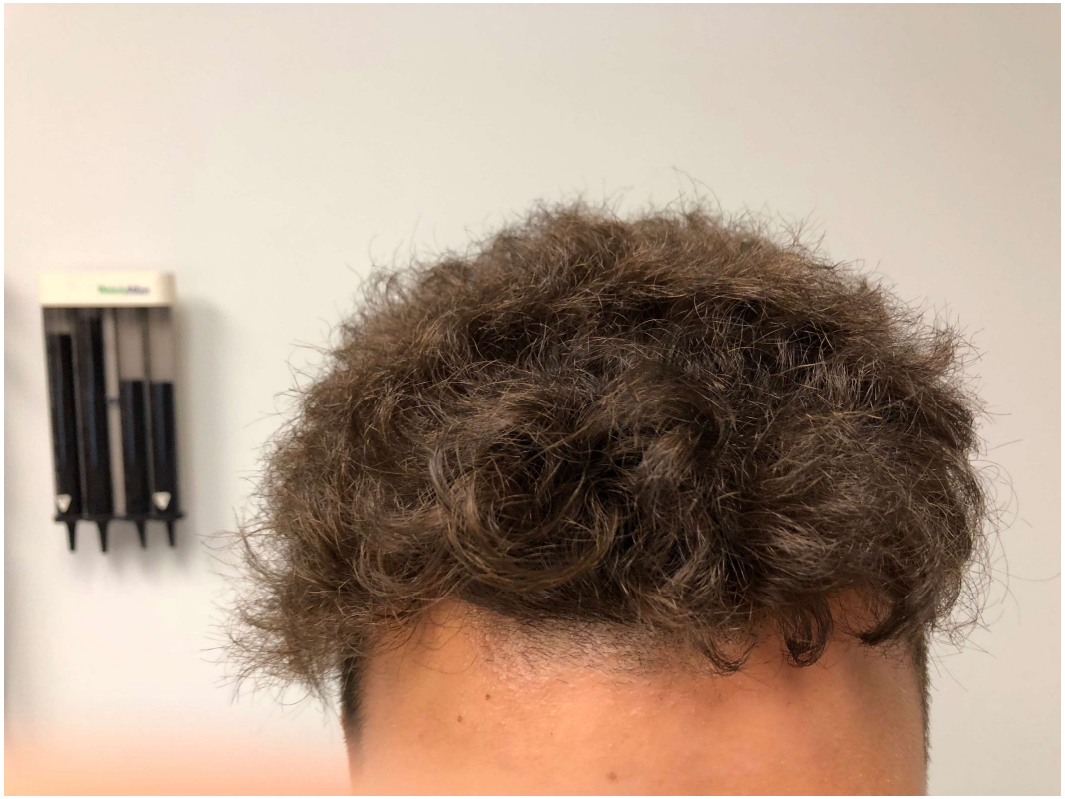
nature Vol 438|10 November 2005|doi:10.1038/nature04256

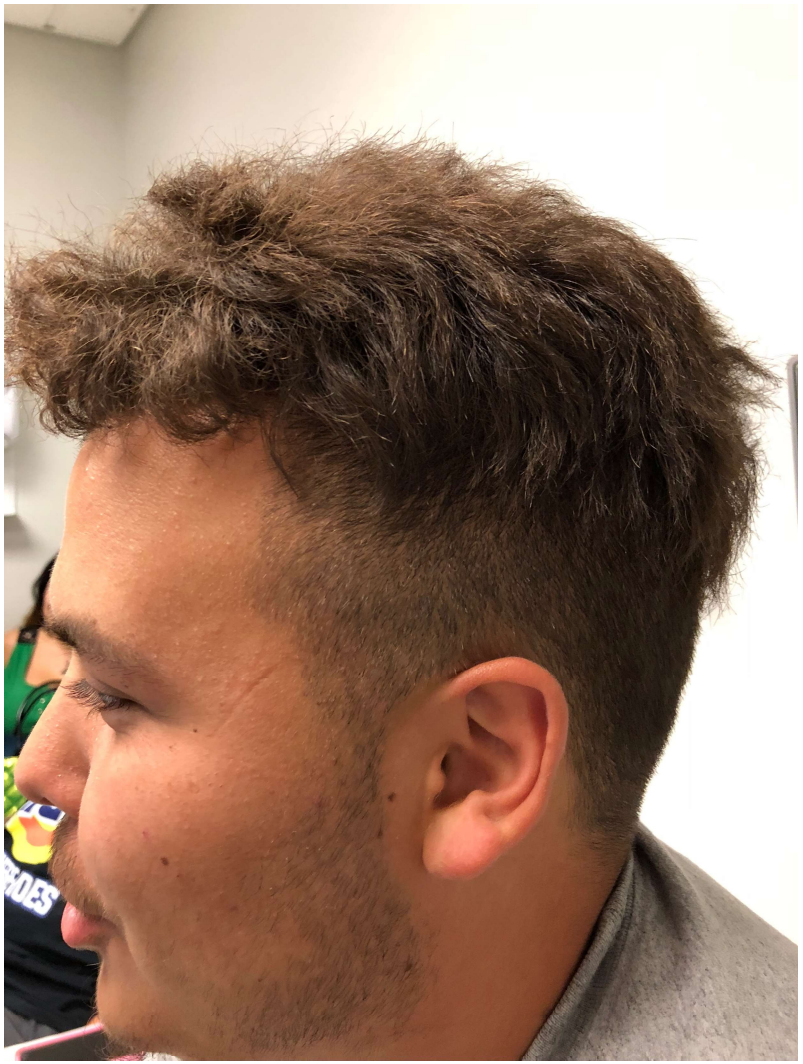
LETTERS

Gigaxonin-controlled degradation of MAP1B light chain is critical to neuronal survival

Elizabeth Allen[1]*, Jianqing Ding[1]*, Wei Wang[1], Suneet Pramanik[1], Jonathan Chou[1], Vincent Yau[1] & Yanmin Yang[1]

Giant Axonal Neuropathy (GAN): Kinky hair





Our patient’s family

Giant Axonal Neuropathy (GAN)

- **Physical appearance:** kinky hair, high forehead, pale complexion, and long eyelashes

Source. https://blog.timesunion.com

Source. https://irp.nih.gov

Source. https://globalgenes.org

Giant Axonal Neuropathy (GAN)

- **Physical appearance:** red and kinky hair, high forehead, pale complexion, and long eyelashes

- **Symptoms:** usually begin before age 5 with gait disturbances and frequent falls due to both weakness and ataxia; numbness is present as well

- **CNS involvement**: cerebellar dysfunction, spasticity, and **optic atrophy**; hearing can be affected; intellectual disability, seizures, and dementia can occur

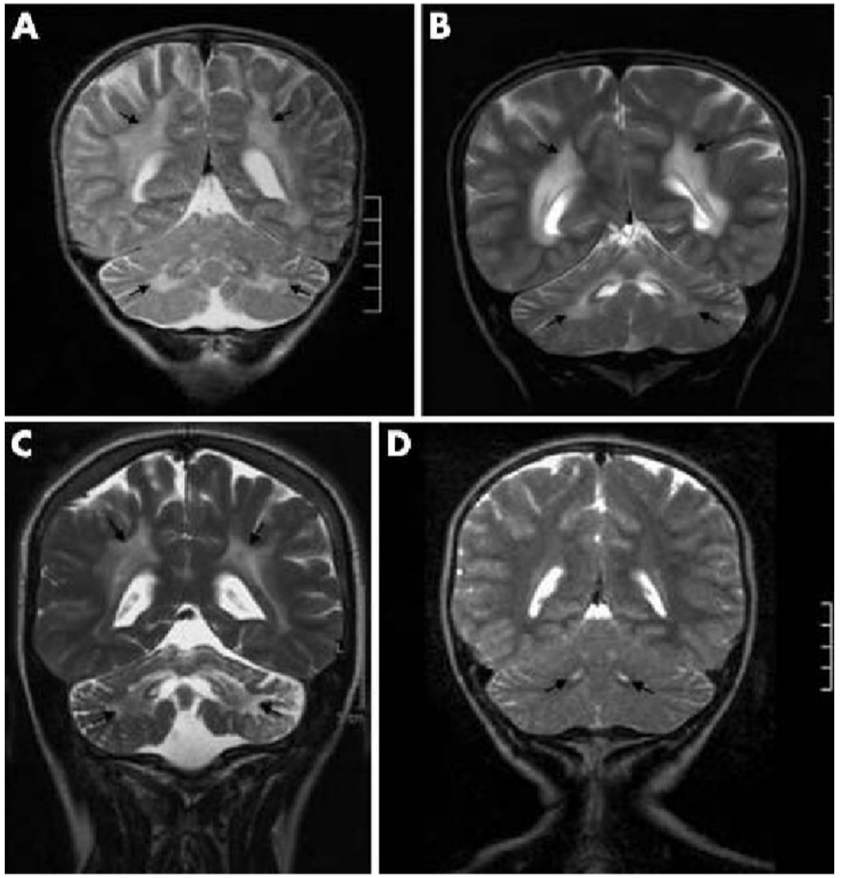
- **Autonomic nervous system involvement:** neurogenic bladder, constipation, heat intolerance, hypohidrosis or anhidrosis

- Most children become wheelchair dependent in the 2nd decade. Death usually occurs in the 3rd decade most often due to respiratory failure.

Giant Axonal Neuropathy (GAN): Findings

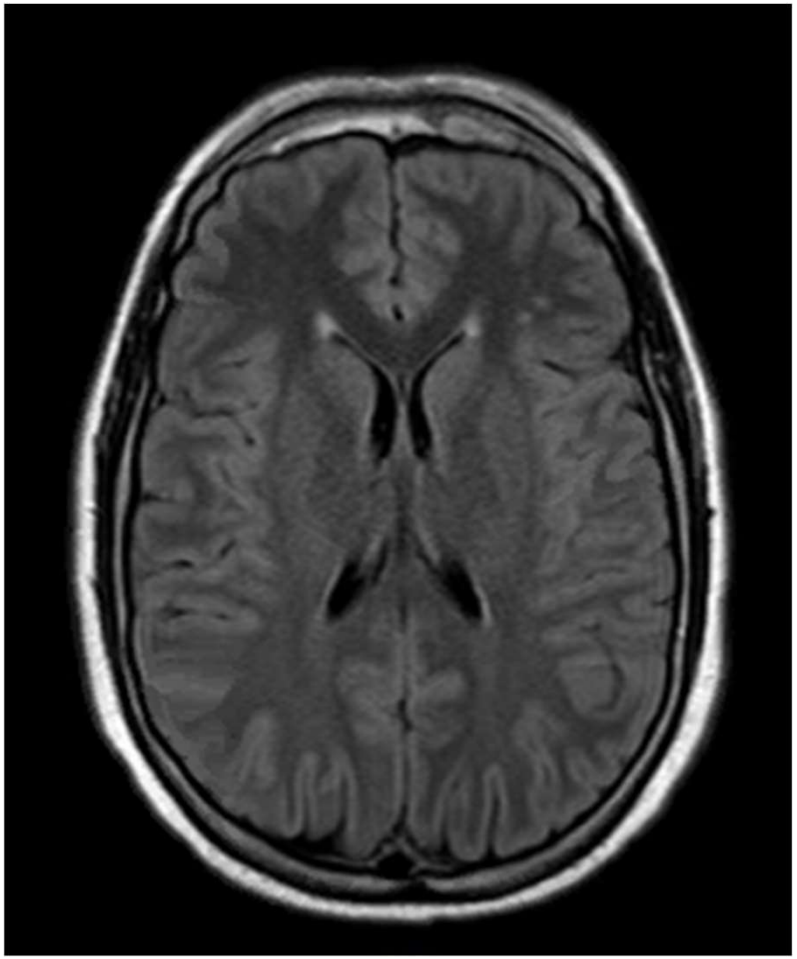
- NCS/EMG: SNAPs are typically absent; motor NCSs can be normal or with amplitude reductions

- Imaging Findings:
  - White matter changes, atrophy of the cerebellum, and optic tracts



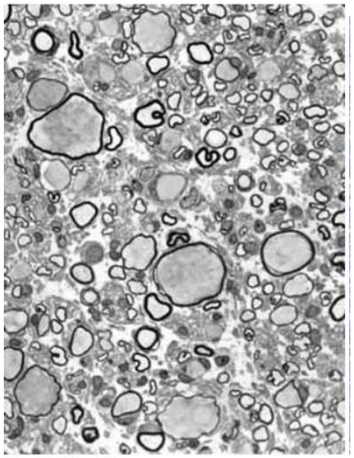
Demir et. al. J Neurol Neurosurg Psychiatry 2005

Giant Axonal Neuropathy (GAN): Our Patient



Giant Axonal Neuropathy (GAN): Diagnosis

- Diagnosis: Nerve biopsy and genetic testing
- Nerve Biopsy: Classic findings include axonal loss, giant axon swelling, densely packed bundles of neurofilaments



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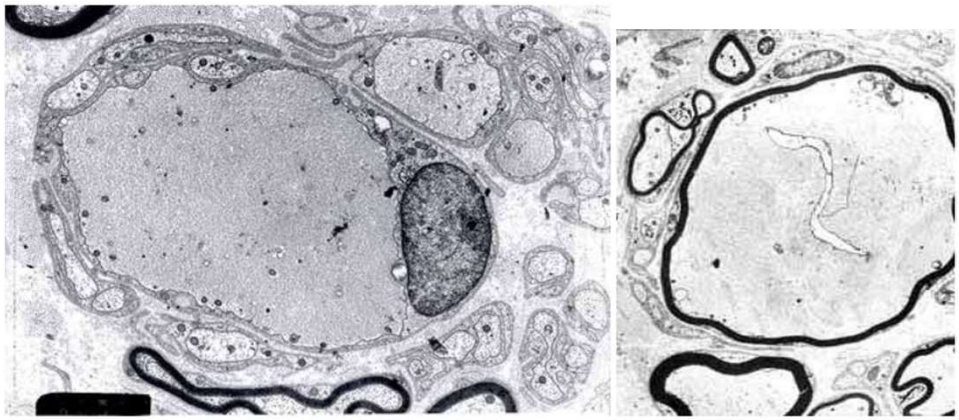
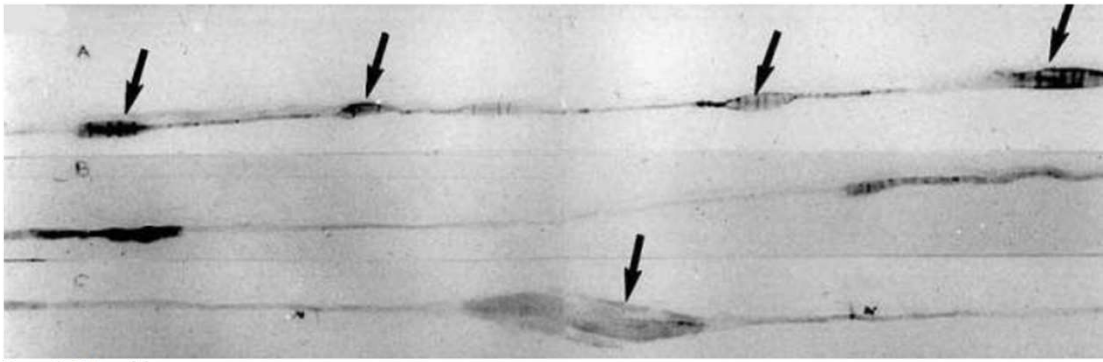


From Pr P Landrieu

Enlarged unmyelinated, or thinly myelinated, axons.



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Teased axons with focal swellings (Arrows).

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Giant Axonal Neuropathy (GAN)

What about Treatment?

Giant Axonal Neuropathy (GAN): Research

- Animal models:
  - Yang Lab mouse model (exon 3-5Δ) (Ding et al. Hum Mol Genet 2006)
  - Julien Lab mouse model (exon 1 Δ) (Dequen et. al. J. Neurochem 2008)
  - Bomont Lab mouse model (exon 3-5 Δ) (Ganay et al. Mol Neurodegener 2011)

Giant Axonal Neuropathy: Pre-clinical studies

- AAV-mediated gigaxonin expression in cultured human GAN fibroblasts-> Reduction in intermediate filaments (Mussche et al. Hum Gene Ther 2013)

- Lentivirus-mediated gigaxonin expression in human iPSC-derived GAN motor neurons-> Reduction in intermediate filaments (Johnson-Kernet et. al. Hum Mol Gen 2015)

- Gigaxonin expression in *GAN* KO mice
  - Clearance of pathological aggregates, improved phenotype (latency to fall) , and preservation of the sciatic nerve ultrastructure (Bailey et. al. Mol Ther Methods Clin Dev 2018)

A Phase I Study of Intrathecal Administration of scAAV9/JeT-GAN for the Treatment of Giant Axonal Neuropathy

- ClinicalTrials.gov Identifier: NCT02362438
- PI: Dr. Carsten Bonnemann
- NIH Clinical Center in Bethesda, MD
- Utilizes an AAV9 vector

Bailey et. al. Mol Ther Methods Clin Dev 2018

- Delivered intrathecally
- Purpose is to primarily target the spinal cord and brainstem motor neurons, as well as the dorsal root ganglion

A Phase I Study of Intrathecal Administration of scAAV9/JeT-GAN for the Treatment of Giant Axonal Neuropathy

-Patients 5yrs and older with a genetic diagnosis of GAN

- Outcome measures
    1. Safety
    2. To determine efficacy by improvement of pathologic, histologic, physiologic, function, and clinical markers
        - MFM-32
        - FARS
        - NIS
        - MRI brain/spine
        - CSF studies
        - NCS
        - BAER
        - Peripheral nerve biopsy


HARLEY-DAVID

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