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Non-aneurysmal Cranial Nerve Compression As Cause of Neuropathic Strabismus: Evidence from High-resolution Magnetic Resonance Imaging

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Abstract

Purpose—To seek evidence of neurovascular compression of motor cranial nerve (CN) in otherwise idiopathic neuropathic strabismus using high resolution magnetic resonance imaging (MRI).

Design—Prospective, observational case series.

Methods—High-resolution, surface coil orbital MRI was performed in 10 strabismic patients with idiopathic oculomotor (CN3) or abducens (CN6) palsy. Relationships between CNs and intracranial arteries were demonstrated by 0.8 mm thick, 162 micron resolution, heavily T2 weighted MRI in fast imaging employing steady state acquisition sequence. Images were digitally analyzed to evaluate cross-sectional areas of extraocular muscles.

Results—In one patient with CN3 palsy, an ectatic posterior communicating artery markedly flattened and thinned the ipsilateral subarachnoid CN3. Cross-sections of the affected medial, superior and inferior rectus muscles 10 mm posterior to the globe-optic nerve junction were $17.2 \pm 2.5 \text{ mm}^2$, $15.5 \pm 1.3 \text{ mm}^2$, and $9.9 \pm 0.8 \text{ mm}^2$, significantly smaller than the values of 23.6 ± 1.9 , 30.4 ± 4.1 , $28.8 \pm 4.6 \text{ mm}^2$ of the unaffected side ($P < 0.001$). In two patients with otherwise unexplained CN6 palsy, ectatic basilar arteries contacted CN6. Mean cross-sections of affected lateral rectus muscles were 24.0 ± 2.3 and $29.8 \pm 3.1 \text{ mm}^2$, significantly smaller than the values of $33.5 \pm 4.1 \text{ mm}^2$ and $36.9 \pm 1.6 \text{ mm}^2$ in unaffected contralateral eyes ($P < 0.05$).

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Appendix available at AJO.com

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Conclusions—Non-aneurysmal motor CN compression should be considered as a cause of CN3 and CN6 palsy with neurogenic muscle atrophy, when MRI demonstrates vascular distortion of the involved CN. Demonstration of a benign vascular etiology can terminate continuing diagnostic investigations and expedite rational management of the strabismus.

Introduction

When investigating the etiology of strabismus caused by cranial nerve palsy, imaging studies are often necessitated to rule out life-threatening intracranial lesions such as aneurysm and neoplasm. However, despite the availability of computed tomography and magnetic resonance imaging (MRI), the cause of neuropathic strabismus in 23% to 35% of patients still remains undetermined.¹⁻³

Ectasia of arteries is diagnosed when the diameter of the vessels exceeds normal along all or part of their course, and when they are also abnormally tortuous. Previous study with cerebral angiography found that ectasia is associated with a variety of neurological symptoms.⁴ Clinical syndromes may be caused by compression by sagging vessels against the cranial nerve root entry zones at brainstem.⁵ After Jannetta proposed this concept for hemifacial spasm, it was suggested that at least some cases of superior oblique myokymia^{6, 7} trigeminal neuralgia⁸ hemifacial spasm^{9, 10} vestibular paroxysmia¹¹ are caused by vessels compressing the trochlear (CN4), trigeminal, facial, and vestibulo-cochlear cranial nerves. Theoretically, if cranial nerve CN3, CN4, or CN6 were compressed by dolichoectatic vessels, associated ocular motility would be hindered and subsequent denervation atrophy of the involved extraocular muscle atrophy would be expected to develop¹²⁻¹⁴ within as little as five weeks based upon findings in monkey following experimental CN4 section¹⁵. There have been few reports of neuropathic strabismus caused by presumed neurovascular compression in the literature review, mostly described cases with abducens nerve paresis¹⁶⁻²⁵. However, neurovascular compression has rarely been considered as a cause of neuropathic strabismus in clinical differential diagnoses. This may be because the pathological anatomy has not been readily demonstrable by conventional imaging studies.

With continuing advances of imaging technology, high-resolution magnetic resonance imaging (MRI) can now display the cranial nerves and their innervation to extraocular muscles. Cranial nerve anatomical relationship with intracranial vessels can also be demonstrated with refocus gradient-echo MRI sequence that is flow compensated²⁶. Using high-resolution MRI, we prospectively imaged patients with idiopathic CN3 and CN6 palsy in whom routine clinical MRI and medical testing had been nondiagnostic, seeking evidence for non-aneurysmal neurovascular compression as a cause of neuropathic strabismus.

Subjects and Methods

Subjects were identified from consecutive cases in an ongoing, prospective study of strabismus employing high resolution MRI. We included patients with CN3 and CN6 palsy who had high resolution imaging of the orbits and subarachnoid motor nerves innervating the extraocular muscles. All of these patients were referred for diagnosis of unexplained extraocular muscle weakness, consistent with cranial nerve palsy, after elsewhere having undergone conventional neuroimaging and typical clinical laboratory evaluation to exclude commonly recognized causes of cranial neuropathy. None of the patients exhibited fluctuation of strabismus or eyelid position, remission with recurrence of strabismus, connective tissue disease, or features suggestive of variable extraocular muscle weakness due to myasthenia gravis. Records of prior MRI and CT were reviewed in all cases, and images re-reviewed when available.

We excluded patients with well-characterized alternative causes of strabismus, including history of trauma, neoplasm, intracranial surgery, diabetes, local infection, demyelination, myasthenia gravis, thyroid disease, and autoimmune disorders. In the sense that conventional etiologies could not be established after thorough evaluation, these patients were considered by the investigators to have “idiopathic” CN6 or CN3 palsies.

Clinical Examination

All the strabismic patients underwent complete ophthalmic examinations by an author (JLD) who is a strabismus specialist. Examinations included assessment of visual acuity, stereopsis, orthoptic examination, Hess screen testing, slit-lamp and funduscopy examination, refraction, and photography in diagnostic gaze positions.

Imaging

Imaging of the orbits was performed using a 1.5-T General Electric Signa scanner (Milwaukee, WI) as previously described.¹² Imaging of cranial nerves at the brainstem was performed using the heavily T2-weighted FIESTA (Fast Imaging Employing Steady State Acquisition) sequence, which provides good contrast of the cranial nerves against the surrounding cerebrospinal fluid.²⁶ Detailed imaging techniques are summarized in the Appendix at AJO.com.

Images were digitally analyzed with the program *OsiriX* Medical Image software (version 3.3.2, www.osirix-viewer.com) on Macintosh computers (Apple Computer, Cupertino, CA). For measurement of cross-sectional areas of rectus muscles, the globe-optic nerve junction was first identified on each quasicoronal image. Muscle cross sections were then identified in each of the 5 continuous image planes posterior to the globe-optic nerve junction. The borders of each extraocular muscle were outlined manually with a digital cursor, and its cross-sectional area was computed by the “ROI” function of the *OsiriX* software. Means and standard deviations were computed for the cross section values for the 5 sampled planes. The maximum inferior oblique muscle cross section was determined at the most temporal part of the straight path found in the quasi-sagittal image plane, passing through the center of the inferior rectus muscle that travels in this plane. The cross-sectional area of inferior oblique muscle in these images was selected for comparison with that of unaffected side.

Statistical Analysis

Ipsilateral and contralateral cross-sectional areas of extraocular muscles were compared by the use of the 2-tailed t-test. Statistical analyses were performed by SigmaStat Version 2.0 (SPSS Science). The 0.05 level was considered significant.

Results

Ten (28%) of the 36 total patients who underwent high resolution MRI in the study who had CN6 or CN3 palsies were considered idiopathic. There were 6 males and 4 females. The average age in the study group was 23.7 (range 3-55) years. Patients were all followed for at least 6 months. Each of these exhibited palsy of a single cranial nerve innervating one or more EOMs whose clinical presentation and course could not plausibly be explained by ischemic mononeuropathy, mass lesion, vasculitis, or neuromuscular disease. High resolution MRI demonstrated CN3 hypoplasia in three patients, and schwannoma in the orbital portion of CN3 in one patient. High resolution MRI was unremarkable in 3 patients. Abnormal neurovascular compression was found in cases of 3 patients, who are described here in detail.

Case reports

Case 1

A 55 year old woman presented with history of binocular diplopia beginning sometime after age 20 years. On four prior occasions over an extended time interval, MRI of the head performed elsewhere had been interpreted as normal. Although electromyographic and antibody evaluations for myasthenia gravis were negative, the diagnosis was nevertheless presumed and she had undergone thymectomy at 23 years of age without benefit. She had undergone multiple strabismus surgeries including right superior rectus recession, right lateral rectus recession, left inferior rectus recession and left lateral rectus recession on the same occasion. A later surgery consisted of re-recession of the lateral rectus muscles, resection of both medial and the right inferior rectus muscles. Corrected visual acuity was 20/25 in the right eye and 20/30 in the left eye. The pupils were 6 mm in diameter, round and appropriately reactive to light and accommodation without afferent pupillary defect. There was marked limitation of right eye supraduction, and moderate limitation of left eye supraduction. There was profound limitation to adduction and infraduction of the right eye. At distance without correction, there was 55 Δ right exotropia. Slit lamp examination, intraocular pressures, and fundoscopy were normal. Hess screen testing demonstrated a central gaze exotropia exceeding 45° with superimposed 26° right hypertropia.

High resolution MRI showed profound hypoplasia of the deep portion of the right inferior rectus, the right medial rectus and the right superior rectus, as well as the right inferior and superior oblique muscles. Intraorbital motor branches of the right CN3 were quite small. The subarachnoid portion of the right CN3 was compressed by the prominent, hairpin contour right posterior communicating artery and posterior cerebral artery (Fig. 1). The right CN3 was markedly compressed by the tortuous vessel, reducing its diameter to only 0.27 mm. The left oculomotor nerve in the same view had a normal diameter of 1.65 mm (Fig. 2).

Cross-sections of the affected medial, superior and inferior rectus muscles 10 mm posterior to the globe-optic nerve junction were $17.2 \pm 2.5 \text{ mm}^2$, $15.5 \pm 1.3 \text{ mm}^2$, and $9.9 \pm 0.8 \text{ mm}^2$, significantly smaller than the values of 23.6 ± 1.9 , 30.4 ± 4.1 , $28.8 \pm 4.6 \text{ mm}^2$ of the unaffected side ($P = 0.00059$, 0.00049 , 0.00010 , respectively, Fig. 3). The cross-sectional area of the right inferior oblique muscle was $17.0 \pm 1.1 \text{ mm}^2$, not significantly different from that of the left inferior oblique ($18.8 \pm 3.4 \text{ mm}^2$, $P = 0.452$). Average cross-sectional area of the lateral rectus was $30.2 \pm 8.1 \text{ mm}^2$ on the right, not significantly different from the value of $28.4 \pm 1.0 \text{ mm}^2$ on the left ($P = 0.768$). Average cross sectional area of the superior oblique muscle was, $8.0 \pm 2.7 \text{ mm}^2$ on the right, not significantly different from the value of $8.5 \pm 2.6 \text{ mm}^2$ on the left ($P = 0.750$).

Case 2

An 11 year old boy was referred for acute onset of horizontal, binocular diplopia in levoversion for 3 months. Routine x-ray computed tomographic (CT) and MRI scans had been performed elsewhere that were unremarkable. He had had no recent illnesses or trauma, no systemic weakness and no personal history of migraine. Uncorrected visual acuity was 20/20 in each eye. There was no preauricular lymphadenopathy or blepharoptosis. The pupils reacted normally. There was a moderated deficiency of full abduction of the left eye, which associated with terminal slowing of the abducting saccade. At distance without correction, there was 6Δ esotropia that increased to 30Δ in levoversion, and was eliminated in dextroversion. The patient was orthotropic at near. Hess screen testing showed about 20° esotropia in levoversion. Slit lamp and fundoscopic examination were unremarkable. Serological testing was negative for myasthenia gravis, including acetylcholine binding antibody, blocking antibody and anti-striated antibody.

High resolution MRI demonstrated no evidence of an intraorbital lesion involving CN6. High resolution imaging with fast imaging employing steady state acquisition sequence, readily demonstrated the right subarachnoid CN6, but an ectatic basilar artery was seen in the location where the left CN6 should have been visible (Fig. 4, Top). Magnetic resonance angiography confirmed the tortuous, ectatic basilar artery extending to the left side of the brainstem in the position normally occupied by CN6 (Fig. 4, Bottom). The cross-sectional area of the left lateral rectus muscle was $24.0 \pm 2.3 \text{ mm}^2$, significantly smaller than the value of $33.5 \pm 4.1 \text{ mm}^2$ on the right ($P=0.00189$, Fig. 3). The average cross-sectional area of the right medial rectus muscle was $27.0 \pm 5.2 \text{ mm}^2$, not significantly different from the value for the left medial rectus muscle of $23.3 \pm 1.6 \text{ mm}^2$ ($P = 0.189$). The mean cross-sectional area of the superior rectus muscle was $24.5 \pm 2.8 \text{ mm}^2$ on the right and $22.5 \pm 3.6 \text{ mm}^2$ on the left ($P = 0.359$). The mean cross-sectional area of the inferior rectus muscle was, $21.7 \pm 6.8 \text{ mm}^2$ on the right, not significantly different from the value of $21.3 \pm 2.6 \text{ mm}^2$ the left ($P = 0.907$).

Case 3

A 52 year old man complained of gradually progressive horizontal, binocular diplopia in dextroversion for 4 years. He had undergone prior neurological evaluation regarding his chronic migraine headaches without specific findings. Previous MRI and MRA of the intracranial vessels had been negative. Corrected visual acuity was 20/16 in the right eye and 20/20 in the left. Pupil reactions, slit lamp and funduscopic examination in both eyes were unremarkable. Prism cover test at distance showed orthotropia in primary position, but 10 Δ esotropia in dextroversion. He was orthotropic at near. There was mild to moderate deficiency of full abduction of the right eye associated with abducting nystagmus. Abduction saccades were slowed in the right eye. Hess screen testing demonstrated approximately 15° esotropia in dextroversion.

The right lateral rectus muscle was atrophic compared to the left lateral rectus muscle on axial MRI (Fig. 5). MRI of the brainstem and motor cranial nerves demonstrated a normal left CN6 and a right-deviated basilar artery that closely contacted the right CN6 (Fig. 6). Cross-sectional area of the right lateral rectus muscle was $29.8 \pm 3.1 \text{ mm}^2$, significantly smaller than the value of $36.9 \pm 1.6 \text{ mm}^2$ on the left side ($P = 0.0229$, Fig. 3). The average cross-sectional area of the right medial rectus muscle was $28.9 \pm 3.6 \text{ mm}^2$, not significantly different from the value of $28.3 \pm 3.1 \text{ mm}^2$ on the left ($P = 0.785$). Mean cross-sectional area of the right superior rectus muscle was $28.8 \pm 7.6 \text{ mm}^2$, not significantly different from that of the left at 25.6 ± 4.8 ($P = 0.447$). Mean cross-sectional area of the right inferior rectus muscles was $26.6 \pm 3.2 \text{ mm}^2$, not significantly different from the left side value of $26.8 \pm 2.4 \text{ mm}^2$ ($P = 0.881$).

Discussion

This report demonstrates by high resolution MRI that neuropathic strabismus may be associated with nonaneurysmal compression of motor cranial nerves by dolichoectatic blood vessels in the subarachnoid space. In Case 1, a tortuous, dilated posterior communicating artery compressed and thinned the subarachnoid oculomotor nerve, causing a chronic, progressive CN3 palsy that was mistaken for ocular myasthenia gravis. In Cases 2 and 3, dilated, ectatic basilar arteries compressed the abducens nerve to produce CN6 palsy. High resolution MRI with the fast imaging employing steady state acquisition sequence was clinically important, both in ruling out mass lesion, and in demonstrating neurovascular contact in the subarachnoid space.

There have been several reported cases where neurovascular compression was presumed to have caused CN6 palsy.¹⁶⁻²² There have been only sparse reports of CN3 nerve palsy

presumed due to neurovascular compression.²³⁻²⁵ The CN6 is more vulnerable to injury than CN3 as a result of its long course, angulated path, and smaller diameter. The second most commonly affected cranial nerve involving ocular motility is CN4¹⁻³. However, current high-resolution MRI technique cannot consistently demonstrate CN4 even in normal subjects¹².

No prior study has evaluated denervation atrophy of extraocular muscles in strabismus presumed caused by neurovascular compression. Extraocular muscle denervation atrophy is important evidence of neuropathic strabismus¹²⁻¹⁵. Other causes such as misdirected innervation of extraocular muscles^{27, 28} or mitochondrial myopathy²⁹ do not produce much extraocular muscle atrophy. Even prior strabismus surgery has little effect on extraocular muscle size, not enough to approach the large atrophic change demonstrated here.³⁰ In our study, the anatomical relationships between subarachnoid nerve segments and compressing vessels were clearly demonstrated by high-resolution T2 weighted MRI. We measured the cross-sectional areas of affected extraocular muscles and compared the results with the unaffected side, which supports the presumed neuropathic cause of strabismus.

Neurovascular contact is not a rare anatomical phenomenon. A previous MRI study found that in 76.6% of cases, CN6 contacted the anterior inferior cerebellar artery.³¹ Liang et al. found that 55.1% of CN3s contacted the posterior cerebral artery and 58.9% of CN3s contact the superior cerebellar artery.²³ Although the neurovascular contact is not always pathogenic, Liang et al. demonstrated abnormal nerve compression in 9 patients with CN3 paralysis.²³ It has been postulated that detection of neurovascular compression may have high sensitivity but low specificity for nerve paralysis.^{8,9} In the setting of cranial nerve paralysis, however, demonstration of neurovascular compression may be of diagnostic value.

It is important to scan the cisternal segment of cranial nerves when neurovascular compression is suspected. In a study of hemifacial spasm, at least 80% of symptomatic sides involved neurovascular contact at the anterior aspect of the root entry zone¹⁰. The root entry zone is defined as the transition zone between central and peripheral myelin. It is generally agreed that abnormalities result from compression only when the site of contact is as or near the transition zone, where the individual nerve fibers are covered by central (oligodendrocyte-derived) myelin rather than peripheral myelin (Schwann cell-derived). The junctional area between central and peripheral myelin lacks perineurium and epineurium therefore is particularly vulnerable to continued pulsatile pressure.³² With the high-resolution MRI using the fast imaging employing steady state acquisition sequence, the small structures within the fluid space can be evaluated.

Pupillary involvement has been considered to have almost pathognomonic significance in compressive CN3 paresis. However, pupil involvement was not observed in Case 1, who had marked oculomotor nerve thinning associated with neurovascular compression. Several studies reported that the pupil may be spared in CN3 palsy caused by aneurysmal compression.^{33, 34} The pupillomotor fibers are located in the superficial medial aspect of CN3, a location suggested to be relatively resistant to chronic and insidiously progressive compression.³⁴ The right CN3 in Case 1 was compressed inferiorly and medially by posterior cerebral artery and posterior communicating artery, which might have spared the pupillomotor fibers.

In the past, no cause could be identified in a large proportion of patients with neuropathic strabismus.¹⁻³ Diagnostic investigation typically involves multiple serological and imaging studies that are both costly and time consuming. When such studies have been unrevealing, diagnoses of exclusion are typically presumed. Sometimes procedures like thymectomy have

been unnecessarily performed in the setting of presumed seronegative ocular myasthenia gravis, as in Case 1. We suggest that non-aneurysmal neurovascular compression be considered in the differential diagnoses of neuropathic strabismus. Although the risks of intracranial microvascular decompression surgery probably outweigh the benefits in most cases, there had been some reports of the treatment success^{17, 23, 25}. Demonstration of a benign vascular etiology can terminate continuing diagnostic investigations and expedite rational symptomatic management of the strabismus. While conventional MRI may fail to provide sufficient resolution to depict subarachnoid cranial nerves, high-resolution MRI with the fast imaging employing steady state acquisition sequence may be useful for clinicians in diagnosing neuropathic strabismus.

A limitation of this study was the small case number enrolled. Further prospective, larger-scale studies are necessary to determine the prevalent rate of neurovascular compression in otherwise idiopathic strabismus.

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Appendix

Typical MRI technique previously performed in referred patients was obtained with: field of view 25×25 cm, matrix 256×256 or 256×162 , image plane thickness 5 mm, possibly skipping 2 mm between image planes, with and without gadodiamide contrast, and in axial and sagittal planes only. In our study, one of the authors (J.L.D) personally performed surface coiled high resolution MRI. Orbital imaging was performed using an array of surface coils embedded in a transparent facemask (Medical Advances, Milwaukee, WI). Imaging at and posterior to the orbital apex was performed using a standard head coil. Orbital images of 2-mm thickness in a matrix of 256×256 were obtained over a field of view of 6 to 8 cm for a resolution in plane of 230 - 312 micron (TR: 3233 msec, TE: 106 msec, Flip angle: 90°). Imaging of cranial nerves at the brainstem was performed in 0.8-mm thickness image planes parallel to the optic chiasm using the heavily T2-weighted FIESTA (Fast Imaging Employing Steady State Acquisition) sequence. In-plane resolution was 162 micron over a 10-cm field of view (matrix 512×512) with 10 excitations (TR: 7.10 msec, TE: 2.80 msec, Flip angle: 70°).

Biography

After graduating with a medical degree from National Taiwan University, Tzu-Hsun Tsai completed her ophthalmology residency and fellowship in Retina and Vitreous surgery at National Taiwan University Hospital. She subsequently pursued another year of fellowship in Pediatric Ophthalmology and Strabismus at Jules Stein Eye Institute, UCLA, California. She is currently back in full-time practice as a pediatric ophthalmologist at National Taiwan University Hospital. Her research interests include strabismus, pediatric cataract and vision science.

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References

1. Rush JA, Younge BR. Paralysis of cranial nerves III, IV, and VI. Cause and prognosis in 1,000 cases. *Arch Ophthalmol*. 1981; 99(1):76–9. [PubMed: 7458744]
2. Richards BW, Jones FR Jr, Younge BR. Causes and prognosis in 4,278 cases of paralysis of the oculomotor, trochlear, and abducens cranial nerves. *Am J Ophthalmol*. 1992; 113(5):489–96. [PubMed: 1575221]
3. Tiffin PA, MacEwen CJ, Craig EA, Clayton G. Acquired palsy of the oculomotor, trochlear and abducens nerves. *Eye (Lond)*. 1996; 10(Pt 3):377–84. [PubMed: 8796166]
4. Yu YL, Moseley IF, Pullicino P, McDonald WI. The clinical picture of ectasia of the intracerebral arteries. *J Neurol Neurosurg Psychiatry*. 1982; 45(1):29–36. [PubMed: 7062068]
5. Jannetta PJ. Neurovascular compression in cranial nerve and systemic disease. *Ann Surg*. 1980; 192(4):518–25. [PubMed: 6968543]
6. Hashimoto M, Ohtsuka K, Hoyt WF. Vascular compression as a cause of superior oblique myokymia disclosed by thin-slice magnetic resonance imaging. *Am J Ophthalmol*. 2001; 131(5):676–7. [PubMed: 11336957]
7. Yousry I, Dieterich M, Naidich TP, et al. Superior oblique myokymia: magnetic resonance imaging support for the neurovascular compression hypothesis. *Ann Neurol*. 2002; 51(3):361–8. [PubMed: 11891831]
8. Boecker-Schwarz HG, Bruehl K, Kessel G, et al. Sensitivity and specificity of MRA in the diagnosis of neurovascular compression in patients with trigeminal neuralgia. A correlation of MRA and surgical findings. *Neuroradiology*. 1998; 40(2):88–95. [PubMed: 9541918]
9. Du C, Korogi Y, Nagahiro S, et al. Hemifacial spasm: three-dimensional MR images in the evaluation of neurovascular compression. *Radiology*. 1995; 197(1):227–31. [PubMed: 7568828]
10. Ho SL, Cheng PW, Wong WC, et al. A case-controlled MRI/MRA study of neurovascular contact in hemifacial spasm. *Neurology*. 1999; 53(9):2132–9. [PubMed: 10599794]
11. Hufner K, Barresi D, Glaser M, et al. Vestibular paroxysmia: diagnostic features and medical treatment. *Neurology*. 2008; 71(13):1006–14. [PubMed: 18809837]

12. Demer JL, Ortube MC, Engle EC, Thacker N. High-resolution magnetic resonance imaging demonstrates abnormalities of motor nerves and extraocular muscles in patients with neuropathic strabismus. *J Aapos*. 2006; 10(2):135–42. [PubMed: 16678748]
13. Kau HC, Tsai CC, Ortube MC, Demer JL. High-resolution magnetic resonance imaging of the extraocular muscles and nerves demonstrates various etiologies of third nerve palsy. *Am J Ophthalmol*. 2007; 143(2):280–7. [PubMed: 17173848]
14. Demer JL, Clark RA, Kono R, et al. A 12-year, prospective study of extraocular muscle imaging in complex strabismus. *J Aapos*. 2002; 6(6):337–47. [PubMed: 12506273]
15. Demer JL, Poukens V, Ying H, et al. Effects of intracranial trochlear neurectomy on the structure of the primate superior oblique muscle. *Invest Ophthalmol Vis Sci*. 2010; 51(7):3485–93. [PubMed: 20164458]
16. Zhu Y, Thulborn K, Curnyn K, Goodwin J. Sixth cranial nerve palsy caused by compression from a dolichoectatic vertebral artery. *J Neuroophthalmol*. 2005; 25(2):134–5. [PubMed: 15937439]
17. De Ridder D, Menovsky T. Neurovascular compression of the abducent nerve causing abducent palsy treated by microvascular decompression. Case report. *J Neurosurg*. 2007; 107(6):1231–4. [PubMed: 18077964]
18. Lin JY, Lin SY, Wu JI, Wang IH. Optic neuropathy and sixth cranial nerve palsy caused by compression from a dolichoectatic basilar artery. *J Neuroophthalmol*. 2006; 26(3):190–1. [PubMed: 16966938]
19. Goldenberg-Cohen N, Miller NR. Noninvasive neuroimaging of basilar artery dolichoectasia in a patient with an isolated abducens nerve paresis. *Am J Ophthalmol*. 2004; 137(2):365–7. [PubMed: 14962438]
20. Ohtsuka K, Sone A, Igarashi Y, et al. Vascular compressive abducens nerve palsy disclosed by magnetic resonance imaging. *Am J Ophthalmol*. 1996; 122(3):416–9. [PubMed: 8794714]
21. Sandvand KA, Ringstad G, Kerty E. Periodic abducens nerve palsy in adults caused by neurovascular compression. *J Neurol Neurosurg Psychiatry*. 2008; 79(1):100–2. [PubMed: 17717022]
22. Narai H, Manabe Y, Deguchi K, et al. Isolated abducens nerve palsy caused by vascular compression. *Neurology*. 2000; 55(3):453–4. [PubMed: 10932293]
23. Liang C, Du Y, Lin X, et al. Anatomical features of the cisternal segment of the oculomotor nerve: neurovascular relationships and abnormal compression on magnetic resonance imaging. *J Neurosurg*. 2009; 111(6):1193–200. [PubMed: 19267538]
24. Hashimoto M, Ohtsuka K, Akiba H, Harada K. Vascular compression of the oculomotor nerve disclosed by thin-slice magnetic resonance imaging. *Am J Ophthalmol*. 1998; 125(6):881–2. [PubMed: 9645733]
25. Nakagawa H, Nakajima S, Nakajima Y, et al. Bilateral oculomotor nerve palsies due to posterior cerebral arterial compression relieved by microvascular decompression--case report. *Neurol Med Chir (Tokyo)*. 1991; 31(1):45–8. [PubMed: 1712923]
26. Seitz J, Held P, Strotzer M, et al. MR imaging of cranial nerve lesions using six different high-resolution T1- and T2(*)-weighted 3D and 2D sequences. *Acta Radiol*. 2002; 43(4):349–53. [PubMed: 12225473]
27. Kang NY, Demer JL. Comparison of orbital magnetic resonance imaging in duane syndrome and abducens palsy. *Am J Ophthalmol*. 2006; 142(5):827–34. [PubMed: 16989758]
28. Demer JL, Clark RA, Lim KH, Engle EC. Magnetic resonance imaging of innervational and extraocular muscle abnormalities in Duane-radial ray syndrome. *Invest Ophthalmol Vis Sci*. 2007; 48(12):5505–11. [PubMed: 18055799]
29. Ortube MC, Bhola R, Demer JL. Orbital magnetic resonance imaging of extraocular muscles in chronic progressive external ophthalmoplegia: specific diagnostic findings. *J Aapos*. 2006; 10(5):414–8. [PubMed: 17070475]
30. Demer JL, Clark RA, Engle EC. Magnetic resonance imaging evidence for widespread orbital dysinnervation in congenital fibrosis of extraocular muscles due to mutations in KIF21A. *Invest Ophthalmol Vis Sci*. 2005; 46(2):530–9. [PubMed: 15671279]

31. Yousry I, Camelio S, Wiesmann M, et al. Detailed magnetic resonance imaging anatomy of the cisternal segment of the abducent nerve: Dorello's canal and neurovascular relationships and landmarks. *J Neurosurg.* 1999; 91(2):276–83. [PubMed: 10433316]
32. Sweet WH. The treatment of trigeminal neuralgia (tic douloureux). *N Engl J Med.* 1986; 315(3): 174–7. [PubMed: 3523243]
33. Lustbader JM, Miller NR. Painless, pupil-sparing but otherwise complete oculomotor nerve paresis caused by basilar artery aneurysm. Case report. *Arch Ophthalmol.* 1988; 106(5):583–4. [PubMed: 3358719]
34. Soria E, Camell H, Dang H. Pupil-sparing oculomotor palsy caused by fusiform arteriosclerotic aneurysm of the basilar artery--a case report. *Angiology.* 1989; 40(10):921–7. [PubMed: 2802262]

Figure 1. Neurovascular compression in Case 1 of right oculomotor nerve (CN3) palsy. High-resolution heavily T2 weighted MRI in 0.8 mm thick contiguous oblique axial plane parallel to the optic chiasm showing cerebral vasculature and bilateral oculomotor nerves. Compared to the intact left CN3 (Top Left), more caudal images showed that the right CN3 is compressed by a prominent hairpin contour of the right posterior communicating (P-Com A) artery and posterior cerebral artery (PCA) (Top Right, Bottom Left, Bottom Right).

Figure 2. Neurovascular compression in Case 1 of right oculomotor nerve (CN3) palsy. High-resolution heavily T2 weighted MRI in 0.8 mm thick contiguous sagittal planes showing compression of the right CN3. The left CN3 was intact and had a diameter of 1.65 mm (Top Left, Top Right). The right CN3 was markedly compressed by the tortuous vessel and with a diameter of only 0.27 mm (Bottom Left, Bottom Right). (P-Com A: posterior communicating artery)

Figure 3. Cross-sectional areas of extraocular muscles, averaged in 5 contiguous image planes, in affected and unaffected orbits of three patients with unilateral neurovascular compression. *P < 0.05 (MR: medial rectus muscle, SR: superior rectus muscle, IR: inferior rectus muscle, IO: inferior oblique muscle, LR: lateral rectus muscle)

Figure 4. Neurovascular compression in Case 2 of left abducens nerve (CN6) palsy. High-resolution heavily T2 weighted MRI in 0.8 mm thick contiguous oblique axial plane showed an intact right CN6 and a left deviated basilar artery in contact with left CN6 (Top). MRA confirmed the finding of a tortuous and left deviated basilar artery (Bottom). (ICA: internal carotid artery, VA: vertebral artery)

Figure 5. Axial orbital MRI in Case 3 showing extraocular muscle atrophy caused by neurovascular compression. Right lateral rectus (LR) muscle is smaller than the left LR.

Figure 6.

Neurovascular compression in Case 3 of right abducens nerve (CN6) palsy. Heavily T2 weighted MRI in 0.8 mm planes. (Top) Oblique axial view shows intact left CN6 and deviated basilar artery that closely contacts the right CN6. (Bottom) Sagittal view shows neurovascular contact between the right CN6 and basilar artery. There were no space occupying lesions along the path of either CN6.