Introduction

Optometrists are often the first people to evaluate patients with intraorbital or intracranial lesions. Therefore, it is important to have at least a basic understanding of neuroimaging. Having an understanding of neuroimaging will allow one to communicate with other professionals, guide neuro-radiologists in deciding what tests are necessary, and understand radiology findings. It is important to recognize the limitations of specific scans so lesions are not missed due to improper interpretation. Additionally, your combined knowledge of the clinical data and neuroanatomy may aid in evaluating and finding conditions that would otherwise be missed on neuroimaging.

Illustrative Case

A 23-year-old Hispanic male was referred to the Neuro-ophthalmic Disease Service due to bilateral optic nerve edema. The patient had recently visited the emergency department for severe, daily headaches that were worsening over the last year. The bilateral disc edema seen on fundus exam and OCT (Figure 1) prompted us to order an MRI of the brain with contrast. This study was reported as unremarkable. I obtained the images to evaluate them further based on my suspected differential diagnosis. I found the MRI showed an empty sella turcica, tortuous optic nerves, and flattening of the posterior globes, consistent with increased intracranial pressure. Although the MRI findings were consistent with a diagnosis of idiopathic intracranial hypertension, the patient was thin and male, which is not the typical demographics associated with this diagnosis. Therefore, I evaluated the images again, looking more closely for other
causes of increased intracranial pressure. On careful inspection I noted an asymmetric appearance of the jugular veins (Figure 2). After finding this, I called the neuroradiologist who performed the initial read, and she agreed that this should be evaluated further and recommended an ultrasound as alternative testing after the patient refused to further evaluates the veins with MR venography due to cost.

Figure 1: Bilateral disc edema seen on fundus examination and OCT.

Figure 2: MRI showing occlusion of the left jugular vein (red arrow). Compare this to the normal jugular vein appearance on the right (blue arrow).
Introduction to Neuroimaging in Eye Care
Denise Goodwin OD FAAO, COPE Course # 40075

Discussion

This case emphasizes the importance of neuroimaging in the proper diagnosis of ophthalmic disorders. It is critical to evaluate your patient’s neuroimaging results personally based on what you know about the case. If the neuroimaging report that you are given does not make sense with the clinical picture, reevaluate the images yourself looking for your differential diagnoses. Additionally, the neuroradiologist is a valuable member of the medical team and is generally available to consult and aid in case management. In order to fully communicate with the neuroradiologist, both before and after the order, it is critical that optometrist have a basic understanding of neuroimaging.

The use of neuroimaging techniques to view cross sectional images of neural anatomy is a relatively recent advancement. Computerized tomography (CT) wasn’t used clinically until the early 1970’s. Magnetic resonance imaging (MRI) came into use shortly thereafter in the late 1970’s. Since that time, the quality and functionality of neuroimaging has improved drastically.

Neuroimaging is viewed on one of three planes (Figure 3). An axial cut is a horizontal slice that divides the body into caudal and rostral portions. A coronal cut involves vertical slices that divide the body into posterior and anterior portions. A sagittal cut refers to a vertical slice that divides the body into right and left sides.
Figure 3: Orientation of neuroimaging. A. Axial T2 MRI. B. Coronal FLAIR MRI. C. Sagittal T1 MRI.

Axial images are oriented as if you are standing at the feet and looking toward the head of an inclined person. Therefore, the right side of the body is on the left of the image and the left side of the body is on the right side of the image (Figure 3). With coronal images, the images are viewed as if you’re standing in front of the person looking at them. The result is the same as with the axial images: the person’s right side is on your left and their left is on your right (Figure 3).
Both CT and MRI technologies allow visualization the brain. The main difference between CT and MRI is that CT uses x-ray beams while MRI employs radio waves to form images. Both technologies can be adapted to look specifically at arteries and veins. Each of these technologies are discussed below.

-Computed Tomography

Computed tomography uses x-rays to measure relative densities of tissue (Figure 4). The x-ray beam is rotated around the patient. The data is acquired and then reconstructed by a computer to form the image. Material with increased density, such as metal and bone, will appear white on CT images. Less dense structures, such as air and cerebral spinal fluid, appear black on CT images. Tissue with high water content appears dark gray, and substances with a high protein concentration will be lighter gray. Brain tissue has a light gray color. The terms hyperdense and hypodense are relative terms used to describe structures that are, respectively, lighter or darker than brain tissue. Something with similar intensity to the brain is described as isodense to brain tissue.

Figure 4: Axial CT image without contrast. Bone is bright white (orange arrow), and air is black. Gray matter (blue arrow) is slightly lighter than white matter (yellow arrow). Calcification, which is bright on CT, occurs normally in the choroidal plexus (red arrow) and adult pineal gland (white arrow).
Intravenous contrast is used to improve visualization of areas where there is breakdown of the blood brain barrier. This can result from a tumor, infection, or inflammation. The contrast material used for CT scanning contains iodine. Because iodine is denser than brain, it will appear hyperdense to brain tissue. Contrast medium should not be used in patients with renal impairment or those allergic to iodine.

CT is the method of choice in emergent situations, when looking for fractures or other bone abnormalities, identifying acute intracranial hemorrhage, or evaluating sinus disease or lesions with calcification. With CT it is possible to see skull fractures with exquisite detail (Figure 5), and three-dimensional renderings (Figure 6) can be invaluable in determining proper treatment. Acute blood products will be hyperdense on CT compared to brain tissue (Figure 7). Compared to MRI, CT is faster, cheaper, and more readily available. However, it can be difficult to distinguish small areas of soft tissue pathology with CT, particularly in areas with lots of bone. In these cases, the use of MRI is more appropriate.

Figure 5: Coronal CT demonstrating a fracture of the right inferior orbit.
Introduction to Neuroimaging in Eye Care
Denise Goodwin OD FAAO, COPE Course # 40075

Figure 6: Three-dimensional CT following a motor vehicle accident. Multiple fractures are present, most notable surrounding the left orbit.

Figure 7: Axial CT without contrast demonstrating a hyperdense subdural hemorrhage (arrow) following a motor vehicle accident.

Radiation is the main concern with CT, particularly in children. CT should be avoided in children and pregnant women. Decreased slice thickness and increased number of slices cause increased radiation dose. With newer techniques acquisition time and radiation dose are reduced.
Magnetic Resonance Imaging

Magnetic resonance imaging provides better resolution of nervous system anatomy compared with a CT scan. Because of this, an MRI is more appropriate when looking at soft tissue disease, such as tumors, multiple sclerosis, or inflammation. MRI is particularly useful in evaluating lesions of the pituitary and parasellar regions. However, MRI is more expensive and time intensive. In addition, MRI is not as good as a CT in evaluating fresh hemorrhage or bone. MRI is contraindicated in those with metal fragments in body, a pacemaker, or cochlear implants. The magnetic field may cause ferromagnetic components to become dislodged causing injury to blood vessels, nerves, or organs. Additionally, metal implants conduct electrical current within the MRI and can cause burns. Finally, electrical devices, such as pacemakers, can malfunction due to interference from the MRI. Those with severe claustrophobia may need to be sedated prior to the MRI examination.

Magnetic resonance imaging exposes a person to a strong magnetic field causing hydrogen protons in the tissue to align. Radiofrequency coils then convey electromagnetic energy to the tissue changing the alignment of the protons. Following the radiofrequency pulse, the protons return to their original position causing a change in electrical signal. The speed with which the protons return to the original position (relaxation time) depends upon the density and mobility of the molecules in the tissue. For example, hydrogen in water relaxes at a different rate than hydrogen in gray matter. This difference influences the contrast between various tissue in the MR image.
Manipulating the MRI scan parameters alters the proton relaxation time and, therefore, the appearance of tissue images. The most common sequences are T1-weighted and T2-weighted images, but other types of weightings are possible. T1 images have increased contrast between gray and white matter, making them especially valuable when looking at anatomical detail. Fluid, such as cerebral spinal fluid (CSF) and vitreous, are dark on T1 scans (Figure 8A). These fluids are bright on T2 scans (Figure 8B). Because fluid is bright on T2 scans, pathology is generally more evident on T2 scans compared to T1 scans.

Figure 8: T1 axial MRI (A) and T2 axial MRI (B). Note that areas with pooled fluid, such as the cerebral spinal fluid in the fourth ventricle (red arrows) and the vitreous (blue arrows), are dark on a T1 MRI and bright on a T2 MRI.

Fluid attenuated inversion recovery (FLAIR) images are a type of T2 image in which the signal from free water (as seen in CSF and vitreous) is suppressed. As with other T2 images, fluid found within pathologic tissue, such as that associated with edema, remains bright on FLAIR images making this an ideal scan to look for areas of edema of neural tissue. FLAIR images are
particularly useful when looking for plaques associated with multiple sclerosis that are near the ventricles. The plaques show up on the T2 images, but they are much more obvious on FLAIR images (Figure 9). Also, subtler plaques surrounding the ventricles can be missed with T2 images since the CSF is bright in the ventricles and the plaques are bright directly adjacent to the ventricles. It is easy to mistake the plaques as being a continuation of the ventricles themselves.

Figure 9: Axial T2 MRI (A) and axial FLAIR image (B) of the same person. Note how much easier it is to differentiate the lesions near the lateral ventricles.

Fatty tissue, such as that seen within the orbit, is bright on T1 MRI scans. Similar to how the signal from free water is suppressed with FLAIR images, the bright signal created from fat can be attenuated by manipulating MRI parameters. Fat suppression can be particularly useful when imaging the orbit with a contrast enhanced T1 MRI because it eliminates the bright signal from the normal orbital fat so you can better visualize pathology that also has a bright signal (Figure 10).
Introduction to Neuroimaging in Eye Care
Denise Goodwin OD FAAO, COPE Course # 40075

Figure 10: Orbital MRI with contrast, but without (A) and with (B) fat suppression demonstrating showing right optic neuritis. Without fat suppression the optic neuritis is difficult to see. With fat suppression the optic neuritis involving the right nerve is much more obvious.

A.  

Diffusion weighted imaging (DWI) highlights areas of reduced water movement (Figure 11). These scans are particularly useful when evaluating for ischemia but are also helpful in differentiating various lesions. Normally water is able to diffuse freely between cells. With ischemia, cells swell due to dysfunction of the sodium/potassium pump. This swelling decreases space between the cells which then restricts how easily water can diffuse around the cells. An infarction can be seen within minutes on DWI.

Figure 11: DWI scan showing ischemia in the right occipital lobe.
The terms isointense, hyperintense, and hypointense are used are to describe the relative brightness of MR images. The intensity of MR images depends on the presence of hydrogen protons. Because air (e.g. within sinuses) and calcified bone lack water, they appear hypointense to brain tissue on MR images. Relative appearances of common tissues are highlighted in Table 1. Larger blood vessels will appear dark on MRI. This occurs because the stimulated protons in flowing blood leave the area before the image can be obtained.

Table 1: Tissue appearance on T1 and T2 weighted images.

<table>
<thead>
<tr>
<th>Tissue</th>
<th>T1</th>
<th>T2</th>
</tr>
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<tbody>
<tr>
<td>CSF</td>
<td>dark</td>
<td>bright</td>
</tr>
<tr>
<td>Air</td>
<td>dark</td>
<td>dark</td>
</tr>
<tr>
<td>Dense bone</td>
<td>dark</td>
<td>dark</td>
</tr>
<tr>
<td>Calcium</td>
<td>dark</td>
<td>dark</td>
</tr>
<tr>
<td>White matter</td>
<td>Light gray</td>
<td>Darker gray</td>
</tr>
<tr>
<td>Gray matter</td>
<td>Dark gray</td>
<td>Lighter gray</td>
</tr>
<tr>
<td>Fat</td>
<td>bright</td>
<td>bright</td>
</tr>
<tr>
<td>Edema</td>
<td>dark</td>
<td>bright</td>
</tr>
<tr>
<td>Flowing blood</td>
<td>dark</td>
<td>dark</td>
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</tbody>
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Similar to CT, the use of a contrast agent with MRI highlights areas of breakdown of the blood-brain barrier or increased vascularity. This can improve the contrast between normal and pathological tissue (Figure 12). Gadolinium is the intravenous contrast agent used in MR imaging. This is generally well tolerated. However, those with severe kidney disease can
Introduction to Neuroimaging in Eye Care
Denise Goodwin OD FAAO, COPE Course # 40075

develop nephrogenic systemic fibrosis, a rare but serious complication of gadolinium-based contrast agents. Although less likely compared to iodinated contrast, anaphylaxis can occur. Contrast agents should be avoided during pregnancy.

Figure 12: Sagittal T1 MRI without (A) and with (B) contrast in a patient with a pituitary macroadenoma. Note how much more evident the pituitary adenoma appears following the administration of contrast.

A.  

B.  

-Neuroangiography

Three-dimensional reconstructions of the blood vessels can be obtained non-invasively using either MR or CT technology. CT angiography (CTA) or MR angiography (MRA) is helpful in screening for carotid stenosis, aneurysm, arteriovenous fistula, or arteriovenous malformation (Figure 13). CT venography (CTV) or MR venography (MRV) can be helpful in determining the presence of cerebral sinus thrombosis, which puts the patient at significant risk for stroke and can cause papilledema. Conventional catheter angiography may still be necessary if the suspicion for a vascular lesion is high despite normal CTA or MRA. However, due to the risks associated with arterial catheterization, as well as the improved sensitivity of CTA and MRA, conventional angiography is rarely used as a first-line modality.
Figure 13: CTA of a patient with an internal carotid artery aneurysm causing severe headache and reduced ocular motility (A). MRA of a patient with an arteriovenous malformation causing papilledema (B).

CTA is the study of choice for emergent neurovascular conditions. Here, the contrast agent is injected intravenously. Varying the time between the contrast injection and the start of the scan will allow imaging of either the arteries or veins.

MRA can be performed either with or without the injection of contrast material (gadolinium). MRA without contrast differentiates between flowing blood and stationary tissue. This method is useful when there is a concern with the use of gadolinium, including pregnancy or kidney dysfunction. When contrast dye is used, an image of the blood vessel lumen is created directly. Particularly with a 3 Tesla magnet, this method allows improved visibility of medium and small arteries. Additionally, contrast enhanced MRA has shorter acquisition times and is less prone to motion and flow artifacts compared to non-contrast MRA techniques.
-Ordering Neuroimaging

Before sending a patient for neuroimaging, assure that the patient’s condition is neurologic. These tests are expensive for the patient and healthcare system, and they are not without risk to the patient. Some ophthalmic conditions that may require neuroimaging include optic nerve edema, ophthalmoplegia, nystagmus, proptosis, vision loss associated with a relative afferent pupillary defect not explained with a careful ocular health examination, bilateral visual field loss that respects the vertical midline, and Horner syndrome.

After determining that the condition is neurologic, use your clinical data to determine the anatomical location of the lesion, as well as likely diagnoses. As a general rule, if you are able to localize the lesion anatomically prior to ordering neuroimaging, you are more likely to find the causative lesion. The localization and differential diagnoses will help determine the most appropriate scan, the area to be evaluated, and whether contrast should be used. If you are trying to visualize bone lesions, acute blood, or calcium deposits, a CT is generally the most appropriate scan to order. Most other conditions we deal with in eye care will require an MRI with contrast. However, some conditions, such as thyroid eye disease, do not require contrast. If a painful post-ganglionic Horner syndrome is suspected CT or MR angiography, with particularly emphasis on the internal carotid artery, should be performed. Consider an MRI of the orbits if you are looking for a lesion involving the anterior visual pathway. Pathology involving the optic radiations, occipital lobe, or cerebellum requires an MRI of the brain. Because of the increased vascularity of many of the lesions that affect the visual system, contrast is generally necessary. Be sure to specify that you want fat suppression with your contrast enhanced orbital MRI if you suspect an orbital lesion.
Communicate with the neuroimaging center the type of scan you want, as well as the localization of the suspected lesion and the differential diagnoses. The more information the neuroradiologist has, the more likely they are to find the abnormality. The imaging center can generally provide you with a standard order form. Otherwise, minimally, you should include the scan you need performed, whether contrast should be administered, and the condition(s) in which you are ruling out. Generally your staff will need to get prior authorization from the insurance company.

Once you receive the results from the neuroradiologist, assure that the information makes sense with your clinical data. If the results don’t support your suspected diagnosis, review the original images based on your clinical data. Keep in mind that no one knows the case as well as you, and this gives you the ability to understand the images. Don’t hesitate to communicate with the neuroradiologist if there is a mismatch between the clinical findings and the imaging report.

Conclusion

A basic understanding of neuroimaging techniques will help the optometrist order appropriate testing. Both CT and MRI have a place within eye care depending on the suspected diagnosis. Variation of each method may be used depending on the clinical situation. Despite imaging technology, it is critical that the clinician use their knowledge of neuroanatomy to accurately localize the process and determine likely differential diagnoses. Detailed communication with the neuroradiologist will aid in obtaining the most accurate and timely diagnosis.