Oculoplastic Imaging Update

Update on imaging techniques in oculoplastics

Altug Cetinkaya, MD*

Abstract

Imaging is a beneficial aid to the oculoplastic surgeon especially in orbital and lacrimal disorders when the pathology is not visible from outside. It is a powerful tool that may be benefited in not only diagnosis but also management and follow-up. The most common imaging modalities required are CT and MRI, with CT being more frequently ordered by oculoplastic surgeons. Improvements in technology enabled the acquisition times to shorten incredibly. Radiologists can now obtain images with superb resolution, and isolate the site and tissue of interest from other structures with special techniques. Better contrast agents and 3D imaging capabilities make complicated cases easier to identify. Color Doppler imaging is becoming more popular both for research and clinical purposes. Magnetic resonance angiography (MRA) added so much to the vascular system imaging recently. Although angiography is still the gold standard, new software and techniques rendered MRA as valuable as angiography in most circumstances. Stereotactic navigation, although in use for a long time, recently became the focus of interest for the oculoplastic surgeon especially in orbital decompressions. Improvements in radiology and nuclear medicine techniques of lacrimal drainage system imaging provided more detailed analysis of the system.

Keywords: Oculoplastic surgery, Imaging

Introduction

Imaging techniques do not establish the diagnosis alone, they are usually complementary to a detailed oculoplastic examination. However, when needed, they provide great benefit to the physician. Imaging is required when the exact diagnosis cannot be established by history taking and clinical examination or to follow-up certain disorders that are not visible to the physician’s eyes. Orbital disorders including foreign bodies, tumors, infectious or inflammatory diseases, thyroid orbitopathy and vascular abnormalities may require imaging. The most common modalities used to view the orbita are computerized tomography (CT) and magnetic resonance imaging (MRI). In certain disorders such as cavernous sinus vascular diseases, conventional angiography is still the gold standard. However, color Doppler ultrasonography, magnetic resonance angiography (MRA) and venography (MRV) are expanding their field of use recently. In lacrimal disorders, CT, MRI, dacryocystography (DCG), dacryoscintigraphy (DScG) and their various modalities are used.

The oculoplastic surgeon needs to keep himself updated about the new imaging techniques to get the best possible aid for the patient and interaction between the surgeon and the radiologist will usually be fruitful. In this review, commonly used oculoplastic imaging techniques will be detailed, however focus will be directed to the recent reports in the literature regarding advances and new techniques.

Computerized tomography and new developments

The basics of CT technology depend on the principles described by the German physicist Rontgen in 1885.1 It found widespread use in the diagnosis of orbital diseases since
1980s, and with the availability of new computer software and the fast contrast injection techniques, it is still very popular among oculoplastic surgeons. Nowadays, CT is faster than ever. Taking of one axial slice lasts less than 4 s with the spiral technique providing as thin as 0.6 mm cuts with 0.4 mm resolution capability. Thus, loss of image quality during reconstruction with the old techniques is now minimized. Faster acquisition times also provided better safety by reducing the radiation exposure to the patient. Fractures, hemorrhage or foreign bodies in case of trauma do not require contrast agents, however, these agents are helpful in infectious disorders and orbital or eyelid masses. CT with contrast is the preferred imaging modality in the diagnosis of idiopathic orbital inflammation, enhancing the focal or diffuse mass.\textsuperscript{3} Lacrimal gland and extraocular muscles retain the contrast agent very well. Contrast is especially useful in vascular lesions including varices, lymphangiomas, hemangiomas and arterio-venous malformations. The susceptibility of dural sheets to contrast -where the optic nerve is not- makes it useful in the diagnosis of meningoomas and gliomas of optic nerve. Contrast helps demonstrate thrombosis and discriminate solid-cystic lesions. It is important to question the patient for iodine allergy, renal insufficiency and metformin use (diabetes) prior to the use of contrast.

Availability of 3-D reconstructions of CT images were limited in 1970s, however despite the improved software and easier access with less cost, it did not find widespread use in the field of oculoplastics. However, in complex fractures and growing orbito-cranial masses or disorders such as fibrous dysplasia or neurofibromatosis that obliterate the visualization of the rim, 3-D reconstruction may help the decision making process. Wang et al. used helical computerized tomography to evaluate the orbital development in children with microphthalmia.\textsuperscript{3} They imported the outputs to a computer-aided design system to produce 3-D reconstructions, which helped them provide clinical evidence for the management, timing and efficacy of intervention.

### Indications and benefits of CT

The variable conductance of orbital tissues to X-rays makes CT ideal in orbital imaging. The intraconal fat itself appears hypointense on CT, thus providing natural contrast difference with the surrounding structures. The globe and extracranial muscles are imaged very well on CT, as well as the section of the optic nerve before the optic canal, lacrimal gland and vascular structures. High density bone appearance enables excellent viewing in cases of trauma, metallic foreign bodies and calcification. The lytic effects of a tumor on bone is best appreciated by CT (Fig. 1).

In the case of proptosis, CT is more frequently ordered compared to MRI. One reason may be the cheaper price. When the clinical diagnosis suggests thyroid related eye disorder, there usually is no need for confirmatory imaging. However, when in doubt, CT may be preferred to rule out inflammatory and infectious diseases and masses, especially with contrast administration. In the case of orbital infections, CT is the investigative procedure of choice.\textsuperscript{3} One great advantage of CT is the ability to view the sinuses in relation to orbita (Fig. 2). Trauma including the fractures and foreign bodies require CT as the choice of initial imaging modality.\textsuperscript{5} In orbital tumors, CT helps identify the shape, type, size, dimensions, capsulation, calcification and relations to bony structures of the tumor. However when the area involves orbital apex and chiasma, CT is overruled by MRI.\textsuperscript{5}

### MRI and new developments

In the technique of MRI, the patient is placed in a magnetic field so that the protons (hydrogen atoms) in tissues become parallel to the axis of the magnetic field. Then, these tissues are exposed to radio waves, which will resonate the protons. When the signal stops, protons release the gained energy to get back to their original position. The receiver collects the radiated energy from different tissues and records it in gray scale accordingly. As in BT, axial and coronal sections are obtained. In the evaluation of the optic nerve, additional sagittal sections are valuable.

In MRI technique, T1 and T2 weighted images are obtained by adjusting the parameters to make inter-tissue contrast differences more distinct. Vitreus is dark in T1 images and white in T2. In case of edema, T2 images get brighter. With fast blood flow, protons cannot be detected by the sensors because they resonate too fast, producing signal void, and the section appears dark. As a simple reminder, T1 weighted images are used to show normal anatomy, and pathologic conditions are better evaluated on T2 weighted images.

There has been a significant improvement in MRI technique after the 2000s, including surface coil technology, signal-to-noise ratio (SNR), and fat signal suppression techniques.\textsuperscript{6} Smaller surface coils are placed just above the imaged field to increase the signal power and decrease the noise. This technique provides better image detail, however the depth of penetration in this technique is limited. The noise is generated from inconsistencies in the magnetic fields, heat in the gradient coils, irregularities in the amplification systems and patient movements. Surface coil technology has advanced greatly so that excellent orbital anatomic details are now acquired with good SNR even when thin slices are obtained.\textsuperscript{5} Fat suppression is required to mask the bright signal from fat in order to better observe contrast enhancing tissues. The common techniques used for fat suppression are chemical shift imaging and short T1 inversion recovery (STIR) sequences.\textsuperscript{5}

Intravenous gadolinium contrast is preferred in some conditions. Gadolinium stays inside the vessels unless there is a barrier problem. When the blood–brain barrier is damaged, it leaks into the interstitial space and increases signal intensity. Unlike the contrast materials used with CT, chelated
Indications and benefits of MRI

Intra-ocular tumors, optic nerve lesions, orbital apex lesions, orbital lesions with intra-cranial extension are the primary indications of MRI (Fig. 3). Non-metallic foreign bodies are better visualized on MRI compared to CT. When optic nerve avulsion or edema/hemorrhage within the optic nerve sheath is suspected, high Tesla MRI sections will be very helpful. It is also easier to diagnose vascular tumors and heterogenous lesions on MRI compared to CT. In case of sinus neoplasms extending toward the orbit, MRI can differentiate mucus (bright) from tumor (dark).

The biggest advantage of MRI is the lack of ionizing radiation. It is not affected by the artifacts associated with dental fillings as in CT scan. However MRI is more prone to motion artifacts (ocular and eyelid movements). Although the resolution in the orbit is worse compared to CT, it is superior in intra-ocular and intra-cranial lesions due to better tissue contrast. It is the ideal technique at the orbito-cranial junction including orbital apex, optic canal and the cavernous sinus, since the bony canal does not obscure the soft tissue identification. Zanni et al. evaluated the sensitivity of a new modality that is widely used in staging of non-Hodgkin lymphoma (fluorine 18 deoxyglucose positron emission tomography) in staging of the ocular adnexal lymphomas, and declared that MRI was superior to this technique in detecting the ophthalmological lymphoma.

CT versus MRI

CT is still more preferred among oculoplastic surgeon for many reasons. It provides detailed anatomical information about the shape, size and location of the orbital mass and its relation to the adjacent bony and peri-orbital structures. Wu et al conducted a study to determine the indications for ordering orbital imaging and the indications for ordering CT versus MRI by oculoplastic surgeons. The researchers determined that CT was ordered more frequently and the most common indication for CT scan was thyroid disease, followed by orbital tumors and inflammatory disease. The most common indication for MRI scan was orbital tumors, followed by inflammatory disease and thyroid disease.

MRI cannot be used in patients with cardiac pacemakers, cochlear implants, intracranial aneurysm clips, metallic implants or foreign bodies and patients on ventilators or cardiac monitors. It is still more expensive and the test takes longer than CT, therefore it is harder to perform in children and claustrophobic patients. However, MRI provides more detail about the soft tissue and is superior to CT in evaluating the tumors of the cavernous sinus and the skull base, including optic nerve tumors with intracranial extension. It is the modality of choice in the orbital lesions that are related to central nervous system pathology.
The SNI system is based on obtaining high resolution images of the surgical site preoperatively and defining them to the cameras with position sensors in the operative field so that exact position of the surgical instruments in relation to critical anatomic structures can be viewed on the screen during surgery. The system has been used widely in the fields of neurosurgery and ENT and there is a growing interest in this system in oculoplastics field especially for orbital decompressions and deep orbital tumours. The system may also be helpful in localizing intraorbital foreign bodies, and guiding the surgical planes that are distorted by previous surgery or the disease process.

Millar and Moloof reported the application of SNI in the maximal debulking of the lateral wall in a series of seven patients with thyroid-associated orbitopathy and concluded that it improved anatomic localization and precision during orbital decompression, increasing confidence, and reducing surgical stress. Collyer found this technique especially helpful in secondary orbital reconstruction, but warned about how it may be uneasy to translate this plan into surgical reality.

Conventional angiography

Angiography was once the imaging modality of choice for all vascular conditions until the developments in CT, MRI and color Doppler. Most orbital vascular abnormalities can now be evaluated with non-invasive techniques. Carotico-cavernous fistula can be diagnosed with CT angiography in most cases. Time-of-flight MRA – based on the phenomenon of flow-rated enhancement of spinning protons that give a higher signal than the surrounding stationary protons – can be used to produce a 3-D image of the vessels analogous to conventional MRI. Conventional angiography is still the gold standard in the evaluation of blood flow dynamics and is frequently used for interventional purposes. It is needed when no structural pathology is identified by other non-invasive methods or when further characterization is necessary.

During angiography, the contrast that is given through the vessel is monitored and information about the vascular system is obtained. Orbital venography may be used to assess varices and vascular masses by injecting contrast through the frontal vein. Carotid arteriography is commonly used in the diagnosis and management of carotico-cavernous fistula and arterio-venous malformations (Fig. 4). The passage of contrast from the internal carotis into the cavernous sinus is diagnostic, supported by the distension of the superior ophthalmic vein. Simultaneously, the fistula may be occluded using balloon or coils.

Angiography is also valuable in the differential diagnosis of vascular tumors that may look identical on other imaging modalities. For instance, cavernous hemangioma may be differentiated from hemangiopericytoma, since the former has no feeders and the latter is rich of vascular supply.

Color Doppler imaging (CDI)

This technique is used to determine the vascular flow characteristics by having the patient look up and gently moving the probe on patient’s closed eyelid. The probe resonates at 5–10 Hz similar to the standard USG, and the average of three measurements are obtained to assess the flow within the vascular structure. The flow is coded in two colors; red represents flow away from the probe and blue represents flow toward the probe. Orbital vessels including the ophthalmic artery, central retinal artery and vein, short posterior ciliary vessels, superior ophthalmic vein and vortex veins may be examined with CDI. The vascular flow rate is measured using this technique, however the volume or the vessel circumference cannot be accurately analyzed. The biggest
disadvantage of this technique is its inability to assess small vessels and slow flow accurately.

The benefits of CDI in retinal diseases, including the evaluation of central retinal artery and vein obstruction, ischemic optic neuropathy and ocular ischemic syndrome have been studied. It was also found relatively accurate as a non-invasive test in the evaluation of temporal arteritis. CDI helps the diagnosis of orbital varices and carotid-cavernous fistula by showing the reversal of flow after Valsalva maneuver. The success of fistula closure may be followed by CDI.

CDI was used to assess Graves ophthalmopathy (GO) activity and response to management with corticosteroids. Monteiro et al. analyzed the superior ophthalmic vein flow in GO patients and controls, and detected significantly reduced flow during the congestive phase, which returned to normal following treatment. In another study, retrobulbar vessels of inactive GO patients were evaluated before and after decompression surgery using CDI. The resistance index (RI) of central retinal artery and ophthalmic artery was found higher in GO patients compared to controls.

Touzamet et al. used CDI in monitoring the response of orbital/eyelid capillary hemangiomas to systemic propranolol in eight children. They noted regression in the tumors with an increase in RI of blood vessels.

Another study suggested combined USG and CDI to be the initial imaging modality in pediatric patients with suspected periocular and orbital capillary hemangioma. The procedure has the advantage of not requiring sedation or anesthesia in children and it may be used in the monitoring of response to treatment.

Magnetic resonance angiography (MRA) and venography (MRV)

The vessels are not clearly demonstrated with routine MRI techniques, because the fast blood flow prevents the protons from producing signals. To better delineate the vascular structure in a tumor, or to search for an underlying aneurysm or vascular pathology for instance in Horner’s syndrome or CNIII paralysis, MRA is extremely helpful (Fig. 5). An MRA provides images of blood vessels by using a magnetic field and pulses of radio wave energy with or without contrast. When the venous system pathology is suspected, images generated by blood flowing through the veins are extracted by a special computer software. This technique is called MRV.

Ramey et al. evaluated the usefulness of orbital and facial TRICKS (Time-Resolved Imaging of Contrast KineticS) MRA in complex orbital vascular tumors. The TRICKS protocol allows measurement of specific tumor characteristics including lesion morphology, vascular anatomy, flow dynamics within the lesion, rapidity and sequential nature of contrast enhancement, and lesion distensibility. The authors found the technique very helpful in selected patients with clinical diagnostic uncertainty and in those patients requiring high-resolution vascular mapping for management planning.

Jackson et al. reviewed the cerebral sinovenous thrombosis in children and found that the combination of MRI and MRV increased the sensitivity of diagnosis to 100%. In patients who are uncooperative or at risk of prolonged testing (neonates, unstable patients), CT venography may be done as it is readily available and fast. We recently reported a case of superior ophthalmic vein thrombosis in an infant who was admitted for recurrent ptosis and proptosis attacks (article in press-OPRS). Patient’s initial MRI showed a large mass including the medial rectus muscle, however additional information gathered from MRV interpreted together with MRI helped establish the diagnosis (Figs. 6A–6C).

Imaging the lacrimal drainage system

There is no single test that can reliably show the anatomic obstruction site and demonstrate the physiological basis of epiphora in all cases, therefore the physician needs to know the details of all techniques used, and demand imaging on the basis of required information individually. In certain cases, a combination of techniques may be required.

The lacrimal drainage system can be visualized using CT, MRI, dacryocystography (DCG), and dacryosцинтigraphy (DScG). However, these techniques are seldom required when appropriate history taking and oculoplastic examination is performed. In a survey conducted among the ASOPRS members, <5% of the respondents stated that they acquire any type of lacrimal imaging for the majority of their patients with epiphora thought due to lacrimal obstruction. When lacrimal imaging was used, CT was the most common technique overall, however DCG was preferred when confirming the site or type of obstruction.

The CT scans are usually needed in cases of trauma, surgery or suspected tumor. In post-traumatic epiphora, a CT scan with 1 mm cuts will be very helpful to show a possible bony fragment along the medial orbital wall toward the fossa pushing against the lacrimal sac or nasolacrimal duct. Either CT or MRI may be used to show masses extending out from
the lacrimal sac, or from the orbita or sinuses toward the sac. Newborn mucocele differential diagnosis requires CT or MRI evaluation, especially to rule out meningocele. In these patients, CT will reveal the dilated duct and the bony changes, as well as the changes in the concha inside the nose. New technologies described above, including the spiral CT and 3-D reconstructions may be helpful in partial obstructions and trauma cases. Yazici et al. reported the evaluation of congenital dacryocystocele with prenatal MRI and found it superior to prenatal sonography. Interestingly, half of the patients were asymptomatic after birth.\textsuperscript{29}

CT with contrast can provide significant details about the relation between the lacrimal system and surrounding soft tissue and bony structures. Vascular tumors will enhance with contrast. However, when soft tissue details and avoidance of radiation are more important, MRI with or without contrast may be preferred. Gadolinium 1:100 dilution may be used as a drop every minute for 5 min as contrast agent to provide superior diagnostic capabilities. Furthermore, new MRI modifications as described above may be used to diagnose difficult cases.

In the classical technique of DCG, the lower punctum is dilated and a small catheter is inserted and taped into position under topical anesthesia. Through the catheter in place, radiopaque contrast material is irrigated into the canaliculus, and X-ray images are taken. Conventional DCG required lipiodol injections into the lacrimal sac and imaging the system with X-rays before injection and at 15 and 30 min of injection to show blockage level and dacryoliths, tumors, diverticulas. However, lipiodol is no longer a preferred contrast agent due to its side effects.

Although DCG is considered the gold standard for imaging the distally blocked nasolacrimal system, it does not allow visualization of the surrounding soft tissues or the bony structure. To evaluate these structures, CT or MRI may be combined to DCG (Fig. 7). MR DCG is simply done by instilling gadolinium chelate into the lower fornix. Coskun and colleagues found MR DCG results comparable with conventional DCG and suggested that the easier and repeatable

![Figure 6B. Non-contrast coronal MRI. (A) T1-weighted and (B) postcontrast coronal fat-suppressed T1-weighted images. Right SOV is enlarged (white arrows) and shows markedly diminished opacification compared to the left SOV (black arrows). Notice the thickening and mild enhancement of medial rectii and superior oblique muscles (small white arrows).](image)

![Figure 6C. The luminal irregularity (A, black arrows) suggesting SOV thrombosis is well-defined on sagittal MR venography. The normal left SOV (B, black arrows) shows prominent luminal enhancement after contrast administration, which is lacking on the right side.](image)

![Figure 7. 3-D CT dacryocystogram. Image taken and reconstructed after irrigation of the left lower canaliculus with contrast. Detailed anatomy is visible and contrast accumulating in the sac points to the site of obstruction in the distal nasolacrimal duct.](image)
MR DCG may be preferred since it requires no cannulation and ionizing radiation.\textsuperscript{30} Distention DCG was described by Iba and Hanafee to show the lacrimal system in distended state after the pressure injection of 0.5–1.0 mL of contrast material.\textsuperscript{31} Although it clearly demonstrates the fistulae, diverticula, abnormal canaliculi and the presence of stones and sac tumors, it does not reveal sac and duct dimensions under normal physiologic conditions.

Digital subtraction DCG is a technique that subtrahs the bone from the images.\textsuperscript{32} A scout film is taken before injecting contrast material and is used to produce bone-free images of the DCG. When the images are magnified it is called macroadacryocystography. Fluoroscopically controlled angiographic equipment and an image intensifier may be added to the method to obtain more details.

In the dynamic MR DCG technique, saline-lidocaine is injected through cannulation of the canalicular system while the MRI images are taken. Dynamic MR DCG was shown to be comparable with conventional DCG for the evaluation of nasolacrimal drainage system prior to surgery.\textsuperscript{33}

Dacryoscintigraphy (DScG) is a non-invasive, simple technique that does not require any added expertise. Scintigraphy may be helpful in patients with epiphora despite the patency of the system to irrigation and suspected of having punctal occlusion or lacrimal pump failure. In these patients, DScG is the only modality that can support the subjective diagnosis. On the other hand, because it is a physiologic test, the anatomical details are limited compared to DCG and it provides no benefit when the nasolacrimal duct obstruction is complete.\textsuperscript{34}

The technique of scintigraphy is variable, however usually radio-isotope (Tc-99 m) is instilled into the fornix by a micro-pipette and the passage is recorded by a gamma camera. The patient is advised to blink normally and the nasolacrimal system is imaged every 10 s for the first 2–3 min, and then late images are taken every 5 min for a total of 20 min. It is especially helpful in patients with facial paralysis, punctal stenosis and common canalicular obstructions. It provides visualization of both right and left systems simultaneously, however the anatomical details are not visualized. Although considered to be safe, Ayati et al. reported a young patient who had undergone DScG with Tc-99 m pertechnetate exhibiting uptake of radioactive material in thyroid.\textsuperscript{35}

Many studies searched for the best uses of DScG. Palaniswamy and Subramanyam studied postoperative symptomatic DCR patients with scintigraphy and found very significant concordance between clinical symptoms and imaging findings.\textsuperscript{35} Chung et al. reported that DScG is valuable for classifying the obstruction types to predict the results of silicone tube insertion.\textsuperscript{36}

Dacryoscintigraphy since 1980s was suggested as the best method for measuring the canalicular tear drainage dynamics, however a recent national survey revealed that CT DCG is preferred for this indication by the many oculoplastic surgeons.\textsuperscript{38,37}

Peter and Pearson compared DSG and DScG in patients with epiphora and apparent outflow obstruction but patent lacrimal systems.\textsuperscript{36} They found that scintigraphy is a more sensitive test that correlated more closely with the clinical examination and it often detected more as a proximal and severe obstruction.

In summary, what you get out of lacrimal system imaging depends on what you are looking to get. The surgeon needs to know about the details of special techniques to diagnose and manage certain rare cases when imaging is needed on top of clinical examination.

References


