

Oculoplastic Imaging Update

Computed tomography of the orbit – A review and an update

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Abstract

Computed tomography (CT) and magnetic resonance imaging (MRI) of the orbit have been competing for the hearts and minds of health care providers for well over 2 decades. While several drawbacks pertaining to CT have been outlined since the introduction of MRI, CT remains the standard diagnostic test for evaluating cross-sectional, 2 or 3-dimensional images of the body.

Keywords: CT orbit, MRI orbit, Basics CT physics, Normal radiologic anatomy of the orbit, CT versus MRI of the orbit

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Introduction

When a patient presents to the ophthalmologist with symptoms related to orbital pathology, a series of diagnostic examinations of ever-increasing complexity should be ordered starting from the obviously beneficial but least complex and ending with the more costly and most complex. Unfortunately there is confusion among general ophthalmologists about the indications for ordering either a CT or an MRI, and the general impression among our peers in ophthalmology is that MRI offers superior visualization of orbital contents and thus is the most common diagnostic modality ordered by eye care professionals and mostly for all the wrong indications.

In short, MRI is abused, instead of being placed near the top of the radiology chain; it is placed right at the bottom. This monograph will attempt to rectify this error and will also summarize the basics, as well as the recent advances in CT technology. The normal radiologic anatomy of the orbit will also be discussed. Some representative clinical examples will be shown with the emphasis on radiologically identical lesions. Finally, we will attempt to answer the quintessential question: When should a CT be ordered and when should an MRI be the primary radiologic exam ordered by the physician?

Historical background

Prior to 1895 when Wilhelm Conrad Roentgen introduced X-ray roentgenography, diagnosis of orbital diseases was simply a guessing game with one of two options only; a tumor or an abscess.¹ While X-ray was grasped immediately by the medical community, and in fact the first medical image recorded was of the hand of Wilhelm Roentgen's wife himself,² the ophthalmic community was slow to realize the importance of X-ray as a diagnostic modality and the first real uses were not introduced until 1912, 17 years after its introduction to the rest of the medical community.³

Introduction to the physics of CT

Computed tomography is a technology using X-ray radiation beams and an array of radiation detectors that surround the part being examined. Simply put, CT works by 2 principles. The first is that images are acquired by rapid rotation of the X-ray tube 360° around the patient, the radiation is then measured by a ring of sensitive radiation detectors located on the gantry around the patient. The final image can be reconstructed in a 2-D or 3-D manner from multiple X-ray projections. The second principle is that CT works by

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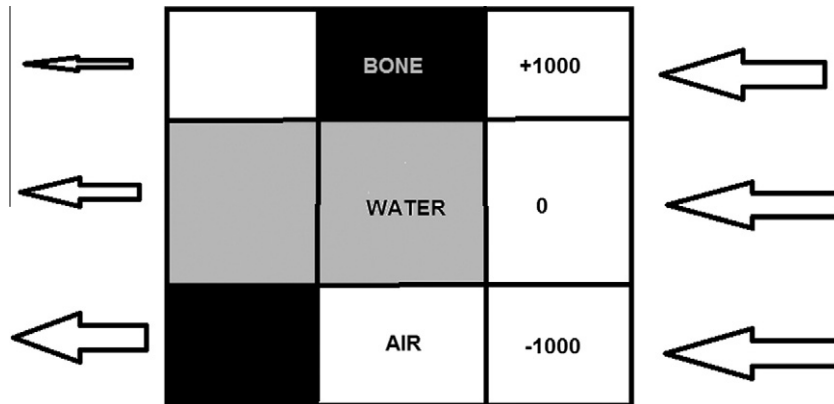


Figure 1. A simplified 2-dimensional illustration explaining the basic concept of CT. As the X-ray passes through the body, the rays are attenuated according to the tissue density they pass through. By convention, and according to the degree of attenuation, each tissue receives a specific Hounsfield unit. Water is given the neutral value of zero, air is given a value of -1000 , and bone $+1000$. (Modified with permission from Diagnostic atlas of orbital diseases, WB Saunders and Company 2000; ISBN: 0721682731, 9780721682730).

measurement of different absorption values of tissues after their exposure to X-ray, because as the X-ray beam traverses the body it becomes attenuated or weakened depending on the density of the tissues it passes through. These absorption values are converted into gray-scale units by preset formulas (Fig. 1), and the reconstructed image is shown on a screen or reviewed on PACS [Picture Archiving and Communication system] or less commonly printed on film which is composed mainly of silver halide and silver bromide salts.⁴⁻⁷ If a simple explanation could be used, CT detects the ability of tissues to block the X-ray beam as it passes through them. Figs. 1 and 2 show simplified illustrations of the basics of CT physics.

While earlier CT units acquired images sequentially one single image at a time, advances during the 1980s resulted in the introduction of the spiral CT which acquires data in a continuous fashion. The X-ray tube rotates in one direction around the patient in a helical manner, while the table on which the patient is lying is moved in one direction only; to and fro. This dramatically reduces scanning times as larger areas of the body can be scanned at once which is a big advantage in children. This is analogous to using a fast shutter speed SLR camera to capture moving subjects like kids playing soccer to 'freeze' the action which would otherwise look blurry if a slower shutter speed was used but it still takes one slice per area.⁸

The next generation of CT scanners or multislice CT solved this problem by placing multiple rows of detectors per area allowing simultaneous scanning of several slices of ever decreasing thickness at the same time. Better detail thanks to the smaller slices, shorter acquisition times, reduction of motion and metallic artifacts, better multiplanar reconstruction (from single plane acquisition), and elimination of stair-step artifacts (Fig. 3) are but a few of the advantages of multislice CT.^{5,9}

As we mentioned earlier, the final image disposition depends upon tissue attenuation of X-ray which is denoted by numerical numbers called Hounsfield units which are represented on the screen and on printed film arbitrarily by various shades of gray. Modern CT equipment can differentiate between 2000 different shades of gray in the final image but the human eye cannot.⁸ It is technically possible to vary or 'set' the window level to view only a certain range of Hounsfield units to allow the human eye to focus on a specific tissue

like bone (Fig. 4). An alternative method to improve visualization in the orbit is through the administration of an intravenous iodine-based medium to facilitate vascular enhancement.

Imaging of the orbit

The normal orbit

Discussing the issue of whatever constitutes normalcy maybe a dull uninteresting subject, and is usually the chapter that is skipped by budding medical practitioners in textbooks, but the ability of the clinician to answer the problem whether the tissue in question is normal or abnormal is as important in interpreting radiologic films as in clinical assessment. Fig. 5 illustrates the normal anatomic findings in axial, coronal and sagittal CT.

The abnormal orbit

Clinicians should realize that imaging studies are not an end in themselves. The wide availability of diagnostic imaging modalities should not push the busy practitioner away from the good old traditional history taking and clinical examination. Imaging should be a part of the spectrum and not the whole picture. Besides, it is imperative to educate fellows and residents that evaluating a CT or MRI alone is not an Olympic competition and no gold medals will be awarded if you clinch or rush to declare a diagnosis based on one single look at the CT. Imaging is part of a spectrum that starts even before the patient sits on the examination chair, and ends as a histopathology slide in the lab. Figs. 6–10 will demonstrate a variety of CT abnormalities in and around the orbit. It may seem rather antithetical to our previous argument that we excluded clinical photographs entirely, but the goal of this particular paper is to illustrate as many educational examples of orbital pathology on CT rather than to show the full clinical spectrum of orbital pathology which may better be discussed in a textbook.

Congenital/pediatric orbital anomalies

Developmental orbital defects may occur in isolation or as part of larger systemic malformation syndromes. The

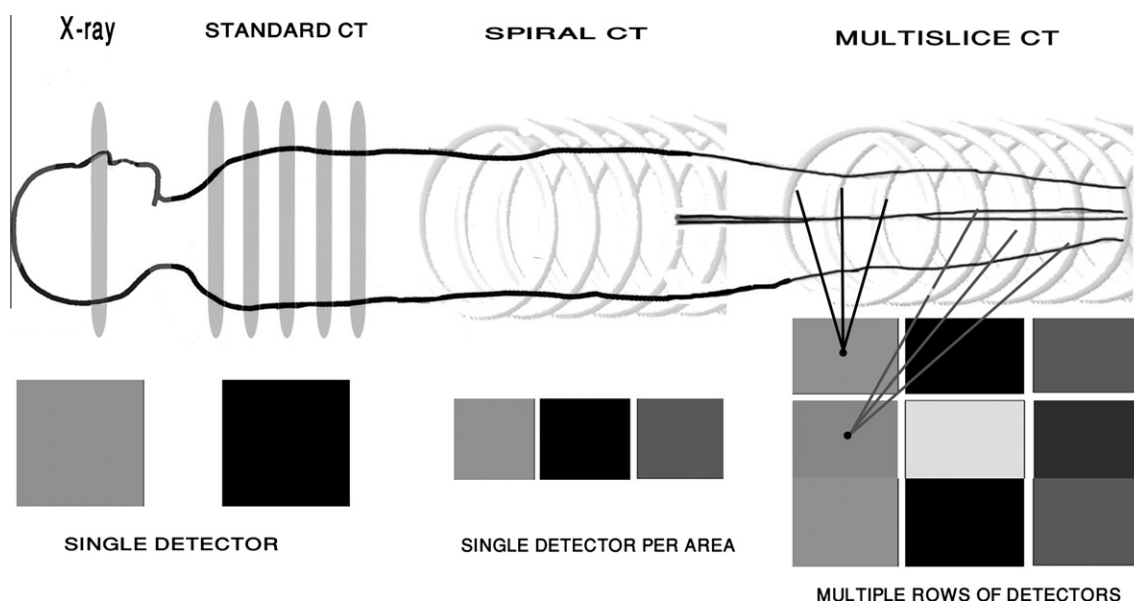


Figure 2. Illustration showing the difference between X-ray, standard CT, helical CT and multislice CT. A dramatic reduction of scan acquisition times as well as artifacts is possible with multislice CT where multiple detectors scan multiple slices simultaneously.

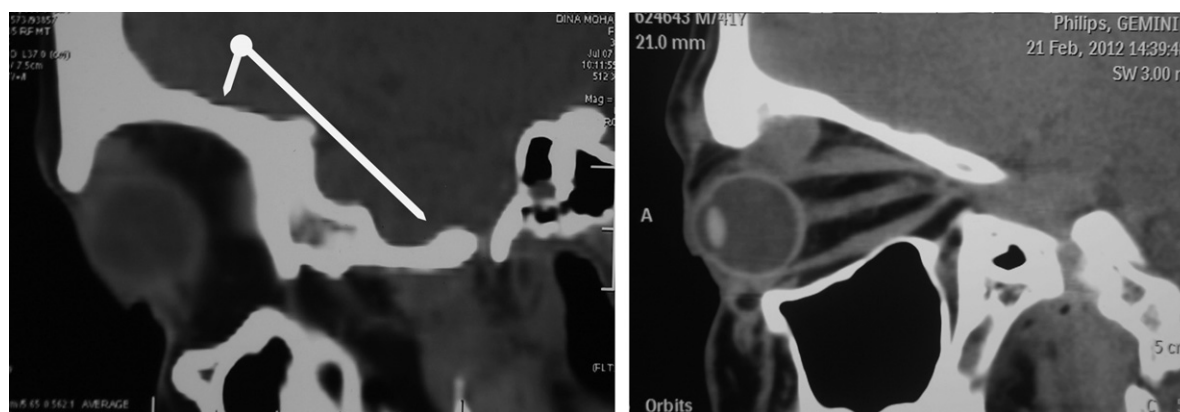


Figure 3. Obvious stair-step artifacts in standard CT reconstruction of sagittal cuts (A), in contrast to the multislice CT where no such artifacts are seen (B).

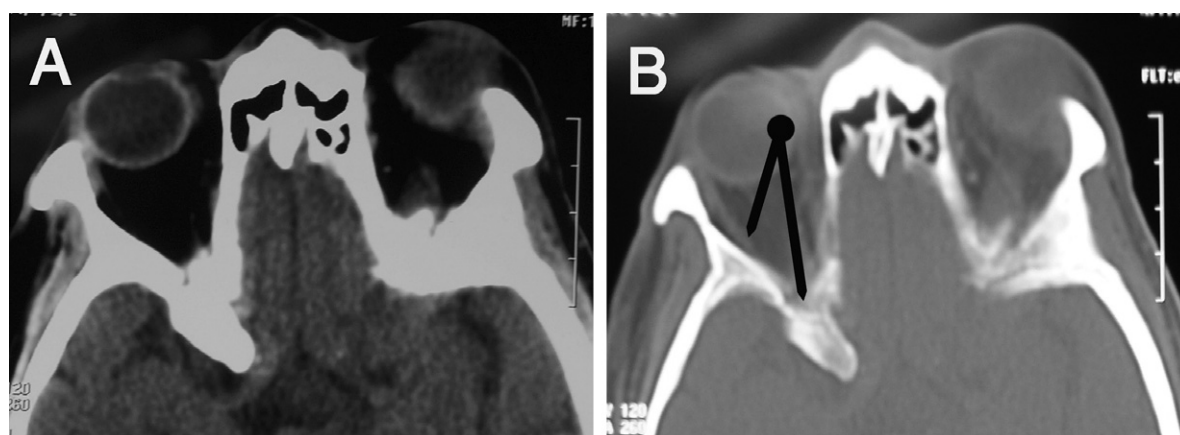


Figure 4. In a soft tissue window (A), the 'window' is set so that the soft tissue contents of the orbit are clearly represented while bone appears as one homogeneously colored white block. In contrast in a bone window, soft tissues are faded while the cortex and medullary portions of bone are easily discerned (arrows). Specifically ordering a bone window in the radiology request sheet is of paramount importance in patients with suspected orbital fractures or metallic foreign bodies; otherwise they could be missed, and in patients with suspected bone tumors or palpable firm masses.

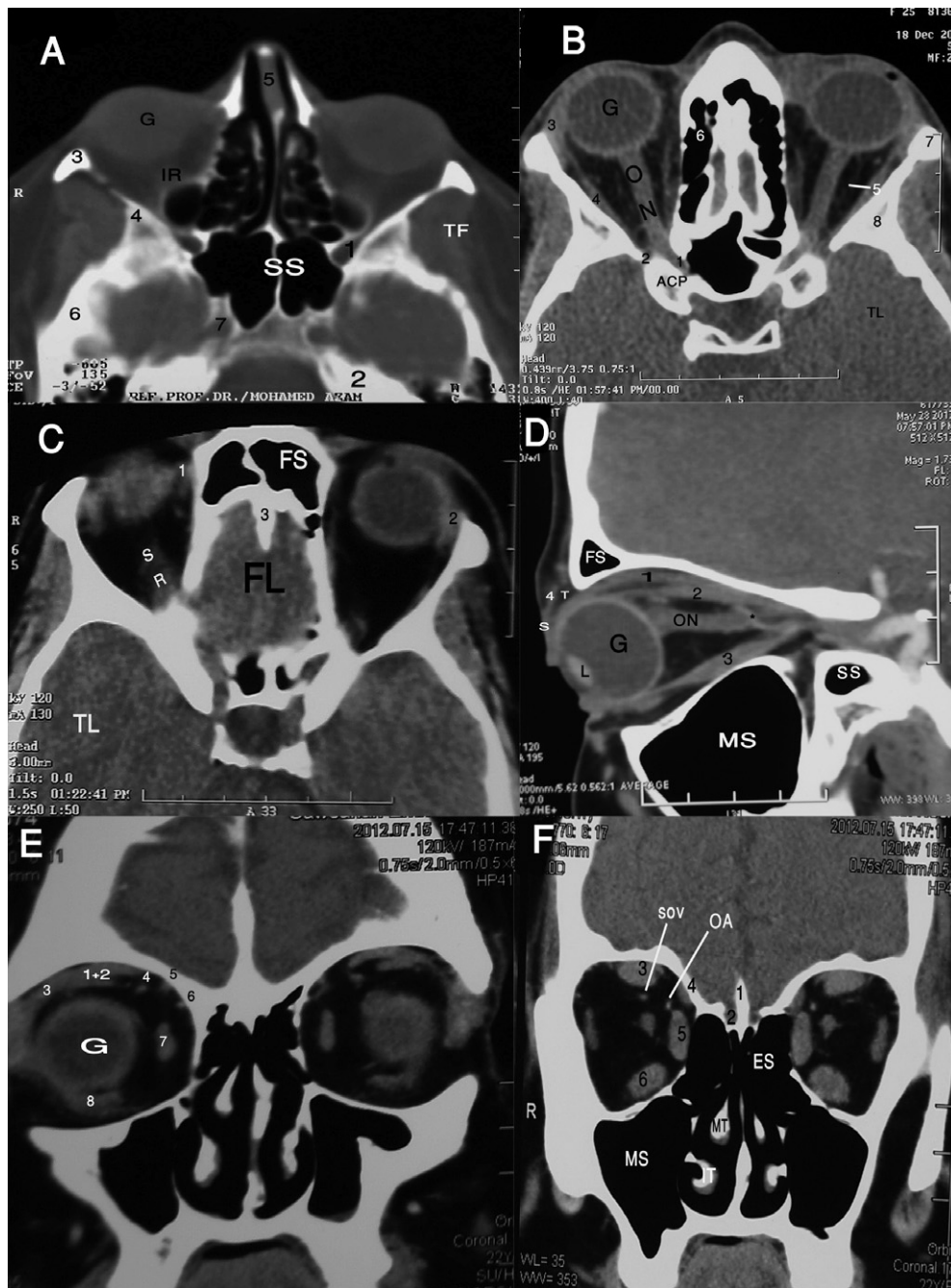


Figure 5. Normal radiologic anatomy of the orbit. (A) Axial, inferior orbit. G = globe, IR = inferior rectus, SS = sphenoid sinus, TF = temporal fossa, 1 = inferior orbital fissure, 2 = petrous bone, 3 = zygomatic bone, 4 = sphenoid bone, 5 = nasal septum, 6 = temporal bone, 7 = internal carotid artery. (B) Axial, mid-orbit. ON = optic nerve, TL = temporal lobe, ACP = anterior clinoid process, 1 = optic canal, 2 = superior orbital fissure, 3 = lacrimal gland, 4 = lateral rectus, 5 = orbital fat, 6 = ethmoid sinus, 7 = zygomatic bone, 8 = sphenoid bone. (C) Axial, superior orbit. FL = frontal lobe, FS = frontal sinus, SR = superior rectus, 1 = superior oblique, 2 = lacrimal gland, 3 = crista galli. (D) Sagittal, mid-orbit. FS = frontal sinus, MS = maxillary sinus, L = crystalline lens, T = tarsus, S = skin, 1 = levator palpebrae superioris, 2 = superior rectus, 3 = inferior rectus, 4 = orbicularis oculi, * = ophthalmic artery crossing the optic nerve from lateral to medial. (E) Coronal, anterior orbit. 1 + 2 = Levator palpebrae superior + superior rectus complex, 3 = lateral intermuscular septum, 4 = superior ophthalmic vein, 5 = superior oblique tendon, 6 = termination of the ophthalmic artery, 7 = medial rectus, 8 = inferior rectus. (F) Coronal, posterior orbit. SOV = superior ophthalmic vein, OA = ophthalmic artery, ES = ethmoid sinus, MT = middle turbinate, IT = inferior turbinate, 1 = crista galli, 2 = cribriform plate of the ethmoid, 3 = superior rectus, 4 = superior oblique, 5 = medial rectus, 6 = inferior rectus.

majority cause significant cosmetic deformity and some of them may cause severe vision impairment. The genetic basis of various congenital orbital anomalies is currently being investigated but this is beyond the scope of the present discussion (Fig. 6).

Orbital trauma

It may be counterintuitive but actually true that the weakness of the floor and medial walls of the orbit which predisposes them so much to fractures actually protects the

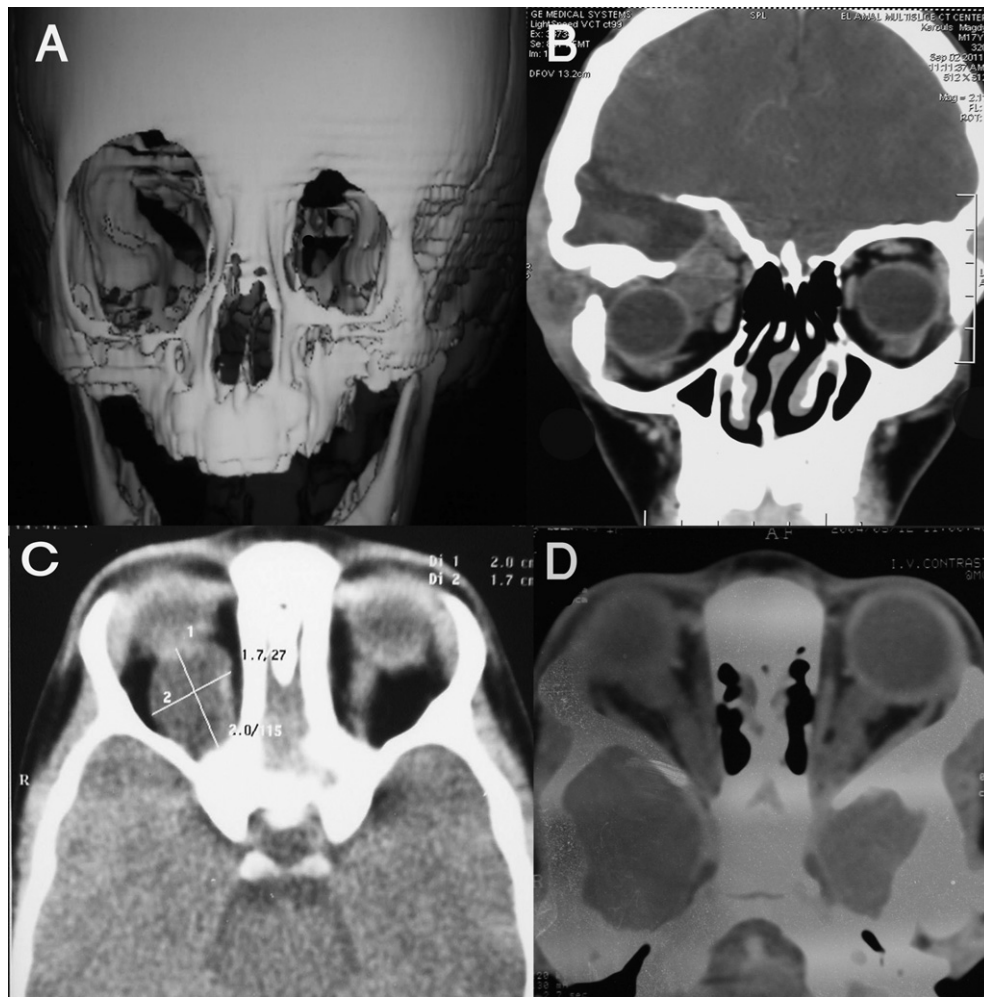


Figure 6. Congenital orbital anomalies. (A) 3-D CT of unilateral clinical anophthalmia with hypoplasia of the ipsilateral bone. (B) Orbitotemporal neurofibromatosis. Coronal CT shows ablation of the greater wing of the sphenoid bone (OD) with herniation of the temporal lobe into the orbit causing hypoglobus and pulsatile proptosis. In the majority of patients repair of soft tissue periorbital deformities may suffice and craniofacial reconstruction of bony defects may not be required (C) Microphthalmos with a cyst. On CT the contents of the cyst have a low attenuation density while the rim or capsule is of higher-density. Little is known about the exact nature of the fluid inside these cysts, but the relative hyperdensity on CT compared to other cystic swellings in the orbit suggests they may have a higher protein content. Because of good visual potential and minimal cosmetic disfigurement the parents were advised against enucleation and/or cyst excision. (D) Crouzon syndrome. Axial CT demonstrates orbital hypertelorism, bilateral shallow orbits, and ocular exorbitism. Increased thickness along the optic nerve sheaths could indicate enlarged optic nerves due to compression and may be an urgent indication for surgery.

globe itself by dissipating the impact force of trauma away from the eye. The golden rule in the management of orbital trauma is that safety of the globe takes precedence over the orbit. CT plays a central role in the management of orbital fractures and devising a plan for management (Fig. 7).

Orbital inflammations

The hallmark disease of orbital inflammatory syndromes is idiopathic orbital inflammation (IOI). Unfortunately IOI is still used as catch-all diagnosis and several malignant and life threatening auto-immune diseases are missed in the process (Fig. 8). This is one instance where proper history taking and detailed assessment of systemic diseases may be more important than radiological evaluation.

Orbital infections

Because the septum acts as a barrier preventing the spread of superficial infections into the deep orbit, orbital infections are usually classified anatomically into preseptal and post-septal infections. While CT may provide very little diagnostic help in preseptal cellulitis which is therefore outside the scope of our present discussion, CT is of utmost importance in deciding the management options for post-septal cellulitis (Fig. 9).

Orbital neoplasms

Orbital tumors are a mixed collection of lesions and, therefore they pose numerous challenges in terms of diagnosis and management (Fig. 10). This is one area of orbital

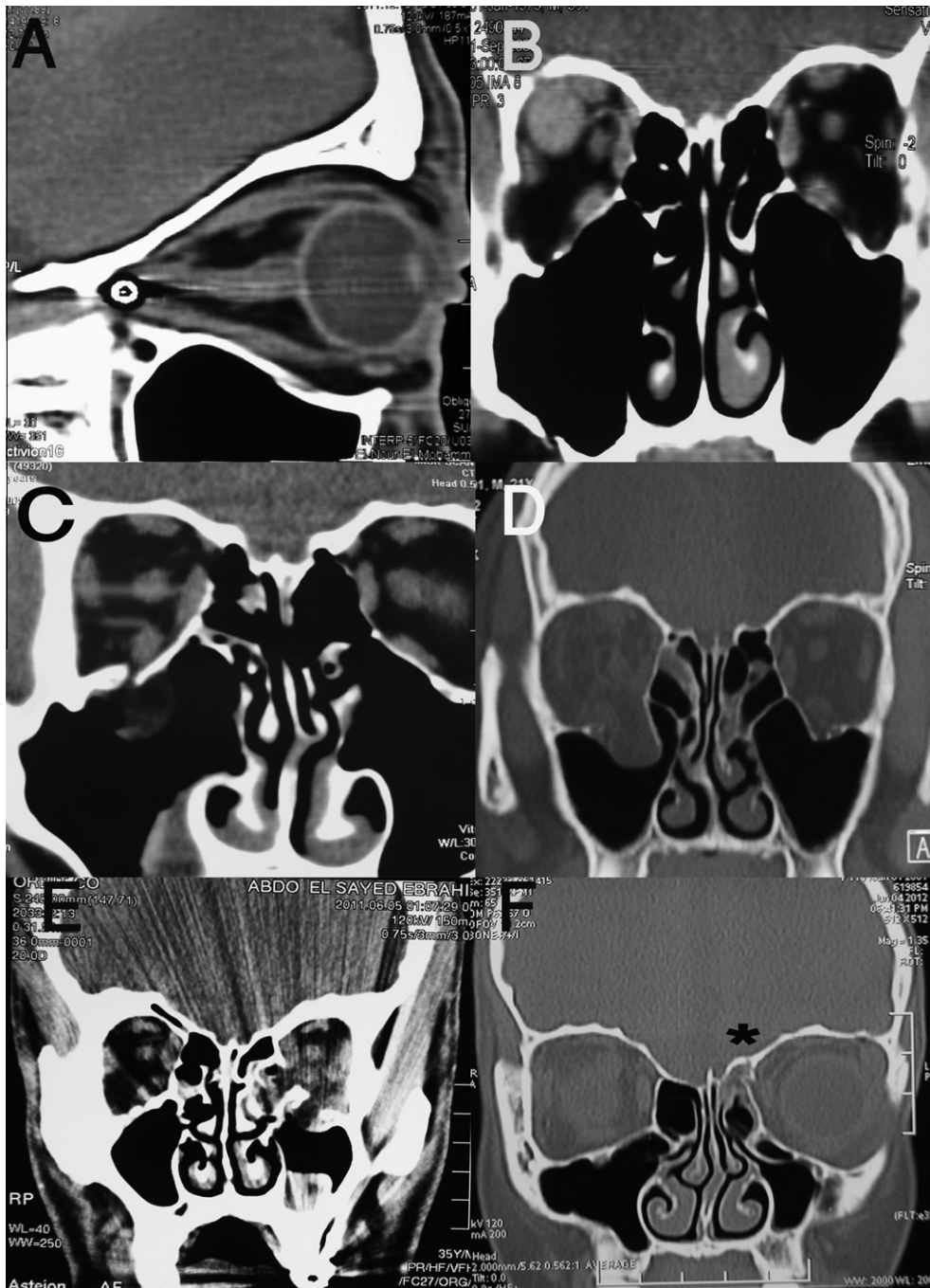


Figure 7. (A) Sagittal CT of an apical iron foreign body (FB). Miraculously the patient sustained 20/20 vision. Typically iron FBs have a low density core with a thick hyperdense outer ring and marked CT artifacts. This image illustrates the ability of helical CT to practically eliminate image artifacts in sagittal reconstructions. One reason why the patient sustained excellent visual acuity despite an apparently large FB is that the image size of all metal FBs appears larger on CT than their actual size. Iron has a radiologic magnification factor of 2.29 so the offending FB is actually much smaller than its appearance on CT.¹¹ (B) Coronal CT showing a well-defined mass in the superolateral orbit with a vessel apparently entering the lesion and an overlying traumatic defect in the orbital roof. The mass turned out to be a thrombosed aneurysm of the meningolacrimal branch of the middle meningeal artery and was ligated through a lateral orbitotomy. C–E. Common types of orbital floor fractures. (C) Trapdoor fracture in a 12-year-old male. Trapdoor fractures transiently separate near the inferior orbital groove and then snap back, trapping soft tissue. (D) Bilateral hinged orbital floor fractures. These fracture pivot at the inferior edge of the ethmoid bone and practically float in the maxillary sinus.¹² (E) Comminuted fracture of the floor and the medial wall. Comminuted fractures are the commonest orbital fractures encountered in the adult population.¹² (F) Coronal CT. Left medial wall fracture, and incomplete (greenstick type) fracture of the ipsilateral cribriform plate of the ethmoid which was not associated with a CSF leak (asterisk).

pathology where MRI and CT may both have a role to play but in a sequential manner. If radiology is needed then CT is ordered first, followed by MRI if further analysis is required.

The verdict: CT versus MRI

To answer this question, unfortunately there is no one short simple answer. Clinical suspicion, age, potential radia-



Figure 8. (A) Infantile orbital and temporal fossa abscess in a 9-month old infant caused by methicillin-resistant staphylococcus aureus. (B) Lacrimal sac mucocele. Axial CT at the level of inferior orbit shows a cystic medial canthal mass arising in relation to the bony nasolacrimal canal which was treated by endoscopic dacryocystorhinostomy. (C) Typical medial subperiosteal abscess (SPA) of the orbit in a 38-year old male that did not respond to treatment with empirical antibiotic therapy and required drainage. In adults SPAs/sinus infections are usually polymicrobial and in contrast to their pediatric counterparts they do not typically respond to antibiotic therapy. (D) Allergic fungal sinusitis in an immunocompetent host: Sagittal CT shows complete opacification of the maxillary sinus with erosion of the floor of the orbit and involvement of the entire orbital cavity and also intracranial extension. Note the heterogeneity of the lesion which is characteristic of fungal sinusitis. (E) Frontal mucocele encroaching on the orbit and eroding the orbital roof. Bone erosion results from mass effect and the massive release of inflammatory cytokines like IL-1 and IL-6. (F) Ethmoidal mucocele invading the orbit. The mass was approached through a transcaruncular approach and did not recur.

tion tolerance, systemic status are all contributing factors that may eschew the clinician away from either modality, but CT units are readily available in most hospitals, the acquisition times are super-fast and with the advent of modern CT scan-

ning techniques and the dramatic improvement in resolution, we believe the majority of questions raised by the practicing ophthalmologist and requiring a non-invasive imaging modality are answered by ordering a CT. Indeed, MRI

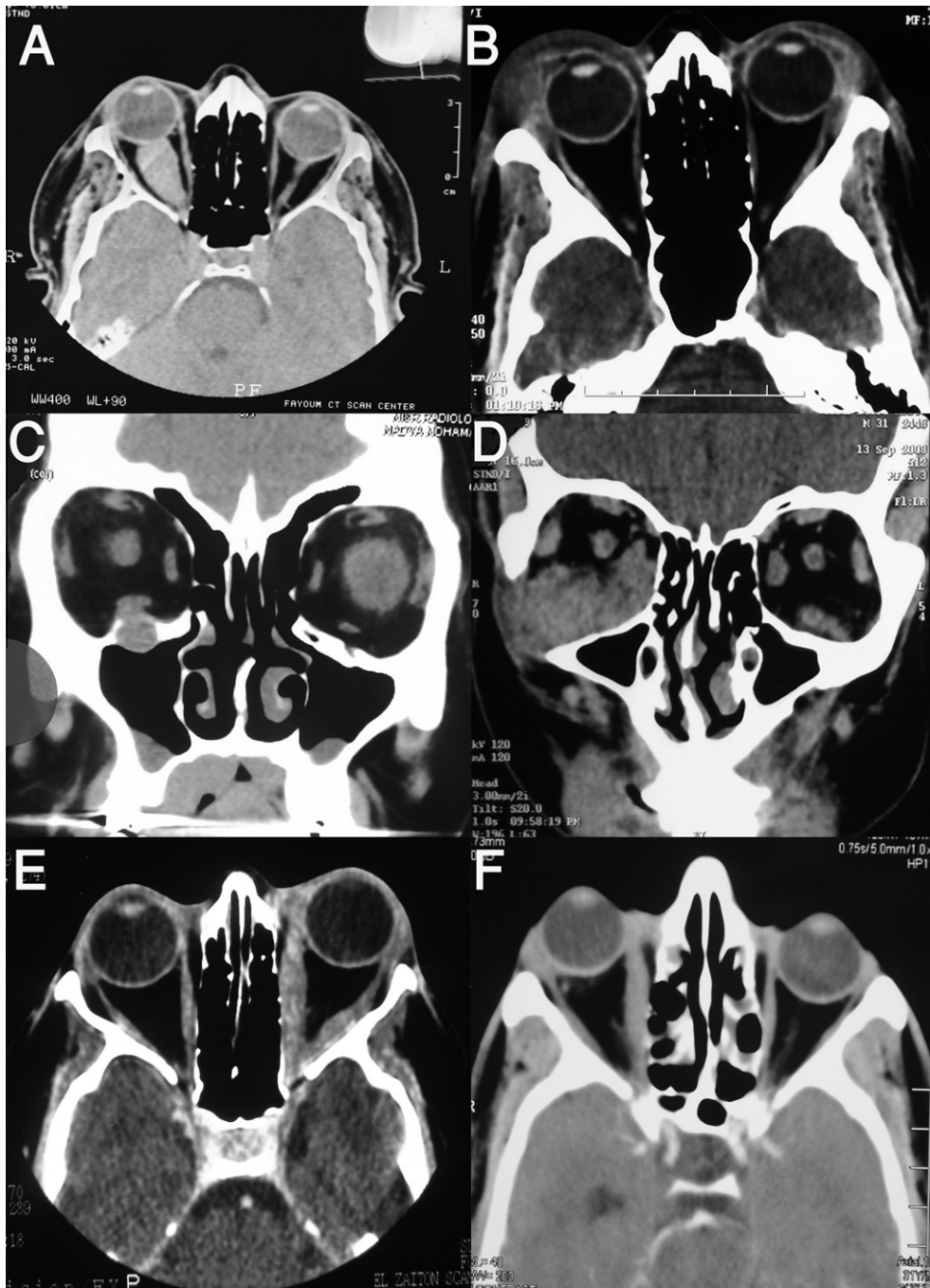


Figure 9. (A) Axial CT of a 47-year old male showing fusiform enlargement of the optic nerve. MRI and not CT was essential to clinch diagnosis as it was clearly separate from the optic nerve on T1-weighted images suggesting it was a meningioma rather than a glioma but it did not enhance with gadolinium therefore also excluding meningioma. The lesion was self-limiting but reappeared 2 years later in the superior rectus muscle. Histopathologic examination revealed it to be one of the desmoplastic inflammatory disorders (Rosai-Dorfman disease). The patient was aggressively treated with steroids but suffered multiple recurrences. (B) Axial CT of a 18-year old female from a rural area who presented with a bilaterally symmetric s-shaped eyelid deformity with minimal inflammatory signs. CT showed bilateral enlargement of the lacrimal gland and no bone erosion. Histopathology revealed a granulomatous reaction with caseation strongly suggestive of tuberculosis. The parents had concealed a prior history of open pulmonary TB 2 years ago for social reasons. (C) Coronal CT showing unilateral isolated enlargement of the infraorbital nerve. Biopsy of the infraorbital nerve showed a polyclonal mixed population of lymphocytes (B and T). A case of idiopathic orbital inflammation of the infraorbital nerve which is exceedingly rare. (D) Coronal CT showing an irregular ill-defined mass in the floor of the right orbit involving and not discernible from the inferior and medial recti muscles. Incisional biopsy revealed chronic inflammation with marked fibrosis and a polyclonal presence of T and B lymphocytes, suggesting a diagnosis of sclerosing idiopathic orbital inflammation. The lesion neither responded to steroids nor irradiation, and progressed to infiltrate the entire orbit resulting in loss of light perception. (E) CT image shows a diffuse ill-defined enlargement of the left medial and lateral recti muscles, with irregular borders and tendon enlargement, suggesting the diagnosis of orbital myositis. Multiple muscle enlargements in the same or the contralateral orbit is not uncommon. (F) Patient with thyroid orbitopathy. Axial CT shows enlargement of the medial rectus muscle belly and tendon with relatively well defined borders. Multiple muscle belly enlargement and tendon sparing is the hallmark of thyroid associated orbitopathy, but as this case demonstrates, the tendon size should not be overstated.

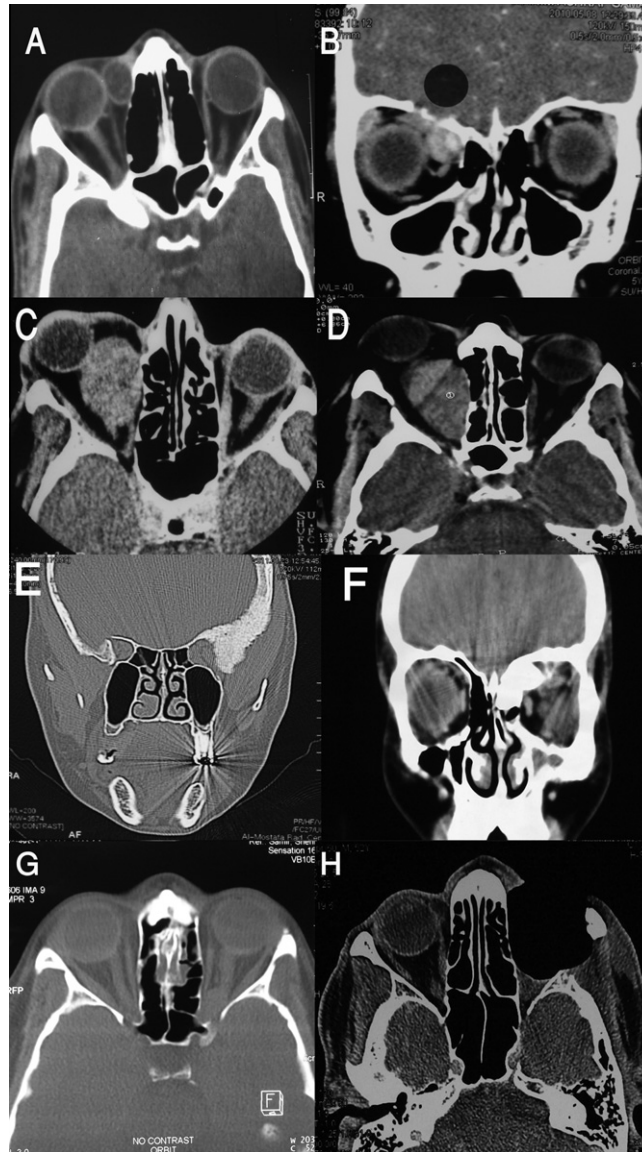


Figure 10. (A) Dermoid cyst. An oval cystic extraconal lesion is seen on axial CT in the medial orbit. A fluid level may occasionally be seen in coronal scans. The surrounding capsule has a higher density than the center of the cyst. (B) Coronal CT with contrast shows a superonasal mass with overlying frontal bone defect. Although infrequently described, adjacent bone defects are a common feature of orbital varices. No treatment was required in this patient because cosmetic disfigurement was minimum however in more severe case, preoperative embolization before excision is advised. (C) Post-contrast axial CT shows a moderately enhancing large fusiform intraconal mass which on excision turned out to be a cavernous hemangioma. Dynamic MRI with Gadolinium may help pinpoint the diagnosis as patchy or stepwise enhancement is typically seen until the entire lesion enhances. (D) Hemangiopericytomas are virtually indistinguishable from cavernous hemangiomas both from a clinical and radiologic standpoint. In our limited experience with 3 patients we failed to observe the frequently described calcification or marked enhancement with contrast CT that are frequently described in the literature. The benign clinical and radiologic appearance of hemangiopericytomas belies a very aggressive tumor that could bleed profusely intraoperatively and recur. (E) Coronal CT, bone window showing the typical hyperostosis of the greater wing of sphenoid bone in meningiomas, the edge of hyperostotic bone is rough and brush-like. The bony component of sphenoidal wing meningioma may look remarkably similar to fibrous dysplasia (FD) and CT may not be the optimal radiologic choice to differentiate between both diseases. One important differentiating point is the age of onset which is lower in FD, and on CT, both the inner and outer borders of FD are convex. In addition meningiomas often have a soft tissue component while FD does not. In general MRI does a better job differentiating both lesions. (F) Osteoid osteoma, Coronal CT, soft tissue window showing a dense, well defined lobulated mass in the superonasal orbit. A predominantly male disease, smaller osteomas like the one shown here have a well-defined plane of cleavage between the osteoma and the normal bone, and are easy to remove with a combination of chiseling and rocking of the mass. Larger lesions may require a multidisciplinary approach. (G) Optic nerve glioma. Axial CT shows an apical well-defined globular enlargement of the optic nerve at the apex which is isodense to the brain. Increased tortuosity or kinking of the nerve is also obvious. Less dense areas on CT (not shown) are more common in pediatric gliomas and denote areas of mucinous degeneration which usually occurs due to the rapid growth of the mass and may not necessarily mean a malignant transformation. The mass was completely removed through an extended lateral orbitotomy. Although adult onset (particularly of the chiasmal variety), and the absence of neurofibromatosis-1 may be alarming signs for malignant glioma, the mass turned out to be a low-grade astrocytoma on histopathology and did not recur. Most gliomas are now considered hamartomas. (H) Recurrent adenoid cystic carcinoma (ACC) stage T4bN0M0 treated with exenteration and removal of the lateral bone wall and part of the roof followed by radiotherapy.¹³ Extensive and mutilating surgery for recurrent ACC may not contribute to a longer survival and is a questionable practice but owing to the rarity of the disease no solid data is available to support either side of the argument.

provides some advantages like better soft tissue contrast, and it excels particularly with optic nerve lesions or lesions at the orbitocranial junction but for the remainder of orbital pathologic conditions CT is just fine.

Besides the alleged inferior soft tissue detail which as we mentioned is of little consequence in the orbit, another disadvantage of CT is the radiation dose. A CT of the head typically delivers 100 times the radiation dose provided by an X-ray of the same area and maintains background irradiation in the body for up to 10 months.¹⁰ Another annoying disadvantage that was more frequently encountered in the past is artifacts. Motion artifacts and 'streak' artifacts behind metallic foreign might have a deleterious effect on the quality of CT however these artifacts are reduced with the use of multislice CT (Fig. 7A).

To conclude, our final judgment in the CT-MRI stand-off is that in general CT should remain as the primary go-to diagnostic imaging modality for the orbit. An MRI could be ordered as a secondary diagnostic tool in orbital vascular lesions, lesions at the orbito-cranial junction, and when the relation to the optic nerve is not entirely clarified on CT. We hope as we reached the end of this article, that health care providers would realize the proper place of CT in the radiology ladder and avoid the MRI overuse that poses a huge and unnecessary financial burden on our health care system.

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