Radiological evaluation of petrous apex lesions: a pictorial review.

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Learning objectives

To highlight characteristic radiological features especially those considered to be pathognomonic for certain conditions involving the petrous apex, and to describe an approach which may facilitate the correct diagnosis.
Background

The petrous apex is the portion of the petrous temporal bone bound by the petro-occipital fissure medially and the inner ear posterolaterally. The internal auditory meatus further divides it into an anterior and a smaller posterior compartment.

The intrinsic anatomy of the petrous apex is relatively simple, with the only main variation being the degree of pneumatisation. However its location within the skull base and the intimate relationship to critical neurovascular structures (some of which course through the petrous apex) make it home to a multitude of pathological processes. Lesions may be completely asymptomatic or may present with headaches and cranial nerve palsies secondary to local mass effect.

A third of petrous apices are pneumatised (1) by peritubal, subarcuate and posteromedial tracts which maintain direct communication with the middle ear cleft. The pneumatisation is asymmetric in 5-10% of individuals (2). This communication makes the petrous apex susceptible to spread of disease from the middle ear and mastoid air cells. With the exception of malignancy, most pathology in this region is directly related to the presence of pneumatisation.

The petrous apex cannot be directly examined clinically, and hence imaging is essential in evaluating suspected regional pathology. CT and MRI examinations are complementary and not only provide an accurate preoperative diagnosis but also allow assessment of the relationship and involvement of adjacent neurovascular structures.

Radiologists often face a diagnostic dilemma, whenever such lesions are encountered. We therefore propose an approach analogous to the more familiar radiological assessment of bone lesions. Thus we categorize petrous apex lesions into three main groups according to underlying bone changes into those that spare bone, lesions with benign features and aggressive lesions. We will describe the features which define these categories, and discuss the spectrum of aetiologies under each heading. Our aim is to highlight characteristic radiological features especially those considered to be pathognomonic for the condition, and to describe an approach which may facilitate the correct diagnosis.
Findings and procedure details

A. Bone Sparing

The presence of benign petrous apex lesions is directly related to the presence of apical pneumatisation. Such abnormalities may merely present entrapped fluid in the petrous apex air cells or asymmetric fatty marrow and have been described in the literature as pseudolesions or "Leave me alone" lesions (3). CT evaluation in these cases demonstrates normal underlying bone texture and trabeculation. MR features are often characteristic and allow the correct diagnosis to be clinched, hence avoiding further unnecessary and potentially harmful evaluation.

1. Asymmetric Fatty Marrow

Diploic fatty marrow in asymmetrically pneumatised petrous apices (4) is noted incidentally in less than 5% (5) of individuals on cross sectional imaging. The finding is especially conspicuous on T1 sequences due to the intrinsic high signal of fat. The appearance may raise concern to the inexperienced observer. High signal is also displayed on T2 sequences and the apical marrow tends to follow the orbital and scalp fat signal. Fat-saturated and inversion-recovery sequences fully suppress the signal and confirm the diagnosis. Fat may also be confirmed by region of interest (ROI) measurements on high resolution CT which give values close to -100HU.

One must be aware of potential pitfalls (6). Certain lesions (including cholesteatomas) display high T1 signal and may erroneously be discounted for asymmetric marrow. On the other hand the area of abnormality may be interpreted as an enhancing lesion on post contrast T1 images if fat saturation has not been applied. The distinction is of paramount importance, and confusion is easily avoided if one is aware of this normal variant.
Fig. 1: Axial T1 weighted image (Panel A) showing a focus of high signal intensity with left petrous apex (when compared with the right) which is losses its signal on the fat suppressed sequences (Panel B) in keeping with fatty marrow.

References: Medical Imaging, Mater Dei Hospital - Birkirkara/MT

2. Petrous Apex Effusion

Trapped fluid within petrous apex air cells is thought to be the sequela of previous otitis media, which fails to drain due to obstructed communicating channels. It often presents as an incidental imaging finding in patients with no otologic complaints. The fluid tends to follow CSF signal on MRI, but the T1 appearances may vary depending on the protein content of the trapped fluid. The T1 shortening effect leads to an iso- or even hyper-intense signal on T1, and may confound the radiological diagnosis. Correlation with high resolution CT is required to confirm lack of bone remodelling, cortical disruption or trabecular erosion. Some authors recommend follow-up in 3 years to ascertain stability in such cases and to exclude an underlying cholesterol granuloma (3). Though trapped apical effusions are expected not to enhance, a thin rim of mucosal enhancement is occasionally seen (7).
Fig. 2: Axial CT on bone window settings showing an expanded right petrous apex (Panel A) which on axial T2 weighted images (Panel B) shows a high signal intensity. Diffusion Weighted B1000 showing no restricted diffusion (Panel C). Coronal T2 weighted image (Panel D) show high signal intensity of the right petrous apex which fails to suppress on T1 (Panel E), indicating that the fluid is proteinaceous in nature. References: Medical Imaging, Mater Dei Hospital - Birkirkara/MT

B. Benign Appearance

Petrous apex lesions may demonstrate benign radiological features including smooth osseous expansion, a narrow zone of transition and cortical preservation. In these instances the underlying process is almost invariably chronic and allows sufficient time for the bone to remodel. Such 'benign' appearing lesions may be further categorised into developmental, vascular, osseous, and neoplastic aetiologies.

i. Developmental

1. Cephaloceles
Petrous apex cephaloceles are rare lesions which represent cystic expansion and posterior herniation of Meckel's cave. They are thought to result from chronic CSF pulsations on congenitally thinned pneumatised petrous apices. They are CSF filled structures lined by dura and do not contain brain tissue as opposed to other skull base cephaloceles. Petrous apex cephaloceles are generally asymptomatic, but the lesion may rarely erode into the otic capsule and the petrous apical cells resulting in recurrent meningitis, otorrhea and hearing loss (8). Treatment in such cases involves surgical obliteration of the cavity with fat or muscle (9).

They appear as non-aggressive scalloped cystic expansions of the petrous apex on CT and follow CSF signal on MR. They are best evaluated on coronal T2-W images, where direct communication with the ipsilateral Meckel's cave is often demonstrated (6).

![Fig. 3](image)

**Fig. 3:** (Panel A) Axial CT on bone window settings showing a scalloped expansion of the left petrous apex. The lesion follow CSF signal on both T2 (Panel B) and T1 (Panel C) and is continuous with the perimesencephalic cistern. (Panel D) Coronal CT on bone window settings. Grey matter tissue is noted within the petrous apex defect (Panel E and F) in keeping with a cephalocele

**References:** Medical Imaging, Mater Dei Hospital - Birkirkara/MT

2. Cholesterol Granuloma
Cholesterol granulomas represent the most common petrous apex lesion and are often the sequela of chronic otitis media in patients with pneumatised petrous apices. The lesion contains granulation tissue, cholesterol crystals and blood breakdown products enclosed within a thick fibrous capsule, but lack a true epithelial lining. The granuloma may enlarge and expand into the mastoid segment, the middle ear or the internal auditory canal. It may rarely also extend to involve the clivus and the ipsilateral cerebello-pontine angle. Hearing loss, headache and tinnitus are the most common presenting symptoms (10).

Fig. 4: Panel A: T2 weighted axial image showing a high-signal and expansion of the left petrous apex Panel B: On axial T1 weighted image the mass in the left petrous apex remains of high-signal intensity when compared with normal brain parenchyma with (Panel C) rim enhancement on contrast administration Panel D: Axial T2 high resolution showing expansion of the left petrous apex E: Sagittal T1 weighted image confirms the location of the lesion to be in the petrous apex.

References: Medical Imaging, Mater Dei Hospital - Birkirkara/MT

CT often demonstrates a central soft tissue density within a well defined, expansile petrous apex lesion with no associated cortical destruction. Diagnosis is reliably made on MR, where the lesion appears intrinsically hyperintense on both T1 and T2 weighted
sequences which reflects the presence of proteinaceous debris and blood products within the lesion. Granulomas do not enhance and an alternative diagnosis should be sought if contrast uptake is seen (11). Symptomatic lesions are often treated surgically, otherwise imaging follow-up is recommended.

3. Cholesteatoma

This is usually a cystic mass consisting of squamous epithelium. They are classified into congenital (2%) and acquired (98%). Congenital cholesteatomas usually arise from ectodermal tissue in the petrous bone while acquired cholesteatomas can develop as a result of chronic otitis media. Treatment is usually surgical and prognosis depends on the size of cholesteatoma. Bone destruction is usually pathognomic and can be associated with erosion of the scutum, ossicular chain, semicircular canals and mastoid process. CT shows a mass of soft-tissue attenuation filling Prussak space with signs of otitis media and erosion of bony structures. MRI shows a hypointense mass on T1 and T2 weighted sequences which does not enhance after administration of gadolinium.

4. Mucocele

Mucoceles are due to the continuous production and accumulation of mucus within an obstructed air cell. This results in a chronic inflammatory response resulting in a well-circumscribed mass causing smooth contour changes with expansion of the bony boundaries, which may extend and compress adjacent structures. CT shows opacification of the petrous apex, erosion of bony septations and expansion of the cortical margins. MRI shows a well-defined mass with a high T2-weighted signal intensity which does not enhance after administration of gadolinium although there may be peripheral enhancement because of the inflammatory response. Patients usually present with localised pain and/or cranial nerve involvement.

ii. Vascular

1. Petrous Carotid Aneurysm

These are usually discovered incidentally in asymptomatic patients (12). They are rare and are usually asymptomatic. Patients may present with hearing loss, pulsatile tinnitus, headaches, diplopia and possibly life-threatening haemorrhage (13,14). They are thought to arise because of developmental weakness of the arterial wall however another significant cause of aneurysms of the internal carotid artery is trauma (15).

The MR imaging appearance of pseudo aneurysm may mimic mucocele or cholesterol granulomas (16). CT angiography is the best study to diagnose petrous internal carotid artery aneurysms. CT would show dilatation of the bony carotid canal with or without
related bony erosions. MR imaging may show a mass of mixed-signal intensities and flow voids. The mass appears as an irregular enhancing mass on administration of gadolinium.

### 2. Intraosseous Dural AVF

Dural arteriovenous fistulas are abnormal shunts between meningeal arteries and meningeal veins, sinuses or both (17). Intraosseous dural arteriovenous fistulas are rare variants of dural arteriovenous fistulas and unlike the typical form, the vascular nidus is situated within bone. In the petrous apex they are predominantly supplied by meningeal branches of the external and internal carotid artery (18).

#### iii. Bones Dysplasias

1. **Paget's disease**

   The petrous apex of the temporal bone is also susceptible to Paget's disease. This is characterised by cortical thickening, osseous expansion, loss of corticomedullary differentiation and accentuated coarse trabecular markings. Together these findings give rise to the 'cotton-wool' appearance in the skull.

2. **Fibrous dysplasia**

   Craniofacial involvement in fibrous dysplasia is usually present in the polyostotic form. When the petrous apex is involved, there is usually narrowing of the skull foramina resulting in compression of vessels or nerves. On CT there is usually expansion of bone with preservation of the cortex and a ground-glass internal matrix. MR shows an expansile lesion with variable enhancement after contrast administration with areas of low intensity on T1- and T2-weighted images.

#### iv. Osseous Neoplasms

These are rare conditions affecting the petrous apex and include chondroblastoma, myxoma, osteoblastoma and Giant cell tumour.

#### iv. Non-Osseous Neoplasms

1. **Meningioma**
The petrous apex is usually involved by petrovlcal and cerebello-pontine angle meningiomas. They extra-axila, dural-based, benign masses which usually affect middle-aged women. They are of high attenuation on CT. On MR they are iso to hypointense on T1 weighted images and iso to hyperintense on T2 weighting. They enhance uniformly on administration of gadolinium. Meningiomas can cause hyperostosis or osteolysis of the petrous apex.

2. Schwannoma

Schwannomas of the petrous apex usually originate from the 5th, 7th or 8th cranial nerves. On CT they are of the same attenuation as the brain and on MR they are iso to hypointense on T1 weighted images and iso to hyperintense on T2. They rarely calcify and rarely cause adjacent bone reaction. They usually enhance uniformly on administration of gadolinium but may 30% show inhomogenous enhancement. Inhomogeneities indicate a potential for malignant transformation.

3. Paragaglioma

These are benign tumours arising from chemoreceptor cells. They can arise from tympanic nerve (Glomus tympanicum tumor) or from the adventitia of the jugular bulb (Glomus jugulare tumor). CT shows a mass in the floor of the tympanic cavity and large tumors show moth-eaten changes of the surrounding bone. Due to the feeding arterial branches in the tumour, paragangliomas have a characteristic "salt and pepper" pattern with foci of decreased signal intensity on T1 and T2 weighted images. They enhance intensely after contrast administration on both CT and MR.

C. Aggressive Lesions

Aggressive lesions of the petrous temporal apex are either inflammatory or neoplastic in nature. Bone destruction is almost a constant feature as opposed to the smooth cortical thinning or expansion which is characteristic of benign lesions. A soft tissue mass or inflammatory collection is typically present and there is often poor delineation of the bony lesion.

i. Infectious and Inflammatory

1. Petrous Apicitis

In children this may occur as a primary pathology but in adults this occurs as a result of extension of acute otitis media into the petrous apex or as a complication of recent mastoid surgery. Patients are usually very ill with fever and some or all the symptoms of the Gradenigo triad (ear pain, facial pain and sixth cranial nerve palsy).
In the early stages, CT demonstrates opacification and coalescence of petrous air cells with otomastoiditis and bone destruction in later stages. On MR the petrous apex demonstrates a low signal on T1-weighted images and a high signal on T2-weighted images. The petrous apex enhances on contrast administration. Due to meningitis there may be enhancement of the adjacent dura and cranial nerves.

2. Osteomyelitis

The difference between petrous osteomyelitis and petrous apicitis, is that petrous osteomyelitis occurs in a nonpneumatized portion of the apex. Unlike petrous apicitis, it is usually cause by direct extension of severe otitis externa or by spread of thrombophlebitis along the venous plexus. Patients with diabetes mellitus or are immunosuppressed are more susceptible. *Pseudomonas aeruginosa* is the most common organism. On CT during the early phases there may be loss of the normal fat lanes beneath the skull base. As the disease progresses bone erosion occurs. MR shows the marrow space of the petrous apex and temporal bone being replaced by soft-tissue with extension into the adjacent soft tissues or intracranial involvement.

3. Inflammatory Pseudotumour

This is a rare inflammatory lesion which rarely affects the temporal bone, however when it does affect the temporal bone, 33% show involvement of the petrous apex (19). There are no specific imaging findings apart from an enhancing soft-tissue mass causing extensive bone erosion in the temporal bone. This may mimic an infection or an aggressive tumour.

4. Wegener's granulomatosis

This is a small and medium vessel vasculitis with associated necrotising granulomas in the lungs and glomerulonephritis. It is also associated with sinusitis. Even if the petrous apex is not affected, involvement of the temporal bone may cause complications such as petrous apicitis. On CT granulomas of the petrous apex appear as soft-tissue masses with destruction of the surrounding bone. On MR these masses are of low signal intensity on T1 and high signal on T2 weighted images which enhance on contrast administration.

**ii. Neoplastic - Primary tumours**

1. Chordoma

This is usually a midline tumour, more commonly arising from the clivus. Mesoderm in origin and more aggressive in the pediatric population. Peak incidence is between 50 and 70 years of age. Bone and soft tissues show areas of low attenuation on CT with
bone destruction, intratumoral calcifications and moderate enhancement after contrast administration. On MR imaging there is marked enhancement with gadolinium (there may be a honeycomb enhancement pattern) and is of low signal on T1 weighted images and high signal on T2 weighted images. Calcifications, mucoid and hemorrhage may cause inhomogeneities.

**Fig. 5:** Panel A: Coronal CT showing a soft tissue mass within the clivus with some calcifications present within it. There is associated bone expansion and cortical destruction with involvement of the right petrous apex which can be appreciated also on the (Panel B) axial CT on bone window settings. Panel C: T2 axial image showing a midline soft tissue mass, materialising towards the right apex with areas of low signal intensity. Panel D: T1 coronal post-contrast showing a characteristic honeycomb enhancement pattern.

**References:** Medical Imaging, Mater Dei Hospital - Birkirkara/MT

2. Chondrosarcoma

These are slow growing tumours and in the petrous apex, they usually arise from cartilagenous remnants of the occipitosphenoid synchondrosis. However occasionally they may also arise from the clivus. Unlike chondromas, they are more lateral lesions
which is a distinguishing feature. Other than that they are indistinguishable on imaging. CT shows a mass in the petrous apex with cortical bone destruction and rings of calcification within it. On MR it is of low to intermediate signal intensity on T1-weighted images and high signal on T2-weighted images. Contrast administration demonstrated significant enhancement which can be uniform or heterogenous.

3. Other

Rhabdomyosarcoma and Plasmyctoma may also rarely affect the petrous apex.

iii. Neoplastic - Secondary involvement

The petrous apex may also be affected by adjacent neoplastic processes including endolymphatic sac tumour, nasopharyngeal/sinonasal carcinoma and lymphoma. Secondary involvement by metastatic deposits is not infrequently encountered.
Conclusion

The complex regional anatomy and the protean pathological processes involving the petrous apex necessitate a comprehensive list of differential radiological diagnosis and a systematic approach of addressing such findings. We have categorized petrous apex lesions into three main groups according to the underlying bone changes into those that spare bone, lesions with benign features and aggressive lesions. This characterization is analogous to the radiological evaluation of bone lesions in general.
References


