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Cerebrospinal fluid rhinorrhea and otorrhea: A multimodality imaging approach

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Abstract Cerebrospinal fluid (CSF) leaks are extracranial egress of CSF into the adjacent paranasal sinus or tympanomastoid cavity due to an osteodural defect involving skull base. It can be due to a multitude of causes including accidental or iatrogenic trauma, congenital malformations and spontaneous leaks. Accurate localization of the site of the leak, underlying causes and appropriate therapy is necessary to avoid associated complications. In this paper relevant anatomy, clinical diagnosis, imaging modalities and associated findings are discussed along with a brief mention about management.

Cerebrospinal fluid (CSF) leak is due to an osteodural defect leading to abnormal communication between the subarachnoid space and adjacent paranasal sinus or tympanomastoid cavity, presenting with rhinorrhea or otorrhea [1]. These patients are at risk of meningitis due to the spread of infection from the sinonasal cavity, ranging from 19—50% in those with persistent leaks [2,3]. The increased risk of life-threatening complications, despite advances in medical therapy, emphasizes the need for early diagnosis, accurate identification of the site of the leak and timely intervention to avoid morbidity.

Transnasal endoscopic surgery for CSF leaks is currently the standard approach for management due to the higher success rate and lower morbidity compared to the transcranial or open approaches [4,5]. Imaging plays a significant role in preoperative workup, identifying the site of the leak and determining the accurate dimensions of the osteodural defect. It also aids in endoscopic repair allowing real-time anatomical navigation using multiplanar imaging and endoscopic views enabling the operating surgeon in avoiding vital structures [6,7].

Imaging helps in determining the underlying cause of CSF leaks. Ommaya et al. classified CSF leaks based on traumatic

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and non-traumatic etiologies, with traumatic being accidental or iatrogenic injury and non-traumatic, occurring in individuals with congenital defects, underlying tumors or spontaneous CSF leaks [8].

In this article, we focus on the relevant anatomical sites and outline the imaging protocol and diagnostic techniques. We also highlight the clinical features and imaging findings in traumatic and non-traumatic CSF leaks and emphasize the findings, which could affect the surgical outcome.

Relevant anatomy

The subarachnoid spaces and the dura are separated from the sinonasal and tympanomastoid cavities by the thin bones comprising the skull base. The imaging anatomy is illustrated in supplementary video 1.

Anterior skull base

The anterior skull base separates the anterior cranial fossa superiorly, from the frontal, ethmoidal sinuses and the orbits below. Anteriorly, the frontal bone forms the posterior wall of the frontal sinus. From medial to lateral, the thin cribriform plate, lateral lamella and fovea ethmoidalis form the roof of the nasal cavity and the anterior ethmoid sinus. Posteriorly, the planum ethmoidale and sphenoidale form the roof of posterior ethmoid and sphenoid sinus. The anterior ethmoidal artery enters the anterior cranial fossa from orbit through the roof of anterior ethmoidal sinus. The site of entry of anterior ethmoidal artery, thin ethmoidal and sphenoidal bony roof are prone to injury and erosion, which may result in CSF leaks [9,10].

Central skull base

The central skull base separates the middle cranial fossa superiorly, from the sphenoidal sinus and tympanomastoid cavities below. Anteriorly, the body of the sphenoid forms the sellar floor; laterally, the tegmen tympani and mastoideum form the roof of the tympanic cavity and mastoid air cells respectively. The eustachian tube is a continuous organ, the lateral end of which, lies in the petrous temporal bone and communicates with hypotympanum. The medial end, protrudes into the nasopharynx, forming the torus tubarius around the tubal ostium. The peritubal cells associated with petrous apex pneumatization directly communicate with the tubal lumen and potentially lead to paradoxical CSF rhinorrhea after ear and skull base surgeries, such as translabyrinthine approach for cerebellopontine angle masses [11—13].

Sphenoid sinus aeration

Another critical factor in the imaging of CSF leaks includes the extent of sphenoid sinus pneumatization. The pneumatization of sphenoid sinus is highly variable in individuals and classified into various subtypes based on clival and lateral extension [14,15]. The pneumatization can extend anteriorly into the clinoid process, laterally into the greater sphenoid wing, inferolaterally into the pterygoid process and posteriorly into the clivus. The hyperpneumatized sphenoid sinus causes bony thinning and vulnerability to iatrogenic injury and erosion leading to spontaneous CSF leaks [16].

Evaluation protocol

The first laboratory test in evaluating a patient with clear, watery nasal or ear discharge and suspected CSF leak includes testing the fluid for the presence of β2-transferrin or β-trace protein. β2-transferrin is produced by desalination of β1 transferrin in the CSF and β-trace protein is produced by choroid plexus, and meninges [17—20]. β2-transferrin is absent in other body fluids such as blood, tears and ear secretions. The reported sensitivity of testing for β2-transferrin ranges from 87 to 100% with specificities of 71 to 94% [19]. However, testing for β-trace protein with lower cost and faster turnaround time, has a sensitivity and specificity approaching 100% [21—23]. The results should be interpreted with caution in conditions with increased likelihood of false positive results such as associated orbital injuries and chronic liver disease for β2-transferrin and chronic renal failure for β-trace protein [23—25]. After the confirmation of CSF leak, imaging is critical to localize and characterize the defect as nasopharyngeal endoscopic localization can be unsuccessful with non-specific findings [26,27].

Diagnostic techniques

The initial imaging modalities in the evaluation of CSF leaks are usually non-invasive, including computed tomography and magnetic resonance cisternography. Invasive studies including computed tomography cisternography, contrast-enhanced magnetic resonance cisternography and radionuclide cisternography are utilized in selected cases. The choice of the imaging modality and its diagnostic accuracy depends on the local experience and expertise along with technical capabilities of the modality.

Computed tomography

The usually preferred modality of imaging in an individual with CSF leak is high-resolution computed tomography (HRCT) of the paranasal sinuses including the temporal bones [16,17]. The current multidetector CT scanners acquire isotropic, volumetric, thin submillimetre sections which allow multiplanar reformations, i.e. evaluation in coronal and sagittal planes in a bone algorithm with excellent delineation of bony anatomy and aids in the identification of a bony defect. The images can also be used for intraoperative navigation along with endoscopic views.

The primary advantage of HRCT is the depiction of bony defect even in a patient without active leak at the time of imaging. However, CT fails to ascertain the concomitant dural defect in a patient with multiple bony defects; to distinguish mucus secretions from the CSF collection within the air cells adjacent to normal areas of bony thinning/dehiscence in the skull base [26]. It also

fails to distinguish dehiscent and thin non-dehiscent bone. The sensitivity of HRCT for CSF leaks varies between 84—95% with specificity between 57—100% and identification of a single defect in a patient with a positive correlation between the location of the bony defect and clinical symptoms obviate the need for further imaging [1,17,28,29].

Magnetic resonance cisternography

Magnetic resonance cisternography (MRC) technique exploits the relative high signal intensity of the CSF in subarachnoid spaces using heavily T2-weighted sequences with suppression of background signal from the soft tissue and cerebral parenchyma. MRC involves the use of a steady state free precession (SSFP) technique, which allows submillimeter acquisition and multiplanar reformats facilitating optimal evaluation of the skull base defects [30,31]. MRC is considered positive when a CSF track communicates between subarachnoid spaces and extracranial space with or without herniation of meninges and cerebral parenchyma [1,32]. However, MRC must be interpreted along with HRCT as MR imaging fails to provide optimal bony detail [28,30,33]. The reported sensitivity of the study in detecting a CSF leak is about 94% [34]. Due to excellent soft tissue resolution, MRC facilitates delineation of contents herniating through the bony defect and differentiates meningocele from an encephalocele with adjacent gliotic parenchyma [26,27].

CT cisternography

CT cisternography (CTC) involves scanning the sinonasal and tympanomastoid cavities after intrathecal administration of about 8—10 mL of non-ionic iodinated contrast and placing the patient prone in Trendelenburg position for about 5 minutes, for craniad migration of contrast to achieve optimal cisternal opacification [1,26,35,36]. However, the study elicits the site of leak only in active cases and should be compared with HRCT done prior to contrast instillation for optimal evaluation of contrast leak.

The primary role of CTC in the evaluation of CSF leaks is for patients with multiple fractures and osseous defects, and those with a suspicious bony defect and clinically confirmed leaks [1,37]. The study is positive when there is contrast pooling (i.e. 50% or higher increase in attenuation values in fluid or soft tissue adjacent to a bony defect on post-contrast scan compared to the pre-contrast scan). The sensitivity of CTC ranges between 85—92% in patients with active leak and 40% in those with inactive leak [28,38].

The main drawbacks of CTC are the low sensitivity in patients with inactive/intermittent leaks and obscuration of small leak due to non-leakage of high viscosity contrast, adjacent to high-density bone [38,39]. Invasive nature, increased radiation dose due to multiple scans, inherent risks associated with a lumbar puncture and intrathecal instillation of iodinated contrast are other disadvantages of CTC.

Contrast-enhanced MRC

Contrast-enhanced MRC (CE-MRC) involves intrathecal instillation of about 0.5 mL of gadolinium-based contrast agents (GBCAs) after a lumbar puncture, followed by two-dimensional (2D) or three-dimensional (3D) thin section T1-weighted images. The imaging is performed about 1—2 hours after contrast instillation and after a delay up to about 24 hours when necessary [40,41]. CE-MRC shows the site of leak as a hyperintense fistulous track on T1-weighted images through the osseous defect and needs HRCT for evaluation of bony detail. CE-MRC has higher sensitivity than CTC in the determination of CSF leaks, particularly intermittent CSF leaks which can be attributed to its ability to perform delayed imaging up to 24 hours [42]. The sensitivity ranges from 92—100% in patients active leaks and about 70% in patients with inactive leaks with a reported specificity of 80% [32,43].

The main advantages of this technique include a depiction of meningoceles and relative ease of assessment of leak compared to CTC, attributable to the differentiation between the hyperintense contrast and adjacent bone. The limitations of CE-MRC include the lack of United States Food and Drug Administration approval for the intrathecal administration of GBCAs and recent evidence of gadolinium chelate deposition in brain following intravenous and intrathecal administration [44—48]. However, the limited dose of GBCAs used in CE-MRC ($\leq$ 1 mL) is usually well tolerated, and the reported adverse effects, including behavioral and neurological effects, occur only with higher doses of GBCAs (> 15 mL) [49,50]. In the wake of recent developments, CE-MRC can be performed only as a problem-solving tool using macrocyclic GBCAs in patients with normal renal function and high clinical suspicion of intermittent leaks, only after obtaining consent from the patient for off-label use of GBCAs.

Radionuclide cisternography

The radionuclide cisternography (RC) involves the intrathecal injection of the radiotracer, usually Technetium—99 or Indium—111 followed by the acquisition of the images. Detection of the radiotracer activity in the sinonasal cavity or the nasopharynx indicates a positive study. The diagnostic efficacy is improved by measuring radioactivity in the pledgets placed in nasal cavity after 24—48 hours to evaluate for CSF leak after comparison with baseline serum values [1,26]. The test is especially useful in cases of intermittent leaks and is considered positive when pledget-to-serum activity ratio is 1.5—3:1 [1]. The accuracy of RC is reported to be 70% in active leaks and much lower, i.e. about 28% in inactive leaks [51].

The most important limitations include low accuracy and suboptimal localization due to the mixing of nasal secretions in all intranasal pledgets on the side of the leak, poor patient compliance resulting in movement of the intranasal pledgets and need for delayed imaging of up to 72 hours [1,17,18,26]. Other disadvantages are same as with CTC including invasive nature and radiation exposure. RC can be used as an alternative modality primarily in cases with intermittent leaks

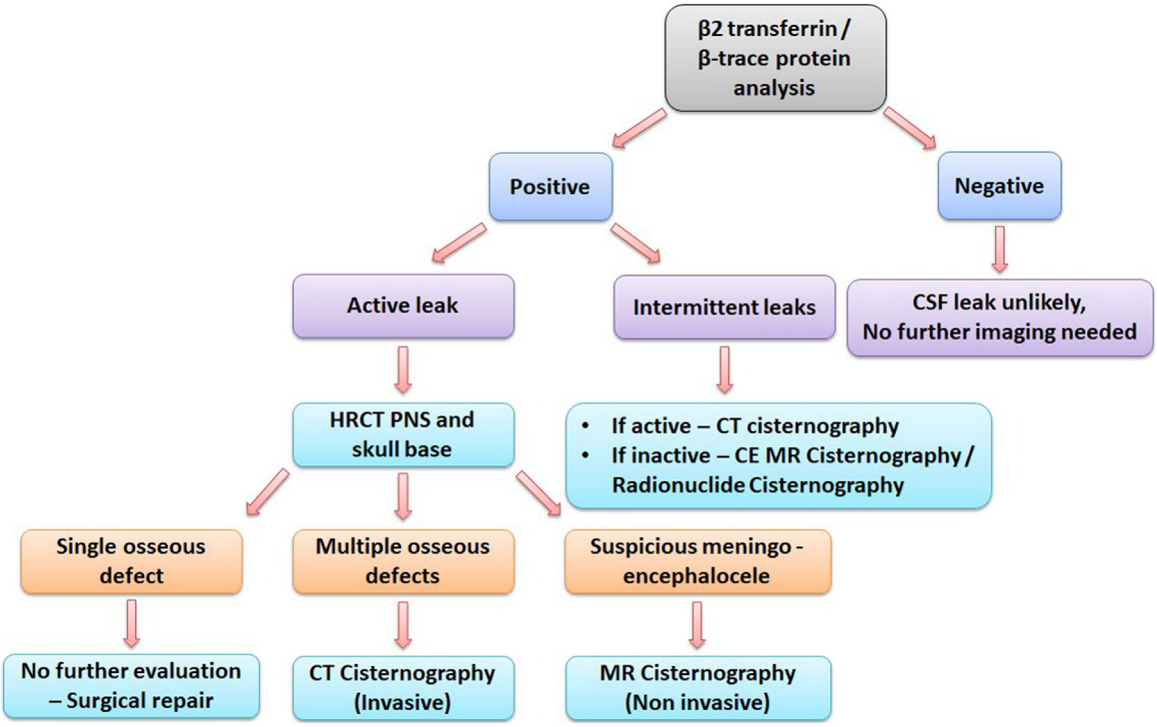

Figure 1. Imaging protocol for evaluation of patients with suspected CSF leaks.

to confirm presence or absence of a CSF leak. Fig. 1, shows recommended imaging protocol for evaluation of patients presenting with CSF leaks.

Imaging findings

Imaging findings in traumatic leaks

Accidental trauma

Traumatic leaks account for about 80—90% of CSF leaks [26,35,51]. CSF leaks are seen in about 30—40% of accidental trauma due to skull base fractures leading to an osteodural defect. Fractures involving the anterior skull base, i.e. cribriform plate, ethmoid roof and posterior wall of frontal sinus are commonly associated with CSF leaks along with central skull base fractures involving walls of the sphenoid sinus [52,53]. The increased propensity of association with anterior skull base fractures is likely due to firm attachment of dura to the underlying bone. Fractures commonly associated with CSF leaks are as described in Table 1. Temporal bone fractures are associated with CSF leaks in about 11 to 45% of patients, more so in otic capsule violating fractures (Fig. 2) [54].

Imaging findings include simple or comminuted, non-displaced or displaced fracture involving the skull base, usually associated with pneumocephalus (Fig. 3). Pneumocephalus along with hemosinus in a background of trauma suggests an osteodural defect affecting skull base, and when seen, calls for a careful evaluation of skull base for underlying fracture. In patients with CSF otorrhea, the presence of temporal bone fracture along with air pockets in inner ear structures, including vestibule and semicircular canals (i.e. pneumolabyrinth should suggest possible posttraumatic CSF — perilymph fistulae) [55]. HRCT imaging alone is sufficient for treatment planning, in cases of posttraumatic leaks with an obvious single fracture. Nevertheless, in cases of delayed presentation, possibly after resolution of the hematoma sealing the defect, wound contraction or bone necrosis, detailed radiological evaluation might be necessary (Fig. 4
).

Iatrogenic leaks

Iatrogenic leaks can be secondary to skull base or trans nasal endoscopic surgery and are reported to account for about 16% of traumatic CSF leaks [56]. In addition to the sellar and parasellar region, transsphenoidal endoscopic approaches to skull base lesions have extended significantly to include tumors of the clivus, anterior skull base,

Table 1 Fractures commonly associated with cerebrospinal fluid leaks.

Site	Prevalence
Frontal sinus	30.8%
Sphenoid sinus	11.4—30.8%
Ethmoid sinus	15.4—19.1%
Cribriform plate	7.7%
Fronto ethmoid region	7.7%
Spheno ethmoid region	7.7%
Temporal bone	11—45%

From references [48—50].

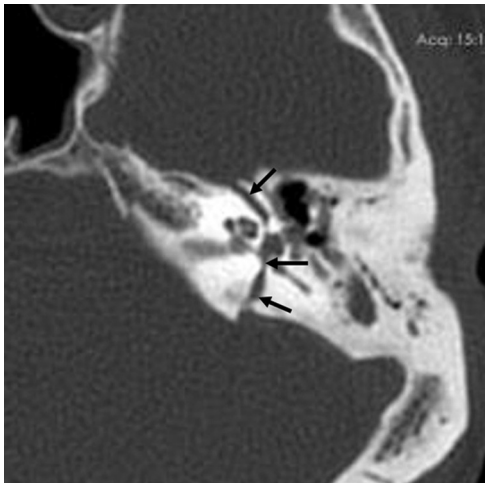

Figure 2. Thirty-seven-year-old man with blood stained watery discharge from left ear after a road traffic accident. Axial high-resolution CT image of temporal bone in bone window shows a transverse otic capsule violating fracture involving the left vestibule (arrows).

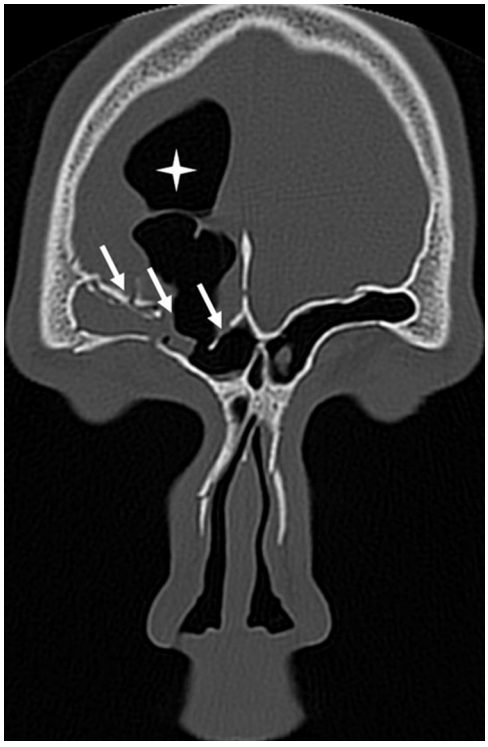

Figure 3. Forty-two-year-old man with watery discharge from right nostril after a road traffic accident. Coronal CT brain in bone window shows fracture involving anteroinferior and posterosuperior walls of frontal sinus (arrows) with pneumocephalus in right frontal region, continuous with air in right frontal sinus (star).

craniovertebral junction and anterior margin of foramen magnum with CSF leak being a potential complication [13]. The radiologist should highlight hyper pneumatization of sphenoid sinus posteriorly into clivus, dorsum sella and anteriorly into planum sphenoidale to avoid the likelihood of iatrogenic CSF leaks during transsphenoidal surgeries [57]. The pneumatization of sphenoid sinus extends into

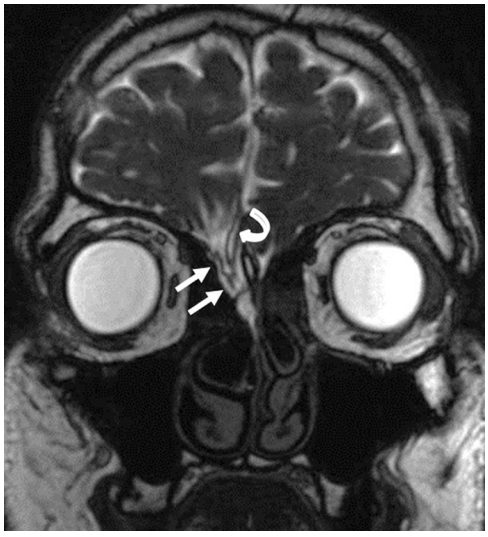

Figure 4. Forty-five-year-old woman with watery nasal discharge on right side, 4 years post-road traffic accident. Coronal FIESTA MR image shows defect in right cribriform plate (arrows) with herniation of gyrus rectus and adjacent gliosis (curved arrow).

the anterior clinoid process in about 11% of individuals, accounting for increased risk of CSF leak post-anterior clinoidectomy of up to 7% [14,58]. Hence, extent of paranasal sinus pneumatization and extension into clinoid process needs a special mention in presurgical evaluation of sellar — suprasellar masses and periclinoid aneurysms (Fig. 5).

Potential sites of injury include olfactory fossa at the vertical attachment of middle turbinate and roof of ethmoidal sinus in cases of chronic rhinosinusitis.

Other causes include surgical craniotomy extending through the frontal sinus or mastoid air cells, such as translabyrinthine or suboccipital retrosigmoid surgical approaches to cerebellopontine angle lesions. The CSF leaks associated with retrosigmoid approach occur through the lateral end of the internal auditory canal (IAC), through the perilabyrinthine cells into IAC or the retrosigmoid air cells (Fig. 6) [13]. The possible sites of inadvertent injury to be evaluated in patients with iatrogenic injury are described in Table 2.

Postoperative leaks require only HRCT imaging for presurgical planning as the site of the leak is near the surgical site. Interpretation of CTC in postoperative period can be tricky due to the presence of packing and hematoma at the surgical site.

Imaging findings in non-traumatic leaks

Congenital leaks

Congenital leaks are associated with skull base cephaloceles (i.e. mesodermal defects at the sutural sites with herniation of brain and meninges). They are classified based on the location of the defect with cephaloceles extending through the skull base defect in less than 10% of cases with an incidence of about 1:40,000 [59,60]. Sincipital cephaloceles are anterior herniations which mostly present with external swelling and are classified into interfrontal and frontoethmoid types (Fig. 7). The basal cephaloceles involve anterior or middle cranial fossa with the absence of any

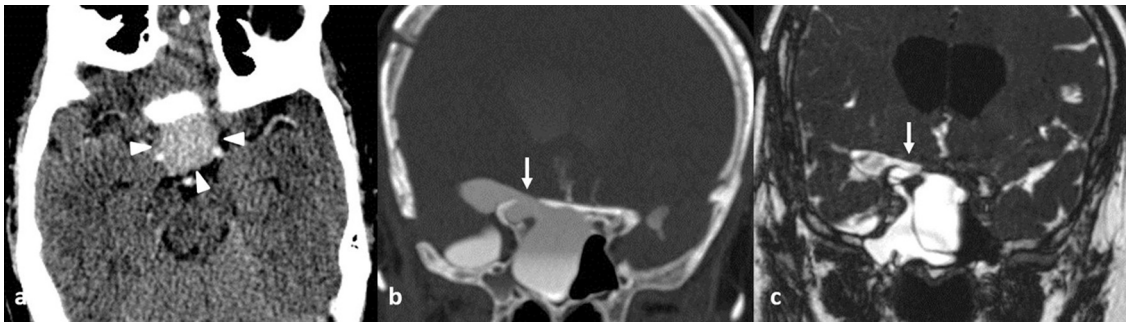

Figure 5. Forty-nine-year-old woman with watery nasal discharge on right side, 3 weeks after surgery for pituitary macroadenoma: a: presurgical CECT brain image in the axial plane shows well enhancing suprasellar lesion abutting bilateral internal carotid and basilar artery (arrowheads); b—c: postsurgical coronal CT and MR cisternography images shows superolateral extension of pneumatization with CSF leakage through the bony defect involving anterior clinoid process (arrow).

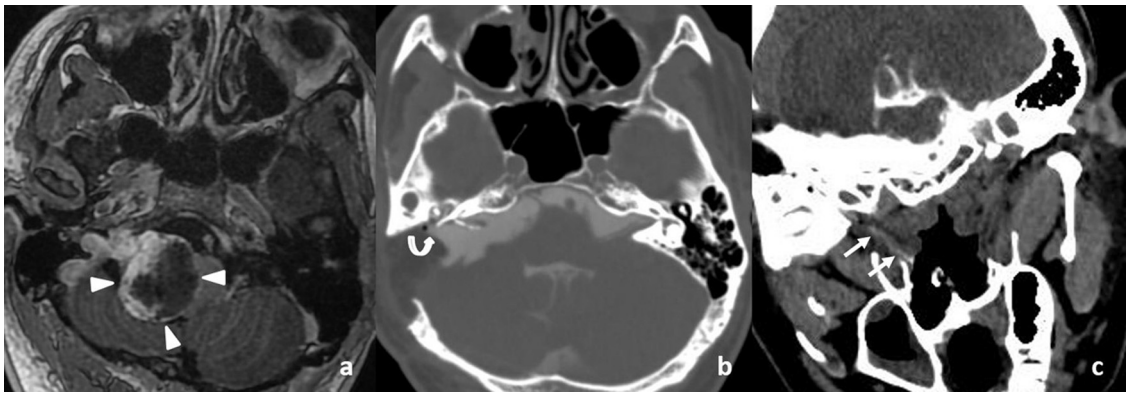

Figure 6. Thirty-year-old man with watery nasal discharge on right side, 2 months after surgery for non-vestibular schwannoma: a: presurgical axial post-contrast T1-weighted MR image shows heterogeneous enhancing mass in right cerebello medullary cistern abutting and displacing the brain stem (arrow heads); b: Post surgical axial CT cisternography image shows bony defect involving posterior aspect of mastoid temporal bone with contrast opacified CSF extending into epitympanum through a defect (curved arrow); c: post surgical coronal CT cisternography image shows opacification of right eustachian tube with leakage anterior to torus tubarius (arrows).

external mass. They are classified into sphenoorbital, sphenomaxillary or sphenopharyngeal types. HRCT shows the congenital bony defect with continuity of the herniated contents into the adjacent paranasal sinus or nasal cavity or externally. MR imaging is the preferred imaging modality as it delineates the contents of herniated sac (meninges and CSF, brain matter or gliotic tissue) and effects on adjacent structures, i.e. olfactory bulb, optic nerve and adjacent venous sinuses. Typical imaging findings include herniation of cerebral parenchyma through the defect with or without adjacent gliosis and elongated ventricles. Although most of the cephaloceles present with CSF leaks, congenital defects involving temporal bone in individuals with intact tympanic membrane may present with meningitis early in life due to ascending infection. Imaging in such patients may show opacification of mastoid air cells mimicking otitis media and paradoxical CSF rhinorrhea through eustachian tube [61]. Other causes of CSF oto-rhinorrhea include translabyrinthine and perilabyrinthine fistulae which mandate imaging evaluation with CT, MRI and CTC along with

Table 2 Possible sites of inadvertent injury to be evaluated in patients with iatrogenic cerebrospinal fluid leaks.

Procedure	Locations
Functional endoscopic sinus surgery	Vertical attachment site of middle turbinate Roof of ethmoid sinus
Transsphenoidal sinus surgery	Hyperpneumatisation of sphenoid sinus Clivus Dorsum sella Planum sphenoidale Anterior clinoid process
Translabryinthine or retrosigmoid approach to posterior fossa lesions	Tegmen tympani or mastoideum Lateral end of internal auditory canal

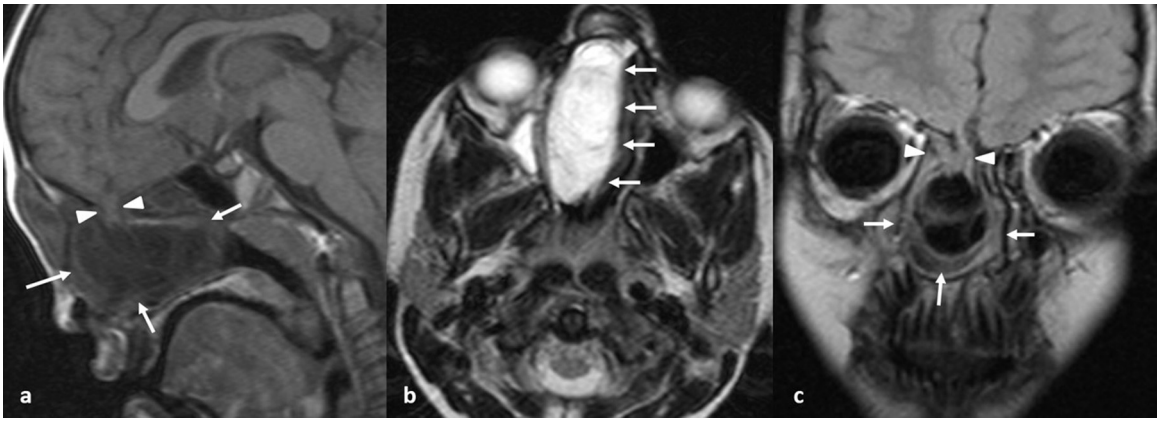

Figure 7. Two-year-old child with intermittent watery discharge from right nostril: a: sagittal T1-weighted MR image demonstrates the hypointense component suggestive of CSF (arrows) and isointense component in right nasal cavity with widening of foramen caecum indicating parenchymal herniation (arrowheads); b: axial T2-weighted MR image shows hyperintense lesion in right nasal cavity indicating fluid component (arrows) with displacement of nasal septum towards left side; c: coronal FLAIR image shows suppression of fluid component in the centre (arrows) with isointense component superiorly indicating herniating parenchyma (arrowheads). [Image courtesy — Dr. Kavinraj Murukesan].

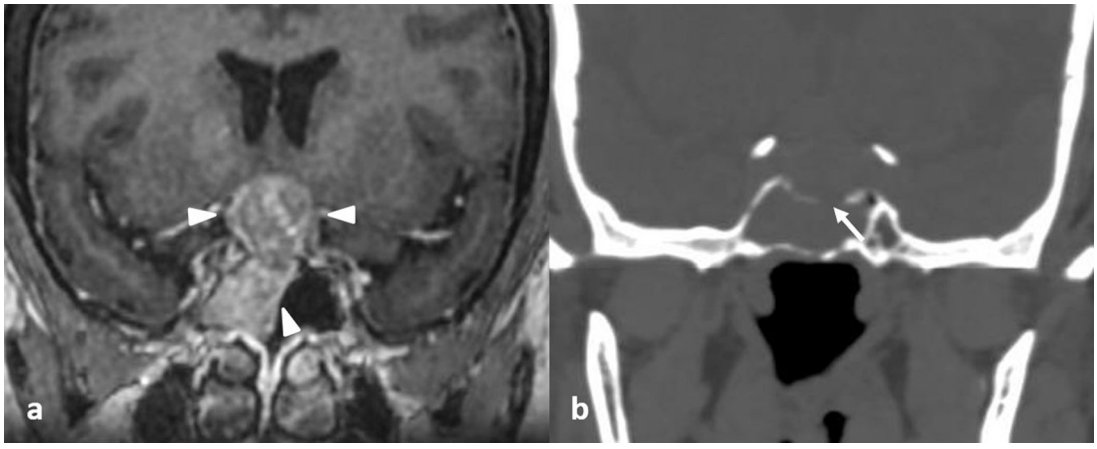

Figure 8. Thirty-five-year-old woman with head ache and bitemporal homonymous hemianopia: a: post-contrast T1-weighted MR image shows well enhancing sella — suprasellar lesion with extension into sphenoid sinus consistent with pituitary macroadenoma (arrowheads); b: coronal CT image in bone window shows erosion of sellar floor with extension of lesion into sphenoid sinus (arrow).

exploratory tympanotomy prior to appropriate obliterative procedures.

Secondary leaks

Non-traumatic CSF leaks can be associated with intra or extra cranial tumors and chronic inflammatory processes with skull base erosions [17]. Although not spontaneous, tumors such as pituitary macroadenomas are prone to CSF leaks commonly after medical therapy or radiotherapy due to tumor shrinkage (Fig. 8) [35]. Other uncommon etiologies include fibrous dysplasia of skull base, cholesteatoma, ecchordosis physaliphora and mucoceles (Fig. 9) [62].

Spontaneous leaks

Spontaneous CSF leaks are those leaks which lack underlying pathologies such as skull base lesions, congenital abnormalities and those with no history of trauma or surgery. Initial reports suggested that spontaneous leaks accounted for only 4% of CSF leaks. However, current data shows a significant increase in spontaneous leaks ranging from 20 to 40%, necessitating an increased emphasis on awareness and the need for early and accurate detection [51,63].

Spontaneous leaks are commonly seen in obese, middle-aged women who present with clinical features and imaging findings of increased intracranial pressure same as idiopathic intracranial hypertension (IIH), postulating if spontaneous leaks form a variant of IIH. IIH is a clinical syndrome comprising increased intracranial pressure, normal CSF and without imaging evidence of mass lesion or hydrocephalus. Typical MR imaging findings include prominence of peri optic CSF spaces, posterior scleral flattening or protrusion of optic nerve head, prominent arachnoid granulations causing skull base erosions, empty sella and meningoencephalocele (Fig. 10) [1,16,40]. Other reported findings associated with IIH include bilateral transverse sinus stenosis and low-lying cerebellar tonsils along with inferiorly displaced brain stem and cerebellum as in Chiari 1 malformation [64]. The proposed mechanism for the development of meningoencephalocele and spontaneous leaks in IIH is due to

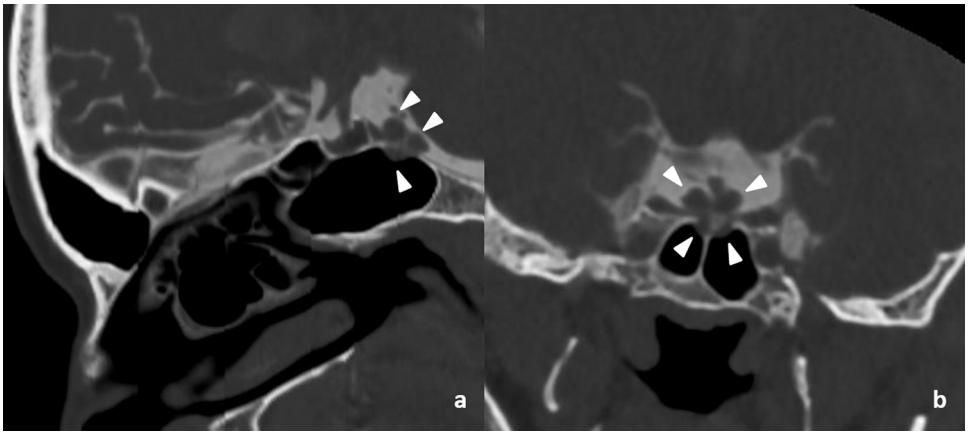

Figure 9. Thirty-two-year-old woman with watery nasal discharge on both sides: a—b: coronal and sagittal CT cisternography images in bone window shows a lobulated soft tissue lesion in prepontine cistern with bony erosion and extension into sphenoid sinus on both sides, consistent with ecchordosis physaliphora (arrowheads).

impaired CSF absorption by arachnoid granulations causing fluctuating or persistent elevation in intracranial pressure leading to bony erosions which can facilitate herniation of meninges and brain tissue through the areas of least resistance [19,65]. The bony scalloping due to arachnoid granulations and meningoencephaloceles due to IIH usually involve thin bone or in the vicinity of hyperpneumatized paranasal sinuses, such as cribriform plate, the lateral recess of sphenoid sinus, the floor of anterior and middle cranial fossa, i.e. diaphragma sella, planum sphenoidale and ethmoidale, tegmen tympani and roof of peritubal cells around the eustachian tube (Figs. 11—13) [12,28]. In cases of spontaneous leaks involving skull base, coexisting meningoencephaloceles are seen in about 50—100% of individuals [19]. The imaging findings in IIH are as described in Table 3.

The etiology of IIH must be highlighted to the operating surgeon in cases with typical imaging findings of spontaneous CSF leaks, due to its overall worse prognosis and increased incidence of recurrence post-therapy either at the initial or any other site of bony thinning/dehiscence when the underlying IIH is not tackled. Recurrence rates range up to 87% in cases of idiopathic leaks allowing consideration of additional medical therapy with acetazolamide or weight reduction therapy for optimal management [17,66]. Surgical management with CSF diversion procedures such as ventriculo — peritoneal or theco — peritoneal shunts should be the final option [19].

Diagnosis and management

Clinical and imaging diagnosis

The clinical diagnosis of CSF leaks is confirmed by the presence of β_2 transferrin or β trace protein in the CSF. Endoscopic findings of CSF leaks include visualization of clear fluid discharge which increases with provocative methods such as Valsalva maneuvers along with the presence of a bluish mass in cases of associated meningocele. The findings are most evident in cases of obvious leaks; however, the demonstration would need intrathecal administration of sodium fluorescein in cases of obscure leaks. The administration may be performed prior to surgery and/or perioperatively with lumbar drain to diagnose the leak and confirm adequate closure of the leak. Due to a higher rate of false negative studies ranging from 15% to 44%, the technique is utilized only in selected cases as a problem-solving tool [67].

Imaging studies are indispensable in localizing the site of the leak and in providing adequate insight for presurgical planning and guidance (Table 4). HRCT and MRC can demonstrate the presence of osseous defect with fluid in the adjacent paranasal sinus or tympanomastoid cavity. Polypoidal nondependent masses adjacent to the bony defect should suggest the possibility of meningoencephalocele. Surgical therapy can be considered in patients after identification of single osteodural defect on HRCT/MRC with a positive clinical correlation as it precludes the need for further imaging. In cases with multiple bony defects, CTC shows contrast extravasation at the site of concomitant osseous and dural tear confirming the active leak. CE-MRC is essentially performed in cases of intermittent leaks and demonstrates the continuity of hyperintense contrast extending from subarachnoid space into the adjacent paranasal sinus or tympanomastoid cavity. CTC and CE-MRC need to be compared with plain studies performed prior to intrathecal contrast administration to improve the sensitivity of detecting CSF leaks.

Management

Most of the posttraumatic CSF leaks resolve with conservative measures such as bed rest, head elevation and avoidance of straining [18,26,35]. In patients with spontaneous leaks, medical therapy with acetazolamide may help to reduce intracranial pressure [19]. Certain patients would need repeated CSF taps or lumbar drain placements to reduce intracranial pressure and facilitate healing [68]. Prophylaxis with antibiotics to prevent infection due to the risk of contamination remains controversial [17,18].

Surgical management is indicated in cases of persistent CSF leaks (> 2 weeks), iatrogenic, intermittent leaks and those associated with skull base tumors due to increased risk

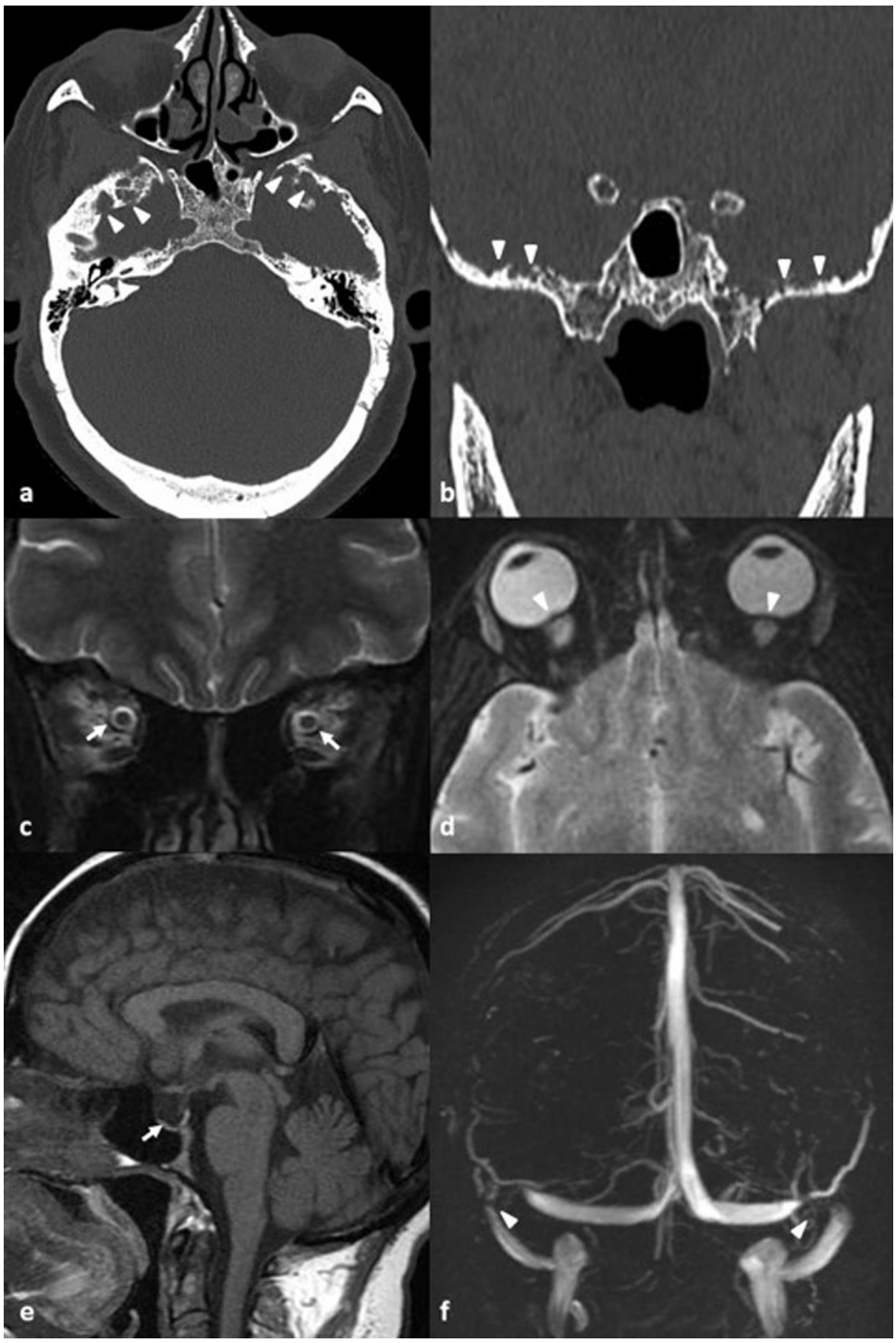

Figure 10. Thirty-six-year-old woman with intermittent headache and visual disturbance: a—b: axial and coronal CT images in bone window showing bony scalloping in floor of middle cranial fossa (arrowheads): c—d: coronal and axial T2-weighted fat saturated images of orbit showing prominence of perioptic CSF spaces (arrows) and mild protrusion of optic nerve head into the posterior chamber (arrowhead); e—f: sagittal T1-weighted and MR venography images showing empty sella (arrow) and bilateral transverse sinus stenosis (arrowhead) consistent with Idiopathic intracranial hypertension.

of brain infections. The transnasal endoscopic approach is currently the standard approach due to higher success rates and low morbidity. Spontaneous leaks may require additional medical or surgical therapy due to higher recurrence rates. Small osteodural defects are treated with mucosal or fascial overlay grafts [26]. However, CSF leaks with increased intracranial pressures and large bony defects require additional bony graft with overlay graft for proper healing

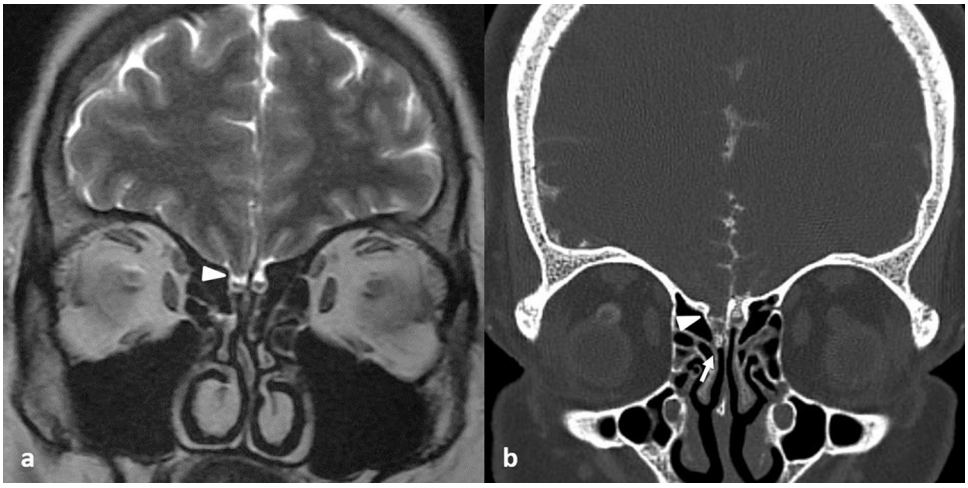

Figure 11. Forty-year-old woman with watery discharge from right nasal cavity. Low-lying gyrus rectus sign: a—b: coronal CT and MR cisternography images show decreased distance between gyrus rectus and olfactory bulb on right side (arrow head) with CSF leak into the right nasal cavity through cribriform plate (arrow).

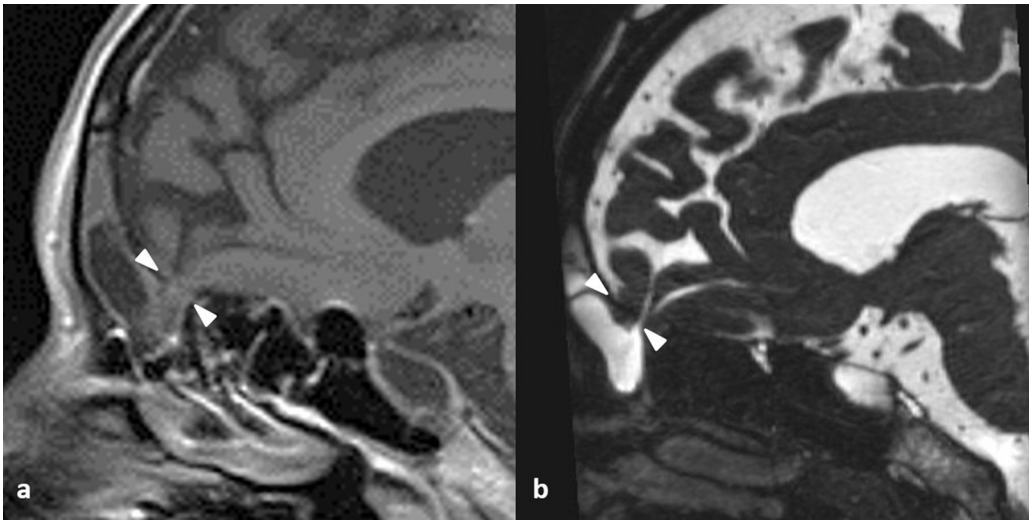

Figure 12. Forty-two-year-old woman with watery nasal discharge from left side: a—b: sagittal T1-weighted and MR cisternography images show herniation of frontal parenchyma (i.e. meningoencephalocele through the defect in posterior wall of frontal sinus) (arrowheads).

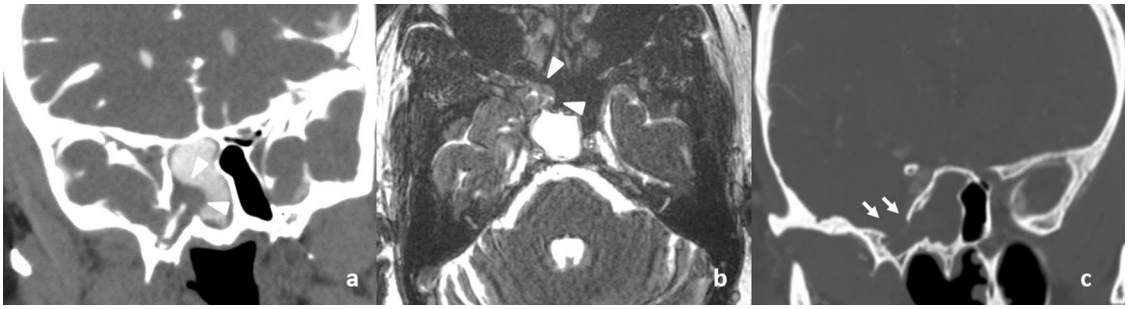

Figure 13. Thirty-six-year-old woman with watery nasal discharge on right side: a—b: CT and MR cisternography images show herniation of right medial temporal lobe into the sphenoid sinus with leakage of CSF into sphenoid sinus i.e., Sphenoidal encephalocele (arrowheads); c: coronal CT image of sphenoid sinus in bone window shows erosion of the lateral wall of sphenoid sinus (arrows).

Table 3 Imaging findings in idiopathic intracranial hypertension.

Computed tomography findings	Bony scalloping involving floor of middle cranial fossa i.e. prominent arachnoid granulations and dural ectasia Empty sella Inferiorly placed cerebellar tonsils
Magnetic resonance imaging findings	Conventional MR imaging: empty sella; prominence of perioptic CSF spaces; flattening of posterior sclera; protrusion of optic nerve head in posterior chamber; meningocele or meningoencephalocele, inferiorly placed cerebellar tonsils MR venography: bilateral transverse sinus stenosis

CSF: cerebrospinal fluid.

Table 4 Radiology reporting highlights.

Describe location, site and size of the osteodural defect
Emphasise on anatomical variations influencing vulnerability to iatrogenic injury/CSF leaks in those with, Pneumatization of the clivus, anterior clinoid process and presence of an anterior recess in cases with sellar masses Pneumatization of the anterior clinoid process in cases with paraclinoid aneurysms Pneumatization of greater wing of the sphenoid and pterygoid process in cases with Idiopathic intracranial hypertension Highlight defects in tegmen tympani, if any, in patients with paradoxical CSF rhinorrhea Emphasise on imaging findings of idiopathic intracranial hypertension (IIH) in patients with CSF leaks due to increased likelihood of recurrence and poor prognosis; when IIH is not treated Highlight the presence of meningoencephalocele and adjacent gliosis as the herniated cerebral parenchyma and meninges or both can be treated with resection or reduction into the cranial cavity

CSF: cerebrospinal fluid.

[18,26,27]. Transcranial or open approaches are preferred in CSF leaks with associated intracranial pathology which mandates surgical resection [17,26,35]. In cases of meningoencephaloceles, the herniated cerebral parenchyma and meninges or both are treated by resection or reduction into the cranial cavity.

Conclusion

CSF rhinorrhea and otorrhea are extracranial leaks due to a concomitant osseous and dural defect. It needs a structured approach for evaluation of skull base defects due to a multitude of causes. HRCT is the most preferred imaging modality with CTC reserved for patients with multiple bony defects and CE-MRC for intermittent leaks. Radiologists must be aware of skull base anatomy, variations influencing surgical approach and post-surgical prognosis as well as highlight points relevant to operating surgeon.

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Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://.dx.doi.org.10.1016/j.diii.2018.05.003.

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