Cerebrospinal fluid (CSF) leak occurs when there is an osseous and dural defect at the skull base, with direct communication of the subarachnoid space to the extracranial space, usually a paranasal sinus. Recognition of the leak site and source and appropriate treatment are necessary to avoid rhinorrhea or otorrhea, low-pressure headaches, and meningitis, known complications of CSF leak. The imaging evaluation has evolved over the past several decades. Description of current techniques available to direct treatment options, including multidetector thin-section computed tomography, and imaging recommendations are presented.

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A cerebrospinal fluid (CSF) leak or fistula describes the egress of CSF from the intracranial cavity through an osseous defect within the skull base. It implies a breach or disruption of the underlying dura mater and adherent pia-arachnoid mater, resulting in a communication between the intracranial cavity and either the nasal or middle ear cavity. Leakage of spinal fluid into either the nose or the ear has been termed CSF rhinorrhea or otorrhea, respectively, and was first described as a pathologic entity in 1899 by St Clair Thompson (1). Over the subsequent decades, the clinical importance of a CSF leak was recognized, demonstrating affected patients to be at risk of developing meningitis, up to 50% in some earlier studies (1).

CSF leaks have been classified as to the etiology and presentation. The most widely accepted classification system, described by Ommaya in 1960, divides leaks into two categories: traumatic and nontraumatic (2). A third category, spontaneous, has been defined recently and describes patients with no history of trauma or other predisposing etiology. Spontaneous CSF leak is most commonly found in the obese middle-aged woman (3–5). While the radiologic evaluation for otorrhea or rhinorrhea is similar in both the adult and the pediatric population, the emphasis in this review is on an adult CSF leak.

**Essentials**

- Cerebrospinal fluid (CSF) leaks can occur at multiple sites, and predisposing events include trauma, prior skull base or sinus surgery, chronic increased intracranial pressure, and arachnoid granulations.
- Rhinorrhea should be collected and sent for β₂-transferrin, a protein found almost exclusively in CSF, to confirm the presence of a CSF leak.
- Historically, multiple modalities have been used for the evaluation of CSF leak; however, thin-section multidetector CT with reformations may be all that is necessary for appropriate evaluation.
- Axial, coronal, and sagittal MR imaging of the skull base and MR cisternography are recommended if meningoencephalocele is suspected.
- Comprehensive evaluation should be coordinated and carefully planned by the radiologist and clinician, and a treatment algorithm is provided after the β₂-transferrin levels are obtained.

## Nontraumatic CSF Leaks

Nontraumatic CSF leaks can occur in both normal and elevated intracranial pressure states, and causes include tumors, infection, or congenital lesions. Skull base tumors may cause CSF leaks directly through erosion of the skull base or indirectly through the development of hydrocephalus. Additionally, CSF leak may be seen as a sequel of radiation and chemotherapy for treatment of large skull base tumors, with the resultant shrinkage of the lesion leading defects in the skull base and dura. For this reason, many surgeons recommend treatment of advanced skull base tumors with craniofacial resection and dural reconstruction either prior to or after tumor ablation with chemotherapy and radiation therapy to prevent CSF leak and infection (8). Osteoradionecrosis of the temporal bone has also been reported to cause CSF otorrhea (9).

Tumors or congenital lesions, such as untreated aqueductal stenosis, may lead to noncommunicating hydrocephalus and eventual ventricular decompression through the cribriform plate or sella turcica (10). In these cases, the chronically elevated intracranial pressure causes CSF to leak from a weak or potential pathway, usually with massive dilatation of the frontal horns of the lateral ventricles that expand and leak into the cribriform plate. However, CSF leak secondary to massive untreated hydrocephalus is currently relatively uncommon in the United States.

Other congenital causes of CSF leak are due to developmental skull base de-
fected with associated meningoceles, meningoencephaloceles, large arachnoid granulations or cysts, or congenital inner ear anomalies (1–4).

**Spontaneous CSF Leaks**

Finally, spontaneous, or primary, CSF fistula is considered a separate entity, describing patients with no other discernible etiology for their CSF leak (i.e., history of trauma, tumor, or congenital abnormality). Demographically, these leaks most frequently occur in obese middle-aged women and frequently coexist with a small encephalocele (11–14). Although spontaneous leaks have been reported to be rare (11), our experience suggests that they are more common than previously appreciated, and with increasing average body mass indexes in the United States, we expect them to be even more frequent.

In these patients, associated empty sella syndrome can occur, leading some to hypothesize a similar etiology to that of idiopathic or benign intracranial hypertension (formerly termed pseudotumor cerebri). One theory proposed to explain spontaneous CSF leaks is that chronically increased intracranial pressure results in arachnoid granulations that fill small pits in the inner table of the calvarium or sinus wall (Fig 1). The dura thins and small diverticula of arachnoid extend through the defect and rupture (15,16). Another theory that has been proposed begins with impaired CSF absorption, leading to transiently elevated pulsatile CSF pressure that ultimately causes dural herniation and a CSF leak through anatomic weakened sites (14).

Spontaneous CSF fistula can occur anywhere in the skull base, but is most common at the ethmoid roof, cribriform plate, or at two locations in the sphenoid sinus, perisella or at the inferolateral or pterygoid recesses (11,14,16).

**Diagnosis**

The accurate diagnosis of a CSF leak is necessary prior to any potential intervention. The method of diagnosis depends greatly on the patient’s clinical presentation. Patients who present early after trauma may have pneumocephalus or active CSF rhinorrhea or otorrhea. However, the classic clinical presentation is a patient with intermittent clear nasal discharge, frequently unilateral, often exacerbated by Valsalva maneuvers.

Regardless of the presence or specific etiology, the clinical diagnosis is confirmed by obtaining a sample of the nasal or otologic secretions and measuring the β2-transferrin activity. β2-Transferrin, a protein highly specific for human CSF, is an immunohistochemical test that is considered the standard for the clinical diagnosis of a CSF leak (17–20). At least 0.5 mL of fluid is necessary, and there may be a false-positive result in the setting of chronic liver disease or inborn errors of metabolism of glycoprotein (21). A positive β2-transferrin result confirms an active CSF leak, but cross-sectional imaging is necessary to locate the site of the defect. Some patients experience intermittent leaks, and β2-transferrin can only be collected when the CSF is actively leaking. Finally, occasionally patients will present with recurrent episodes of meningitis, without symptoms of nasal drainage. This implies an occult CSF fistula, and careful imaging work-up should be performed (22).

**Imaging Evaluation**

Imaging studies are paramount in the work up of a presumed CSF leak. The goals of imaging are to confirm the diagnosis, evaluate for an underlying cause, localize and characterize the defect site prior to surgical repair, and exclude an associated meningocele at the defect. Since small skull base defects are now routinely repaired with nasal endoscopy, accurate localization is imperative.

Imaging was first used, to our knowledge, by Dandy in 1926, when he recognized the value of radiographs to diagnose pneumocephalus (1). Since that time, a variety of nuclear medicine and cross-sectional computed tomographic (CT) and magnetic resonance (MR) imaging techniques have been applied to diagnose, localize, and characterize skull base defects responsible for leakage of CSF. That there has been no imaging “gold standard” reflects the difficulty with this elusive diagnosis.

Nuclear Medicine

Nuclear medicine studies, specifically radionuclide cisternography, became...
popular in the 1970s and 80s in the diagnostic evaluation of a CSF leak (23). The CSF must be actively leaking at the time of the study. Regardless of the radiotracer used, the procedure involves lumbar intrathecal administration of a radionuclide tracer, placement of patient in a Trendelenburg position to facilitate cranial flow of the tracer, followed by image acquisition of the head and paranasal sinuses in both anterior and lateral projections once the radiotracer has reached the basal cisterns. The most widely used radiotracer is technetium 99m-labeled diethylenetriaminepentaacetic acid, which has a relatively short half-life of about 6 hours. The accumulation of the radiotracer within the nasal cavity or nasopharynx heralds a positive finding that suggests a CSF fistula and provides some information regarding the location of the communication (24,25). In our practice, radionuclide cisternography is used only when CSF leak is suspected but is occult, β2-transferrin cannot be collected, and imaging does not show a definite skull base defect.

Radionuclide cisternography is limited to detecting CSF leaks that are active at the time of the study. Several techniques have been utilized to increase the sensitivity of the examination. The first and most universally accepted technique involves the strategic endoscopic placement of nasal pledgets by the otolaryngologist prior to administration of the radiotracer agent. These are most frequently placed in the office setting, usually 1–2 hours before intrathecal radiotracer administration, bilaterally in the sphenoid recess, adjacent to the middle meatus, and either in the region of the cribriform plates, olfactory recess, or eustachian tubes. At our institution, planar image acquisition is performed 2–4 hours and 24 hours after intrathecal radiotracer administration (indium 111 [111In] diethylenetriaminepentaacetic acid, see below), with imaging of the head and neck (and often spinal) regions, depending on the clinical history. The pledgets are removed when the patient returns 24 hours later, and the activity of the radiotracer within the pledgets is measured and compared to that within the serum. A positive result is indicated by a pledget-to-serum activity ratio of 1.5–3.0:1 (24,25). While this technique increases the sensitivity of the examination, reportedly up to 76% (26), opponents still argue that precise localization of the site of the defect is limited, as nasal secretions mix to collect on all of the pledgets on a given side (5). In our experience, few patients tolerate six intranasal pledgets for 24 hours, and when they return after 24 hours, one or more of the cotton pledgets have fallen out.

For intermittent CSF leaks, prolonged cisternography by using 111In diethylenetriaminepentaacetic acid, with a longer biological half-life of 2.8 days, is available, allowing delayed image acquisition of up to 24–72 hours after the original administration of the radiotracer. In one study (25), this method resulted in a 25% success rate of demonstrating intermittent leaks. This technique requires great patient compliance to return for repeat imaging, sometimes up to 72 hours later, and prolonged placement of the nasal pledgets (26). In an effort to shorten the duration of the examination, improve placement of the radiotracer bolus to the basal cisterns, and possibly accentuate small or pinpoint dural fistulas, the method of high or overpressure cisternography was developed. It involves administration of the radiotracer, and transiently and under a controlled setting, it elevates the intracranial pressure by intrathecal infusion of saline or artificial CSF. The major side effect is patient discomfort and headache (27). Thus, in our practice, we do not perform intrathecal high-pressure techniques to exacerbate a leak. Finally, positioning the patient in a provocative position, such as prone, or in a head-hanging position during image acquisition may improve observation of intermittent leaks (28).

Even if the patient can tolerate the nasal pledgets, none of the nuclear medicine examinations adequately localize and characterize the defect well enough to be the sole diagnostic examination. Therefore, radionuclide cisternography is reserved for complex cases when the diagnosis is in question (5,7,23,26).

**CT Imaging**

The use of CT for evaluation of skull base defects has become a mainstay in the work up of CSF fistula, due to its ability to resolve osseous structures (29,30). With the advent of modern thin-section and multidetector CT scanners, smaller defects are visualized with
a reported sensitivity as high as 92% and specificity of 100% (31) (Figs 2, 3). An active leak does not need to be present for performing a multidetector CT of the skull base.

Most studies to date have been performed with the use of conventional single-detector CT scanners, in which 1–1.5-mm-thick axial and direct coronal sections are obtained through paranasal sinuses and temporal bones without the use of intrathecal contrast material. A bone algorithm should always be used. Axial images are considered best for evaluation of the posterior wall of the frontal sinus, the posterior and lateral walls of the sphenoid sinus, and the mastoid complex. Coronal images are necessary for evaluation of the cribiform plates, roof of the ethmoid and sphenoid sinuses, and tegmen tympani (5,16,18,23,26,29,30).

In our opinion, direct coronal imaging is no longer necessary for CT imaging alone when thin-section multidetector CT is available. Multidetector CT involves rapid, continuous volumetric acquisition of raw data by using thin collimation, allowing for isotropic voxels, which leads to improved resolution for three-dimensional and multiplanar reformations (32). Thus, with multidetector CT, images can be acquired in only the axial plane, then the raw data can be reformatted into additional planes without a compromise in image resolution. Minimum detector collimation is recommended, with reconstruction intervals chosen so that the multiplanar reformations are optimized.

The CT findings suggestive of a CSF leak include a skull base bone defect and an air-fluid level or opacification of the contiguous sinus. In the evaluation of temporal bone CT scans, a unilaterally opacified mastoid and middle ear, in the presence of a tegmen defect or fracture through an inner ear structure, is consistent with CSF fistula (Fig 4). CT may also be helpful in evaluation of additional nontraumatic causes of CSF leak, such as an intracranial or skull base tumor or meningocoele and/or meningoencephalocele, which may then require further evaluation with MR imaging (26,30,31). Finally, the CT data can provide intraoperative image guidance for the endoscopic repair of a CSF leak.

At our institution, multidetector CT is the first study, and frequently the only study, used to localize the site of the skull base defect and CSF leak (33). However, as discussed below, situations may arise that complicate the diagnosis, such as multiple osseous defects and adjacent opacified sinuses (ie, in the posttraumatic patient). In this instance, further imaging and evaluation may be necessary to localize the site of the leak with CT cisternography.

CT Cisternography Since its development in the late 1970s, CT cisternography has been the stan-
standard for evaluating a possible CSF fistula (34–38). This technique traditionally involves obtaining thin-section coronal and axial CT images in both prone and supine positions through the region of interest (maxillofacial or temporal region) both before and after intrathecal contrast material. Approximately 3–10 mL of an iodinated nonionic low-osmolar contrast agent is administered by means of lumbar puncture, and the patient is placed in a Trendelenburg position to opacify the basal cisterns, followed by CT imaging immediately after administration of contrast material. Maneuvers that provoke an active leak, such as sneezing or head hanging, are performed prior to the CT portion of cisternography. Postcontrast images are then compared with the precontrast images. A positive result involves the presence of a skull base defect and contrast opacification within the sinus, nasal cavity, or middle ear (Fig 5). If the sinus contents do not visually show an attenuation increase after cisternography, the region of interest feature of the workstation may be used to measure the Hounsfield units of fluid opacification within the sinuses on both pre- and postcontrast CT scans. An increase in Hounsfield units of 50% or greater after CT cisternography is considered a positive study for a CSF leak (26). Acquisition of precisternogram images is important to differentiate extracranial contrast material accumulation from sclerotic sinus walls, benign high-attenuation inspissated sinus secretions, or blood (Fig 6). Optimal window and level settings are chosen on the workstation to enable differentiation of the bony sinus walls from the contrast material accumulating in the sinus (23).

While this examination appears to combine the best of both worlds, being able to identify the presence of an active CSF leak and dural fistula and the precise anatomic characterization and localization of the osseous defect, there are limitations to CT cisternography. Similar to radionuclide cisternography, the usefulness of the cisternogram portion of the examination is limited to patients in whom the CSF is actively leaking at the time of the examination, either spontaneously or with provocative maneuvers. High-pressure cisternography, to precipitate an intermittent leak, reportedly increases the yield (27), but we do not perform that technique due to potential complications of headache or “opening” a defect. When the leak is intermittent or nonactive, CT cisternography may be no more sensitive than noncontrast CT alone (23,24,26). The overall reported sensitivity of CT cisternography is 48% (26), with sensitivity...
from 92% in active leaks and only 40% in inactive leaks (31).

CT cisternography is a minimally invasive procedure, but adds to expense and contains small but inherent risks of infection and lumbar CSF leak. While low-osmolarity contrast agents have a very low incidence of the major side effects seen with prior agents, including headache, meningeal irritation, and seizures, the possibility does persist. Finally, both cisternographic techniques, CT and radionuclide, are relatively contraindicated in patients with meningitis or elevated intracranial pressure, and CT cisternography may be performed concomitantly with radiotracer studies; however, we do not feel that this approach is necessary or cost-effective. We only couple the two examinations in the most complex cases, when the presence of a leak is questionable and after all other imaging findings have been unrevealing.

Studies have compared thin-section CT alone with CT cisternography, Lloyd et al (30) have stated that thin-section CT was all that was necessary for the diagnosis of CSF leaks. In 1999, a retrospective review (26) of 42 patients with clinically proved CSF leaks showed a bone defect in 30 patients that was evident on thin-section CT scans, and 20 of those patients had positive results at cisternography. Every patient with a positive cisternogram had an osseous defect that was identified at noncontrast CT. However, 10 patients had an osseous defect seen at CT, without a corresponding positive cisternogram (26).

Another prospective study (31) evaluated 45 patients with clinically suspected CSF rhinorrhea and showed that plain thin-section CT alone depicted the presence or absence of CSF fistula in 42 of 45 patients, citing an accuracy of 93%, irrespective of whether a CSF was actively leaking at the time of the study. Both of these studies advocate thin-section CT alone as the initial screening examination in the work up of a CSF leak, with cisternography reserved for patients with multiple skull base fractures and/or defects, patients with negative CT scans, or those in whom the diagnosis is in question. In our experience, cisternography in patients with negative CT scans rarely confirms a CSF leak. Finally, most of the current studies regarding the use of thin-section CT for the diagnosis of a CSF leak were performed before the routine use of multidetector CT, which allows faster acquisition of thinner images and which likely has only improved resolution and diagnostic capability of CT, although this has yet to be determined in formal studies.

MR Imaging

MR imaging techniques offer noninvasive methods of imaging a CSF leak and are indicated to assess possible encephalocele or meningoencephalocele. Herniation of brain parenchyma or meninges through the bone defect may be difficult to differentiate from obstructed secretions on CT scans but is obvious on MR images (Fig 7). An MR is always performed in our practice if there is an osseous defect and complete opacification of an adjacent sinus in the patient with a possible CSF leak, as these findings could indicate the presence of a meningocele or encephalocele, particularly if the soft-tissue opacification is lobular or nondependent.

MR cisternography typically involves heavily T2-weighted fast spin-echo sequences with fat suppression and subtraction of the adjacent background tissue signal to enhance conspicuity of the fistulous tract, or CSF column (Fig 8). The fast spin-echo sequences have decreased susceptibility artifacts at the air-bone interface of the skull base, compared with conventional T2-weighted imaging (31). Images are generally obtained in coronal, axial, and sagittal planes, and, similar to conventional MR, the finding of a contiguous CSF column communicating from the subarachnoid space to the extracranial space and/or the herniation of brain parenchyma and/or meninges extracranially heralds a positive examination (39).

At our institution, in addition to the routine sagittal and axial T1-weighted and fluid-attenuated inversion recovery images of the whole brain, the MR cisternographic technique includes coronal T1-weighted images acquired at 3-mm section thickness with a 1-mm gap, a matrix of 256 × 256, and a field of view of 230 mm. Overlapping heavily T2-weighted fast spin-echo sequences with fat suppression are then performed at 6 mm with a 1-mm gap and

**Figure 7**

Images in adult woman with spontaneous right-sided rhinorrhea. (a) Coronal and (b) axial T2-weighted MR images through anterior cranial fossa reveal right gyrus rectus herniating inferiorly in the region of the right cribriform plate, with loss of normal CSF signal at that level, which is consistent with a small right-sided cribriform encephalocele (arrow). The left side is normal.

(a)

(b)
are reconstructed at 5 mm with parameters of 8000/1000 (repetition time msec/echo time msec), two signals acquired, a turbo factor of 256, and a 250-mm field of view, with images acquired in sagittal, coronal, and axial planes. Gadolinium-enhanced images in all three planes help differentiate potential meningocele from sinus secretions and may detect dural enhancement (Fig 8).

The data on MR cisternography are promising, with studies touting sensitivities of 87% and accuracies ranging 78%–100% (22,31,35). The proponents of MR cisternography state that the noninvasive and nonionizing technique can localize the actual site of a fistulous tract, which may be particularly helpful in patients who have multiple potential fracture sites or osseous defects at CT. While many continue to feel that, similar to CT and radionuclide cisternography, visualization of fistulas is limited to those actively leaking, other authors have reported success in localizing intermittent or low-flow leaks (22,31).

A study from 1998 (31) reported a sensitivity of 87% and accuracy of 89% for MR cisternography, compared with a sensitivity of 92% and accuracy of 92% for thin-section CT alone, taking into account both active and inactive CSF leaks. Additionally, while MR cisternography showed a high positive predictive value, the negative predictive value for both active and inactive leaks is relatively lower for MR cisternography (58%) compared with CT alone (70%).

Early reports in which 0.5 mL of intrathecal gadolinium-enhanced contrast material was used with MR cisternography show promise (40–43). This is currently an off-label use of gadolin-
Radiology Imaging of Skull Base Cerebrospinal Fluid Leaks Lloyd et al

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CT and MR Imaging Findings

The most common location for a CSF leak is at the cribiform plate, followed by anterior ethmoid, posterior ethmoid, and sphenoid and frontal sinus. Tegmen tympani is less common but should be included in the imaging, as CSF leak into the middle ear can manifest with rhinorrhea. In our experience, most defects can be detected at multidetector CT, when the reconstruction intervals are submillimeter (Figs 2–5). Active manipulation of the data on a three-dimensional workstation by the radiologist facilitates defect detection by allowing evaluation in multiple obliquities in addition to standard axial, coronal, and sagittal planes, as well as manual optimization of window and level settings. If a bone dehiscence is detected, the size of the defect should be measured in two dimensions so the surgeon can be prepared to repair the hole. Measurements on a workstation correlate well with the size of the defect found at surgery (33).

Anterior skull base defects, either congenital, secondary to trauma, or iatrogenic, are usually adjacent to the vertical insertion of the middle turbinate or at the lateral lamella. Both the cribiform plate and lamella may be normally very thin, making detection of a defect even harder. Comparison with the contralateral side is helpful. Soft-tissue or mucosal thickening beneath a thin cribiform plate or ethmoid roof, especially if asymmetric, is evidence that the thin skull base may be due to a defect. The roof of the nasal cavity, including the space between the nasal septum and the vertical insertion of the middle turbinates, should be carefully evaluated for fluid or soft tissue. Deviation of the crista galli, probably due to weakness at the junction with the cribiform plate, is associated with a CSF leak (44).

Spontaneous CSF leak, seen in the obese middle-aged female, deserves special mention, especially with the increasing body mass indexes in the United States. In our experience, there are two sites that should be carefully evaluated: the cribiform plate and lateral lamella and the sphenoid sinus roof. Extensive sphenoid sinus pneumatization into the inferolateral recess appears to predispose one to a CSF leak. Coronal reformations show small bone defects lateral to the foramen rotundum, at the most lateral sphenoid sinus roof near the middle cranial fossa floor.

MR of the skull base is always indicated if soft tissue or fluid is present near the bone defect at multidetector CT. At MR cisternography, a continuous high-signal-intensity column on T2-weighted images from the subarachnoid space into the involved sinus is considered a positive study. Multiplanar, T1- and T2-weighted images help characterize the soft tissue and determine whether it is fluid, mucosal thickening, or herniation of brain or meninges through the bone defect. Sagging of the gyri rectus, when the cribiform plate and/or ethmoid roof is the site of the leak, is common. Subtle encephalomalacia is anecdotally often present at the site of leak, seen in all types of CSF leak (not only postraumatic), and especially in cases with meningoencephalocele, possibly secondary to traction on the brain. Dural enhancement after gadolinium chelate administration is another secondary sign.

CT cisternography is usually not necessary, as the defect can be detected at multidetector CT. However, as mentioned earlier, CT cisternography can be useful in cases of multiple osseous defects with adjacent opacification of the sinuses.

At our institution, CT cisternography is always performed with a methodical step-wise approach. First, thin-section submillimeter multidetector CT in the supine position is performed through the sinuses and temporal bones. We obtain the initial pre-cisternogram images according to an image-guided protocol by using supine 0.625-mm-thick sections in an axial plane only to limit motion and ameliorate artifacts which can be seen with direct coronal images. The data set is actively reviewed and manipulated on the workstation by the radiologist, and each site is carefully assessed in multiple planes. The patient then goes to the fluoroscopy suite, where 3–10 mL of nonionic low-osmolar contrast material is placed by means of a lumbar puncture after return of clear CSF. At our institution, we prefer the relatively higher osmolality (300-mg/mL) dose of the iodinated contrast material (iohexol) to the 240-mg/mL dose, as we feel there is better opacification of the basilar cisterns. The cranial flow of contrast material is confirmed with fluoroscopy, and the patient remains head down for at least 90 seconds. Prior to repeat CT imaging, the patient is asked to perform any provocative maneuvers that exacerbate the leak. The patient then returns to CT, where a direct coronal CT scan in the prone position is obtained. This is the only instance where we feel that direct coronal images are warranted, and this is done to provoke the leak in the prone position and to visualize the tract into the sinuses, especially useful for ethmoid leaks. Most patients report increase in rhinorrhea in the prone position. Axial images are also obtained, again in the supine position and according to an image-guided protocol, with 0.625-mm section thickness, which allows for three-dimensional reformations to be generated on a workstation. A positive cisternogram is contrast material accumulation in the nasal cavity, sinus, middle ear, or mastoid complex or an increase in Hounsfield units in sinus fluid, and an associated bone defect. When the leak is high volume and rapid, contrast material at the leak site may be less dense than at the contralateral side, due to rapid washout and leaking of the
contrast material and CSF (Fig 9). With this careful evaluation, even the most elusive CSF leaks can usually be detected.

**Intraoperative and/or Endoscopic Evaluation**

Most patients suspected of having CSF rhinorrhea will undergo endoscopic evaluation by an otolaryngologist as part of their initial examination. Depending on the degree of exposure of the skull base (ie, prior endoscopic sinus surgery) and the size of the defect, Valsalva maneuver may result in CSF pooling that can be seen in the office. Intrathecal administration of 5% sodium fluorescein, a technique described by Kirchner et al in the 1960s, followed by either nasal pledget placement or thorough endoscopic evaluation may also aid in localization of the site of CSF leak on examination (5,18,23,45). Its use is primarily intraoperative, when wide surgical exposure can be obtained to confirm the site of the leak in equivocal cases and also to confirm watertight closure of the defect after repair and graft placement. It is often administered prior to the induction of general anesthesia, occasionally at the time of lumbar drain placement.

**Treatment**

Most CSF leaks (particularly posttraumatic) will resolve spontaneously with conservative measures, including bed rest, head elevation, and avoidance of straining. Occasionally, repeat spinal taps or lumbar drain placements are necessary to decrease the intracranial pressure and encourage healing (46). However, because of the risk of infection, persistent CSF leaks require surgical management. The surgical approach used depends on the size, site, and nature of the defect.

Intracranial repair, or open repair, since its advent in the 1920s has traditionally been the definitive method to address a CSF leak, with the benefits of being able to directly visualize and repair the dural tear, often with the use of a pericranial flap. The disadvantages, however, include the morbidity of a craniotomy, as well as anosmia associated with the disruption of olfactory bulbs and tracts (47). Additionally, the success rates of open repair often approach only 80%, with recurrence rates of up to 40% in some reports (48).

Endoscopic sinus surgery techniques have allowed for a transnasal approach to repair anterior and central skull base CSF leaks. Exposure of the defect can be difficult and pre- and intraoperative localization of the defect is paramount, often by direct inspection or by using intrathecal fluorescein. Some endoscopic surgeons routinely use intraoperative image guidance, particularly for revision surgeries. Once the defect is identified, the recipient bed is prepared, any encephalocele is reduced or resected, and the defect is grafted, either with a bone, fascial, or mucosal graft or often some combination thereof. Harvest sites for grafts or flaps often include the temporalis fascia, nasal septum, and middle turbinate, as well as synthetic materials such as hydroxyapatite and tissue adhesives such as fibrin glue. In experienced hands, the reported success rates of extracranial endoscopic repair approach 90% on initial attempt, an improvement over intracranial repair, without the morbidity of craniotomy. However, limitations still exist with extracranial techniques, and patients with multiple defects, deformed skull bases, invasive skull base tumors with extracranial extension, or high-pressure leaks may require intracranial approaches (5,48).

**Our Approach**

We have developed an algorithm for the patient with a definite or possible CSF leak. A careful history is taken by the surgeon to assess for a predisposing cause that might direct the work-up. For example, if there has been prior endoscopic sinus surgery, the anterior skull base is carefully examined. If the leak is spontaneous with no predisposing etiology, the leak is likely at the anterior skull base, the cribiform plate, or superior wall of the sphenoid sinus, especially in a middle-aged obese patient. Fluid is collected either in the office or the patient is sent home with a vial to collect fluid for $\beta_2$-transferrin analysis.

In our practice, the initial study is bone algorithm multidetector CT with reconstruction intervals of less than 1 mm and multiplanar reformations in all planes. It is suggested that the radiologist manipulate the data and perform reformations at a workstation, as detecting the site of the leak may require oblique planes. We have found that standard coronal and sagittal reformations performed by the technologist are not enough (33). Even if there is a predisposing event that suggests the site of the leak, the entire skull base and mastoid and/or middle ears are scanned.

Our algorithm is described as follows:

1. When the $\beta_2$-transferrin test is positive and multidetector CT scan shows a single osseous defect, no other imaging is necessary to direct the repair. This is the most common scenario in our practice.

2. If the $\beta_2$-transferrin test is positive and the multidetector CT scan shows more than one osseous defect
and an opacified sinus, a CT cisternogram will be obtained to determine which site is actively leaking.

3. If the $\beta_2$-transferrin test is positive but the multidetector CT scan does not show an osseous defect, the $\beta_2$-transferrin test is repeated in the rare chance the result was a false-positive. If a second sample is positive, CT cisternography or MR cisternography may be performed, preferably when the CSF is actively leaking. This clinical scenario is, in our experience, very rare. If all imaging findings are negative and repeat $\beta_2$-transferrin test is positive, the patient is endoscopically examined under anesthesia directed at the side of prior trauma, if applicable, and possibly with the use of intrathecal fluorescein, evaluating for the presence of pulsatile pooling of CSF or fluorescein. This step remains in the algorithm because occasionally osseous defects may be too small to resolve with current imaging techniques.

4. CT cisternography, therefore, is reserved for patients who have a negative multidetector CT scan but in whom the CSF is actively leaking or those with more than one defect.

5. MR cisternography is always performed if multidetector CT reveals an osseous defect with soft-tissue opacification within an adjacent sinus (particularly if it is lobular or nondependent) to exclude the possibility of meningoecele or encephalocele. Gadolinium chelate is performed, preferably when the CSF is actively leaking or those with more than one defect.

6. Only in the most complex cases is nuclear cisternography with pledges performed, and then to help document the presence and side of the leak.

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