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## Neuroradiology

# Dual-energy CT cisternography in the evaluation of CSF leaks: A novel approach

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### ABSTRACT

Cerebrospinal fluid leaks pose a serious threat to patients as they represent an unchecked communication between the subarachnoid space and the extracranial environment. Accurate localization of the leakage site is essential for treatment planning. We describe the novel utilization of dual-energy computed tomography technology in cisternography in the evaluation of a patient with a cerebrospinal fluid leak.

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## Introduction

Cerebrospinal fluid (CSF) leaks occur when the normal separation of the subarachnoid space is disrupted. The causes of CSF leaks have been grouped in various fashions, with the most prevalent grouping being traumatic, nontraumatic, and spontaneous [1–3]. Traumatic CSF leaks, which include both accidental trauma and iatrogenic postsurgical trauma, are the most common cause accounting for 80%–90% of the leaks [1,2,4]. Less common causes include tumors, congenital abnormalities, postradiation exposure, or prior infection. The spontaneous grouping is reserved for cases in which no other apparent cause for the leak is identified.

Although in many instances CSF leaks resolve with conservative care, persistent fistulous connections to the subarachnoid space pose a risk for serious complications ranging from meningitis to stroke or even death. In such cases, it is critical to identify the site of leakage so that appropriate surgical management can be pursued.

Currently, several different radiological modalities are used to identify the site of CSF leaks, including high-resolution computed tomography (HRCT), standard computed tomography (CT) cisternography, magnetic resonance imaging cisternography, and radionuclide cisternography. In this article, we introduce dual-energy computed tomography (DECT) cisternography as a novel technique for evaluating CSF leaks.

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DECT takes advantage of alterations in the x-ray attenuation of materials at different energy levels to improve diagnostic accuracy. Attenuation of materials on CT is based on 2 mechanisms: Compton scatter and the photoelectric effect. The photoelectric effect primarily determines image quality and radiation dose in diagnostic CT, as it is dependent upon both the energy of the x-ray and the atomic number of the material, such that higher atomic number materials are influenced more by this effect and produce greater attenuation. Thus, by altering the energy of the x-ray source, differences in attenuation can be produced that are significant in materials with high atomic numbers (ie, iodine), but not as substantial in materials with lower atomic numbers (ie, those seen in soft tissues) [5,6].

Single-energy CT scans are generally performed at peak energies between 100 and 140 kVp, depending on the clinical indication and the patient size. DECT scanners create image data at 2 different energy spectra simultaneously, frequently a lower energy (80 kVp) and a higher energy (140 kVp). Methods for acquiring DECT data vary, depending on the manufacturer: dual-source CT scanners utilize 2 radiation tubes offset at 90° with simultaneous acquisition; fast peak kilovoltage switching techniques use 1 radiation tube that rapidly alternates between low- and high-energy output; dual detector layer techniques utilize a single radiation tube paired with a dual-layered image detector that alters the effective energy. Ultimately, the data sets generated via the dual-energy scanner are postprocessed to generate reconstructions that are useful in the clinical setting.

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## Case presentation

### Patient

The patient was a 66-year-old woman with a medical history of right CSF otorrhea status post repair via craniotomy with dural patching in the 1980s. The patient presented to our academic medical center complaining of tinnitus and positional right nasal drainage when she was lying on her side for the past several months. Before arrival at our institution, the patient underwent an outside magnetic resonance imaging, which had suggested a possible CSF leak and recommended cisternography for further evaluation. Physical examination at the time of presentation revealed mild bilateral proptosis, with the right greater than the left, but was otherwise unremarkable. A sinonasal endoscopy was performed, which showed a rightward deviation of the nasal septum, but was otherwise unremarkable without being able to identify a site of CSF leak. A decision was made to proceed with DECT cisternography for further evaluation.

### Procedure

The patient was placed in the prone position for lumbar puncture. The site was cleaned with chlorohexidine and local anesthesia was achieved via injection of 1% lidocaine. Under fluoroscopic guidance, the spinal needle was successfully guided into the subarachnoid space at the L2-L3 level. Five milliliters of iodinated contrast (Omnipaque 300 mg/mL) was injected into

the subarachnoid space for a total of 1.5 g of iodine. The patient was placed in a Trendelenburg position until contrast was seen to pass from the lumbar thecal sac into the cranial cavity. The patient was then transported to the CT scanner so that imaging could be obtained.

### Imaging

A Somatom Definition FLASH CT scanner (Siemens, Germany) with dual-energy, dual-source imaging capability was used for the acquisition of cisternography images. The dual-energy protocol was as follows: tube A was set at 80 kVp and 530 mAs; tube B was set at 140 kVp with tin filtration and 265 mAs. Collimation was 0.6 mm, the pitch was 0.7, and the gantry rotation time was 0.28 seconds. Images were obtained from above the frontal sinuses to below the skull base in the axial plane. Standard linearly blended polychromatic images were generated in the axial, coronal, and sagittal planes with a slice thickness of 0.75 mm, consisting of 60% data from the 80-kVp tube and 40% data from the 140-kVp tube with a tin filter. Postprocessing with Syngovia software (Siemens, Germany) was performed to create dual-energy image reformats to maximize the visibility of the CSF leakage. A monoenergetic low kiloelectron-volt data set was generated by selecting data at the 40-keV energy level and windowing images to achieve the best noise optimization. To generate iodine overlay images, the brain hemorrhage algorithm was selected with a resolution of 1, a maximum Hounsfield unit value of 3071, and an iodine ratio of 3.01. Finally, the bone subtraction algorithm was applied to the data set with a resolution of 2, a maximum Hounsfield unit value of 700, and an iodine ratio of 2.5.

Appropriate filling of the cisternal spaces with iodinated contrast was confirmed. Focal opacification of indeterminate attenuation was noted in the right olfactory recess of the nasal cavity on linearly blended images, which most closely approximate the appearance of standard single-energy CT images at 120 kVp (Fig. 1A and 1B). Noise-optimized monoenergetic reconstructions at 40 keV showed a markedly increased attenuation and conspicuity of fluid in the right olfactory recess, confirming an iodinated contrast leakage from the subarachnoid space through the cribriform plate (Fig. 1C). An iodine overlay map fused on anatomic images further increased the conspicuity of the contrast leakage and clearly demonstrated the pathway of the CSF egress (Fig. 2). Bone removal images also enhanced the visibility of the contrast leakage into the nasal cavity by removing the adjacent sinonasal and skull base bony structures (Fig. 3).

### Follow-up

The patient subsequently went to surgery, at which time a CSF leak was identified at the right cribriform plate of the skull base confirming imaging findings. Opening pressure in the CSF space at the time of surgery was elevated at 28 cm H<sub>2</sub>O, and the patient was subsequently started on Diamox for the management of elevated intracranial pressure. Multiple postsurgical sinonasal endoscopies showed appropriate healing of the surgical site without evidence of a CSF leak. Clinically, the patient has done well, although she does continue to have mild tinnitus, which has been chronic since the repair. The patient has



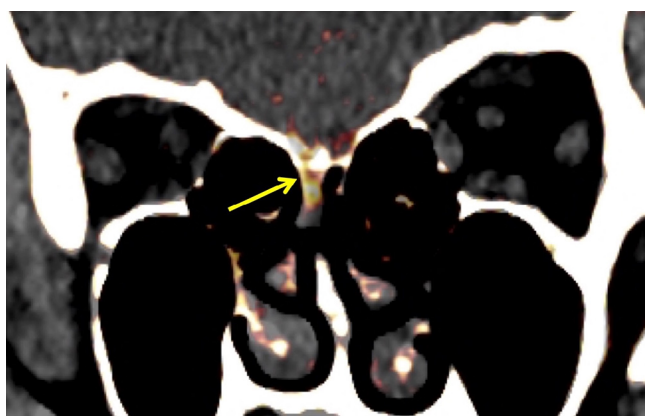
**Fig. 1** – Coronal computed tomography to cisternography images of the anterior skull base. Bone windows (A) and soft tissue windows (B) of blended dual-energy computed tomography data demonstrate an osseous defect of the right cribriform plate. There is opacity of the right olfactory recess below the cribriform plate (yellow arrows), with attenuation that is indeterminate as to iodine-enhanced cerebrospinal fluid leakage or mucosal thickening. The virtual monoenergetic noise-optimized reconstruction at 40 keV (C) demonstrates a markedly greater attenuation of the fluid in the olfactory recess (yellow arrow), unambiguously confirming iodine-enhanced cerebrospinal fluid leakage and improving diagnostic confidence.

not had any additional episodes of CSF leakage in the last year following her repair.

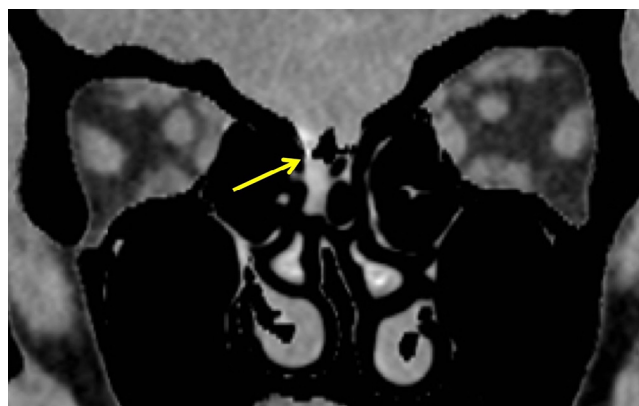
## Discussion

In this case, we demonstrated the utility of DECT technology to enhance the visibility of an active CSF leak at cisternography and to improve diagnostic confidence for surgical planning. Although evidence of a leak could be appreciated on blended images alone, utilizing low-energy monoenergetic reformatting made the communication much more evident by unambiguously demonstrating iodinated material in the nasal cavity. The increased conspicuity provided by DECT reconstructions may allow for the identification of leaks in future clinical scenarios that would otherwise not be appreciated. This may be particularly important for surgical planning for patients with a refractory CSF leak in whom a definitive site of leakage has not yet been identified.

HRCT is currently the initial test of choice for CSF leaks as it provides good bone detail, is noninvasive, does not require active leaking at the time of the study, and is more cost effective than other options. In 1 study of 42 patients presenting with CSF leak, HRCT identified bone defects and extracranial fluid or mucosal thickening in 30 of 42 patients who presented with clinical symptoms of CSF leak compared with only 20 of 42 positive results with CT cisternography or radio-nuclide cisternography [7]. Of the 30 patients, 21 went for surgical repair, and in all cases, the intraoperative findings correlated with HRCT findings. In a study of 19 patients with CSF rhinorrhea, Shetty et al. found that HRCT correctly identified presence or absence of CSF fistulas at surgery in 93% of the patients compared with 89% with magnetic resonance cisternography [8]. Although none of these modalities is perfectly sensitive for CSF leaks, DECT shows promise for further improving the sensitivity and the specificity of CT cisternography in cases where HRCT alone does not convincingly demonstrate a site of leakage.



**Fig. 2** – Dual-energy computed tomography cisternography iodine overlay map (color) fused upon virtual noncontrast computed tomography (gray scale) clearly depicts passage of cerebrospinal fluid through the cribriform plate into the right olfactory recess. Yellow arrow indicates the passing CSF through a defect in the right cribriform plate.



**Fig. 3** – Dual-energy computed tomography cisternography bone subtraction reconstructions increase the conspicuity of iodinated contrast passing through a defect in the right cribriform plate. Yellow arrow indicates the passing CSF through a defect in the right cribriform plate.

Although numerous neuroradiological applications of DECT have been described, this is the first description of DECT applied to CT cisternography [9,10]. As such, future work is suggested to better assess the sensitivity and the specificity of DECT cisternography compared with other currently used techniques. In our practice, we currently utilized DECT cisternography as a second line imaging study for cases in which unenhanced HRCT of the skull base failed to elucidate a site of leakage. In our experience, DECT cisternography offers the best combination of high anatomic resolution, bone detail, and material contrast discrimination compared with other currently used techniques, and may be considered in the imaging workup of CSF leaks.

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