Multimodal radionuclide shuntography for device patency: New procedural tips for anuncommon historical technique

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Abstract

Cerebrospinal fluid (CSF) shunting is an established long-term treatment option for hydrocephalus, and is one of the most commonly performed neurosurgical procedures in western countries. Despite advances in CSF shunt design and management, its failure rates remain high and is most commonly due to obstruction and infection. Cerebrospinal fluidshunt failure diagnosis should be prompt and accurate in establishing timely if its revision is appropriate. Radionuclide shuntography with technetium-99m-diethylenetriamine-petaacetic acid (^{99m}Tc-DTPA) is a useful technique for evaluation CSF shunts and management of patients presenting with shunt-related problems, in particular it can avoid unnecessary replacement interventions. Although its execution and interpretation require specific skills, we suggest its execution for the evaluation of device's patency. We here describe the radionuclide shuntography performed with recent hybrid multimodal technologies, with a procedure customized to a complicated patient with hydrocefalus and neoplastic disease. We suggest considering radionuclide shuntography in association with conventional imaging and strongly recommend the additional performance of single photon emission computed tomography/computed tomography (SPECT/CT) because it also provides valuable information to complete the interpretation of planar images.

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Introduction

Cerebrospinal fluid (CSF) shunting is an established long-term treatment option for hydrocephalus, and is one of the most commonly performed neurosurgical procedures in western countries providing long-term relief in 50% to 90% of adult patients [1, 2].

Cerebrospinal fluidshunt's components are proximal ventricular catheter, pressure-sensitive valve with reservoir and distal catheter. The proximal catheter is the ventricular one and is most commonly placed in the frontal horn of the right lateral ventricle, anterior to the foramen of Monro avoiding the choroid plexus; the proximal catheter is connected to a subcutaneously placed reservoir that is in turn connected to the distal catheter with an intervening one-way pressure valve. The distal catheter is tunneled through subcutaneous tissue into a body cavity, which is more often the peritoneal space and less frequently the right atrium [3]. Although ventriculoperitoneal shunt (VPS) is most commonly used, ventriculoatrial shunt (VAS) serves as an alternative option, especially in case of VPS failure [4, 5].

Despite advances in CSF shunt design and management, its failure rates remain high; current literature on surgical management demonstrates that CSF shunt failure can occurr in 29% of adult in the first year of placement and revision surgery can affect up to 70% of patients in their lifetime [1, 4]. Cerebrospinal fluidshunt failure is most commonly due to obstruction that leads to the new onset of hydrocephalus; the second most common cause of CSF shunt is infection, associated with increased morbidity and mortality [6].

Cerebrospinal fluidshunt failure diagnosis should be prompt and accurate in establishing timely if its revision is appropriate; but although several techniques have been proposed, correct recognition of failure is challenging, especially in recognizing the exact component involved, and no consensus guidelines on this work up exist [1, 7-9]. Cerebrospinal fluidshunt failure diagnosis is usually made with combination of clinical investigations, conventional radiography, computed tomography (CT), and magnetic resonance (MR), but they can be no risolutive [4].

Nuclear medicine functional imaging is alongside anatomical imaging in the study of several diseases, both neoplastic and non-neoplastic. Technological advancement in many cases also determined the transition of imaging with radiopharmaceuticals to a main role in diagnostic flowcharts thanks to the support provided by multimodal hybrid devices [10, 11]. In particular the study of CSF shunt with radiopharmaceuticals has been described firstly in 1966, but standard protocols have not been yet established, neither recently with the availability of new updated technologies [12].

We here describe the radionuclide shuntography performed with recent hybrid multimodal technologies, with a procedure customized to a complicated patient with hidrocefalus and neoplastic disease.

Case report

We report the case of a 35 years-old male patient, hospitalized with suspected pituitary germ cell neoplasm submitted to biopsy. After biopsy his clinical conditions worsened until the onset of drowsiness. For the suspect of biopsy side effects, head CT with contrast enhancement was performed, that showed ventricular air quota in the left frontal horn and in right temporal lobe due to previous biopsy and dilatation of the supratentorial ventricular system particularly evident at the level of the third ventricle, indicative of hydrocephalus (Figure 1).

The patient was then submitted to surgical procedure for the implant of a VPS, followed few days later to head and wholebody CT with contrast enhancement in order to assess the ventricular state and the distal peritoneal catheter position. The head CT showed ventricles on the axis, small in size, no longer dilated, with endoventricular air quotas in the frontal horns and presence of catheter at the distal end at the base of the right frontal horn. Whole body CT showed regularity of the abdominal organs and of the position of the distal peritoneal catheter (Figure 2).

Furthermore, head MR was also performed in order to choose the therapeutic path for the pituitary germ cell neoplasia,

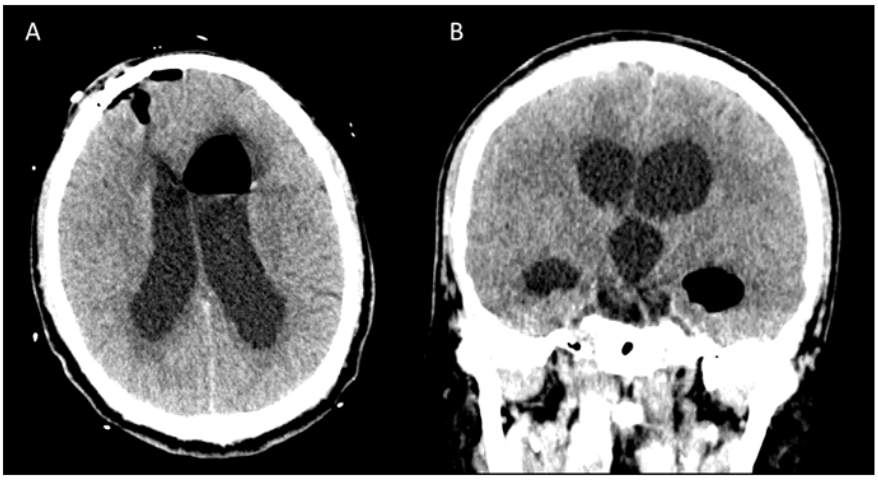

Figure 1. Head CT transaxial (A) and coronal (B) images showed ventricular air quota in the left frontal horn and in right temporal lobe due to previous biopsy and dilation of the supratentorial ventricular system particularly evident at the level of the third ventricle indicative of hydrocephalus.

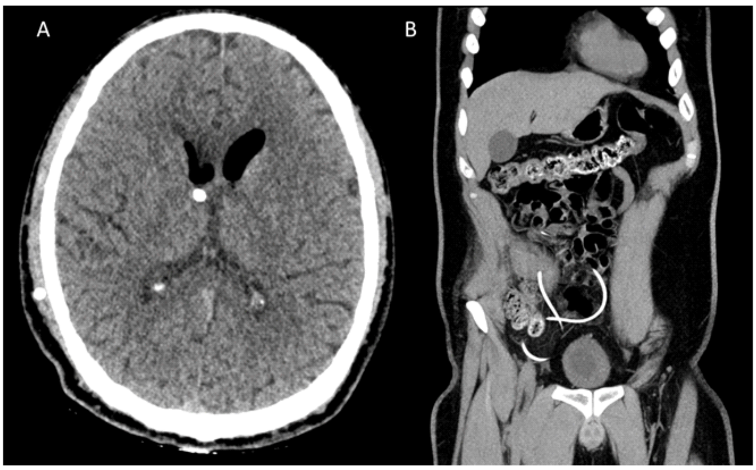

Figure 2. (A) Transaxial head CT with contrast enhancement showed ventricles on the axis, small in size, no longer dilated, with endoventricular air quotas in the frontal horns and presence of catheter at the distal end at the base of the right frontal horn. (B) Coronal whole body CT with contrast enhancement showed regularity of the abdominal organs and of the position of the distal peritoneal catheter in pelvis.

confirmed by the previous biopsy; the pituitary lesion resulted of 15x17.7x19mm in size, with inferior growth towards the posterior portion of the third ventricle and involvement of the superior portion of the aqueduct; ventricles were described on the axis no longer dilatated (Figure 3).

Therapy with PEI scheme (Cisplatin-Etoposide-Ifosfamide, every 21 days) was then started but unfortunately, after 2 cycles, patient's clinical conditions worsened again to drowsiness due to hydrocephalus and he underwent urgent implantation of a catheter into the ventricular system connected to an external reservoir at a predetermined pressure.

The VPS was removed and examined showing positive finding for Serratia Marcensces on the valve and catheter.

After stabilization of the emergency, VAS was then implanted but patient still presented precarious clinical conditions also ascribable to the pituitary germinal neoplasm. In order to remove the catheter connected to the external reservoir, VAS correct funcioning had to be assessed, before the possible new onset of hydrocephalus.

The radionuclide shuntography was then performed using a hybrid gamma camera with low-energy general-purpose collimators with 20% window centered at 140keV (GE Discovery 670™ dual-headed camera Discovery MN/CT, GE Healthcare, Haifa, Israel).

After careful aseptic preparation of the scalp over the shunt reservoir, it was palpated and accessed by the nuclear medicine physician, using an aseptic 25-gauge needle for administration of 1mCi (37MBq) of technetium-99m-diethylenetriaminepentaacetic acid (^{99m}Tc-DTPA) in 0.5mL of sterile water (Figure 4).

Sequential dynamic lateral view images from the skull vertex to the right atrium were obtained from the moment of administration, for a total of 6 minutes using a 2-second frame rate (Figure 5), followed immediately by static lateral and anterior images of the head and neck.

After then, single photon emission computed tomography/computed tomography (SPECT/CT) scanning was performed with the same field of view (128×128 matrix, step-and-shoot scan mode, decreased exposure time of 20s, and each detector rotation angle of 180 degrees; integrated CT scan parameter: 110kV, 75mAs, and pitch 1.3).

All images were recorded digitally and visualized on Xeleris™ workstation (GE Healthcare, Waukesha, WI, USA),where they were processed both manually and automatically with Volumetrix™ software.

Dynamic images showed the radiopharmaceutical flow from

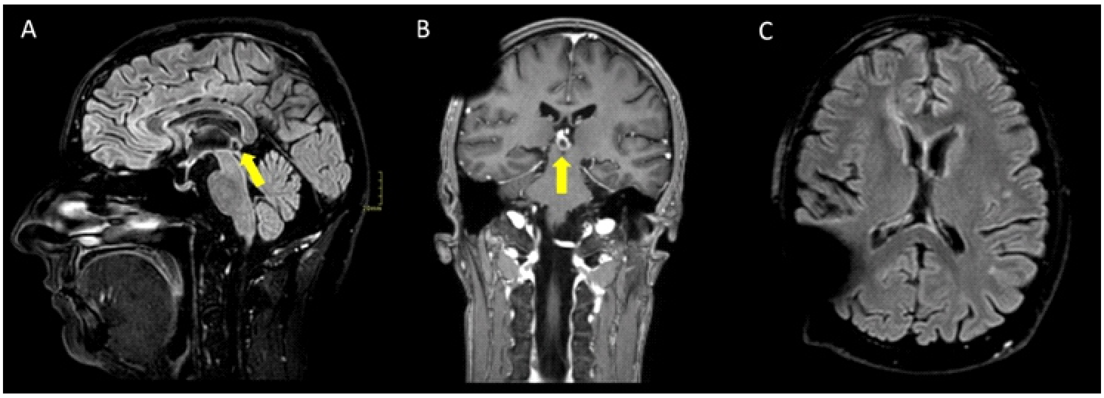

Figure 3. (A, B) Sagittal and coronal MR images after paramagnetic contrast enhancement showed pituitary lesion (yellow arrows) with size 15x17.7x19mm, with inferior growth towards the posterior portion of the third ventricle and involvement of the superior portion of the aqueduct. (C) Transaxial MR FLAIR image showed ventricular system in axis, of normal size and absence of areas of altered signal in the brain; ferromagnetic artifact is observed in the right parietal area.

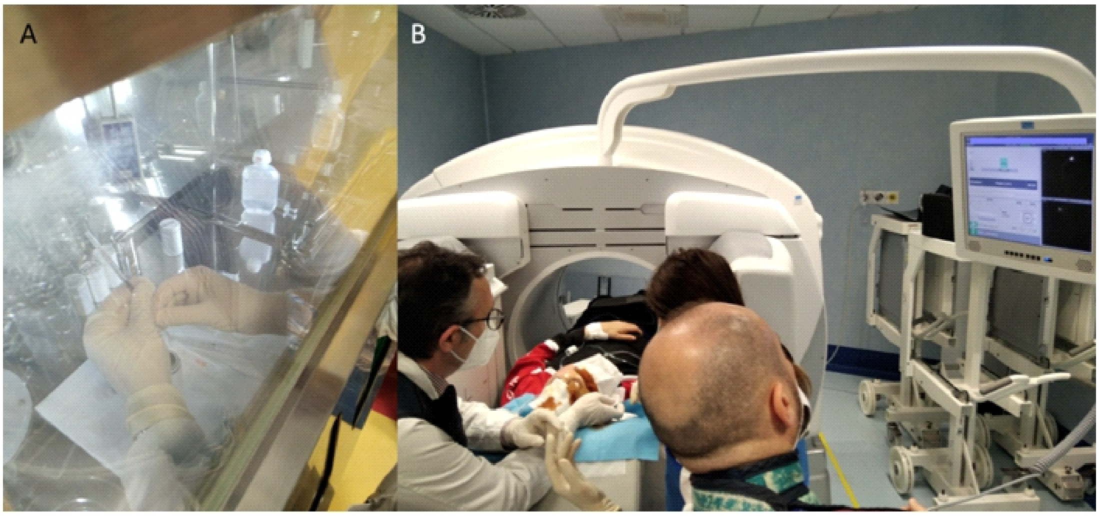

Figure 4. (A) Sterile preparation of the radionuclide ^{99m}Tc-DTPA. (B) Radionuclide somministration in the reservoir after preparation of sterile field.

the reservoir to the distal atrial catheter and few seconds later to the proximal catheter in the right cerebral ventricle, demostrating the absence of obstructions. Time activity curves generated from the regions of interest on the VAS valve, distal and proximal catheter showed regular filling and following emptying of ^{99m}Tc-DTPA of all the VAS components (Figure 5).

Single photon emission computed tomography/CT images showed the presence ^{99m}Tc-DTPA minimal trace only in the VAS components without extravasion, and the regular position and course of the distant catheter until the right atrium (Figure 6), confirming the good functioning of the CSF shunt.

Two days later, head MR with contrast enhancement was performed that showed regular shape of ventricular system, presence of air in the righ ventricular horn and diffuse dural enhancement after gadolinium administration (Figure 7).

The external shunt device was then removed and the patient was followed for the next 6 months, without new onset of hydrocephalus.

Discussion

Cerebrospinal fluidshunts still remains the main treatment for hydrocefalus but the onset of malfunction is always possible, despite the advancements in shunt system and valve design, as well as improved sterile techniques [6].

Cerebrospinal fluidshunt malfunction can occur at any time after insertion, in all points along the shunt course, and its clinical presentation is often related to the new onset of hydrocefalus [3, 13].

Clinical condition of the patient we described was further difficult due to the concomitant presence of the pineal gland germinal tumor: diabetes insipidus altered the regulation of the amount of water in the body, and chemotherapy increases risk of infections due to a drop in white blood cells, as it actually happened in our patient.

The diagnosis of CSF shunt failure is challenging and the early detection still remains fundamental. Anatomical imaging studies, including CT and MR are the more diffuse tec-

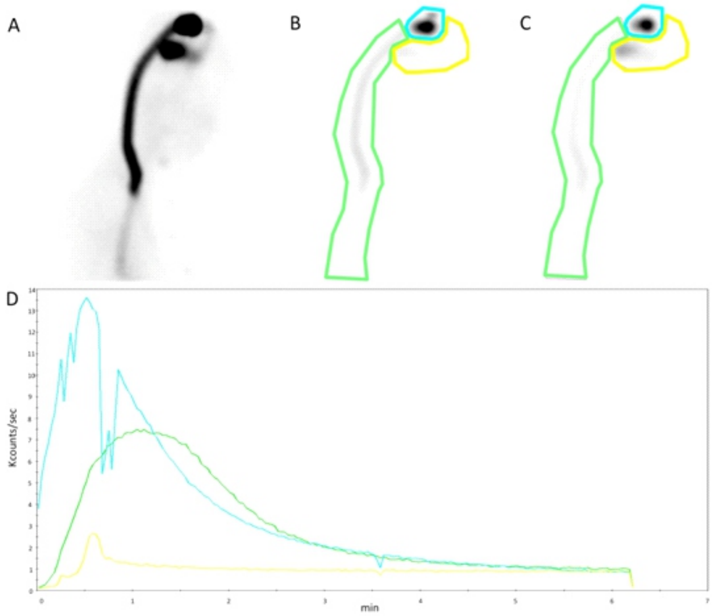

Figure 5. (A) Composite image of the dynamic cisternoscintigraphy showed the presence of ^{99m}Tc-DTPAin all the VAS components. (B, C) Composite images respectively of the first 30 seconds and of the remnant part of the dynamic images with region of interest drawn on the reservoir and valve (light blue), distal catheter (green) and proximal catheter (yellow). (D) Time activity curves generated from the three regions of interest showed the regular flow of ^{99m}Tc-DTPA in the VAS components.

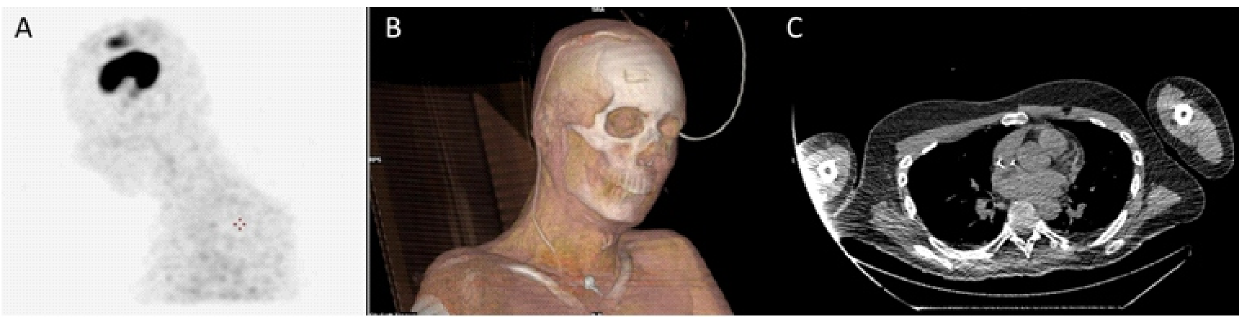

Figure 6. (A) Lateral view of SPECT acquisition increased in contrast showed the residual ^{99m}Tc-DTPA only in cerebral ventricular chambers and in the valve. (B) 3D CT images recostruction and (C) transaxial CT image showed the regular position of the distant catheter.

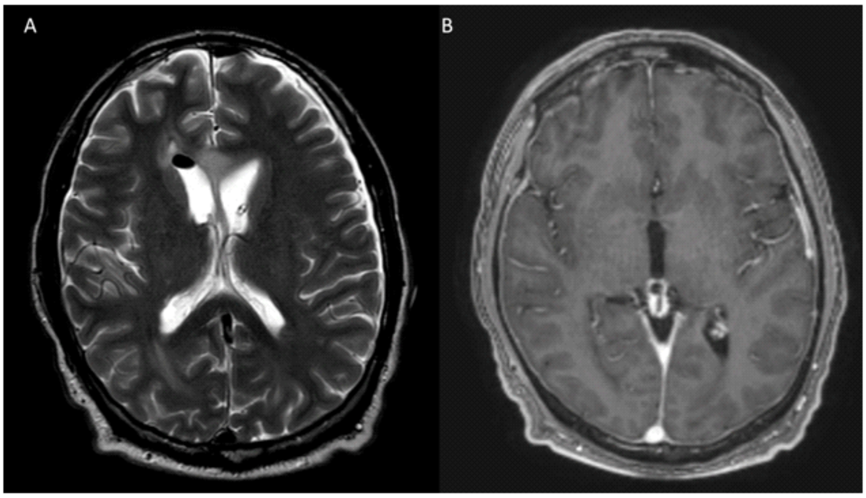

Figure 7. (A) MR transaxial T2 image showed hiperintensity in the periventricular white matter and presence of air in the righ ventricular horn. (B) Transaxial T1 image after gadolinium administration showed diffuse dural enhancement.

niques for assessment of CSF shunt malfunction. Head CT is useful in assessing the shunt location and integrity of its components, but above all, it is performed to assess ventricular size: changing of configuration of frontal horns, temporal horn and 3rd ventricle are signs of hydrocefalus [3, 13]. Computed tomography of the chest and abdomen is performed to evaluate the assessment the distal end of the catheter.

In our patient the head CT was performed firstly at the onset of the symptoms of hydrocephalus confirming the presence of dilation of the supratentorial ventricular system particularly of the third ventricle and subsequently as a control before the removal of the external shunt. Furthermore, it was repeated after the implantation of the VPS shunt to check the ventricles and the proximal catheter. The whole-body CT was also performed to verify the correct position of the distal catheter.

Brain MR is necessary for evaluation of the ventricular size, subdural effusions, CSF over drainage, ventriculitis, and ventricular loculations, but it should be considered that MR is not available in all emergency department, requires the patient's cooperation, and is considered time consuming [1, 3].

In our patient the brain MR was performed in order to assess the germinal pituitary disease and demonstrate whether it could create problems for the circulation of the CSF, in order to start the planned chemotherapy. However, anatomical imaging can be equivocal, even if associated with the clinical evaluation of the patient [13].

In our patient, due to the concomitant presence of neoplastic disease and the fragile clinical condition after the VPS infection and its explantation, it was decided to re-evaluate him with radionuclide shuntography before proceeding with subsequent therapeutic decisions. In particular, it was necessary to ensure the good functioning of the VAS before removing the external shunt, considering his high risks of complication for surgical procedures.

Radionuclide shuntography is an effective and low-radiation dose functional method to assess shunt patency. This method is not familiar to many physicians and not frequently requested; currently there is lack of guidelines regarding this procedure or consensus on image interpretation, which considerably limits its clinical applications [4, 13]. Despite radionuclide schuntography related literature is scarce, especially for VAS, it is considered a useful tool in the management of patients presenting with shunt-related problems not elucidated by conventional radiological examination [4, 14]. Technetium-99m-DTPA shuntography is a safe procedure if applied with all the necessary precautions. Technetium-99m-pertechnetate is the most used isotope because it is a gamma-emitting tracer (no particle emission) and is the least expensive and most readily available radiotracer in nuclear medicine departments in Europe, United States, and Asia [14]. Diethylenetriaminepentaacetic acid is the ideal tracer because it is not lipophilic, not metabolized, and not absorbed across the ependyma before it reaches the arachnoid villi [15].

The radiopharmaceutical preparation already must guarantee sterility, but in this case, it was essential that sterility was also maintained for external materials; sterile drapes were used to cover the gamma camera bed, sterile gloves were used to handle the syringe with the radiopharmaceutical and the syringe's lead cover for radioprotection was sterilized by autoclaving, like a surgical instrument.

Other important precautions concern the speed of administration and the quantity of radiopharmaceutical to be used, as they should not interfere with intracranial pressure. The dynamic examination starts together with the administration of the radiopharmaceutical and the images must be analyzed from the first frame. Initial images frames have to show radioactivity as round/ovoid configuration at the injection site in conjunction with lack of radiopharmaceutical extravasation and absence of early systemic radiopharmaceutical, indicative of subcutaneous tissue absorption. Proximal catheter patency was demonstrated by appearance of the intracranial radioactivity in the ventricles that can be even progressive in case of initial ventricular negative pressure. In a normal CSF shuntogram, the radiopharmaceutical activity is seen uniformly in the entire shunt system with rapid spillage into the distal draining body cavity and no focal activity around the distal end of the catheter [13].

Literature reports that the finding of a normal radionuclide shuntography makes surgical intervention unnecessary, whereas presence of interruption in radiopharmaceutical flow or presence of the radiopharmaceutical in sites different from the shunts components indicates shunt failures and the necessity of repositioning or replacement of the shunt [16]. There are few studies that investigated the diagnostic performance of the radionuclide shuntography in detecting shunts failure; due to the differences in procedures, Graham et al. (1982) showed sensitivity, specificity and accuracy of the radionuclide shuntography were 97%, 90%, and 93%, respectively [17].

Hybrid imaging with SPECT/CT added to 2D planar scintigraphic images, offer help in interpreting radionuclide shuntography making it more accurate and easier. The fused SPECT/CT images led to major improvements in diagnostic accuracy by fusing functional studies with anatomic images; not only does this technique provide accurate localization of radiotracer activity within the precise anatomic spaces, it also provides information on the presence or absence of other structural abnormalities that can contribute to the patients' symptomatology [16].

It should be pointed that the radiation dose added is considerably lower compared to the standard cranial CT [18].

In conclusion, radionuclide shuntography is a useful technique for evaluation CSF shunts and management of patients presenting with shunt-related problems, in particular it can avoid unnecessary replacement interventions. Although its execution and interpretation require specific skills, we suggest its execution for the evaluation of device's patency.

We suggest considering radionuclide shuntography in association with conventional imaging, as it allows you to evaluate the device patency without risks if performed with the right precautions. The additional performance of SPECT/CT is strongly recommended because it also provides valuable information to complete the interpretation of planar images.

The authors declare that they have no conflicts of interest.

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