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Practical Aspects of Nuclear Medicine Ventriculoperitoneal Shunt Evaluation

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The radionuclide ventriculoperitoneal shunt evaluation study is a simple test that involves injecting a small volume of radionuclide into the shunt reservoir and then observing its disappearance using dynamic γ-camera imaging. Although it seems simple, there are several potential pitfalls that can result in a misinterpreted or uninterpretable study. This paper is a detailed description of how to avoid the pitfalls and also how to interpret the results.

Key Words: ventriculoperitoneal shunt; pitfalls; overdrainage; syphoning

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Ventriculoperitoneal shunts are used to drain excess cerebrospinal fluid (CSF) from the ventricles of the brain. This can be a problem because of overproduction of CSF or inadequate absorption. Elevated CSF pressure can cause headaches, nausea and vomiting, visual or balance disturbance, or worsening mental function. The causes include congenital hydrocephalus, head injury with scarring of the lining of the brain (arachnoiditis), infection (such as meningitis), stroke, or tumor. The shunts function to drain the excess CSF from the brain ventricles into the peritoneal cavity, where the CSF is absorbed into the circulation. All of the shunts have a valve that slightly retards the flow, to maintain a normal CSF pressure. These shunts have been very effective in normalizing the pressure in the CSF and allowing the patients to lead normal lives.

The shunts consist of a catheter into one of the ventricles deep within the brain, a connection at a small reservoir at the top of the head, proximal tubing to the valve (typically just behind the ear), and distal tubing under the skin of the chest and into the peritoneal cavity of the abdomen. Both the reservoir on top of the head (Rickham reservoir) and the valve have silicone domes that can be penetrated with a hypodermic needle to collect samples of CSF or to inject drugs or radiotracer (Fig. 1).

Occasionally these shunts malfunction. The 2 most common problems are obstruction (either proximally or distally) or valve failure, which means that there is no resistance to flow, and CSF is freely syphoned from the brain into the peritoneum when the patient is upright. This condition is also called overdrainage and is the most common abnormal outcome in ventriculoperitoneal shunt studies. Proximal obstruction usually results from choroid plexus growing around the tubing in the ventricles and covering the holes in the tubing. Distal obstruction usually results from mesentery or omentum growing around the distal tubing. Occasionally distal obstruction is due to migration or misplacement of the distal tubing such that a loculated collection of CSF forms in the abdomen. This is called a CSF-oma.

Treatment usually consists of replacement of the valve or tubing. The proximal tubing cannot be pulled out of the ventricles, since it would also rip out some of the choroid plexus and cause significant bleeding. If the problem is proximal obstruction, usually a new catheter has to be inserted into the ventricles and a new Rickham reservoir put in place. If the problem is overdrainage, the valve can be replaced and reconnected to the prior tubing. If the problem is distal obstruction, new distal tubing can be inserted. Occasionally an entirely new ventriculoperitoneal shunt may be inserted, leaving the old, nonfunctioning one in place. This means that occasionally a patient may have 2 or even 3 valves. In that case, it is essential to determine which one needs to be assessed.

Both obstruction and overdrainage can cause symptoms of headache or nausea and problems with balance or vision. These are the indication for doing the study. When patients with ventriculoperitoneal shunts develop symptoms, the radionuclide shunt study is one of the best ways to determine whether the problem is obstruction (proximal or distal) or overdrainage.

Radionuclide evaluation of CSF shunts was initially described in 1966 (*1*) and began to be used clinically in the

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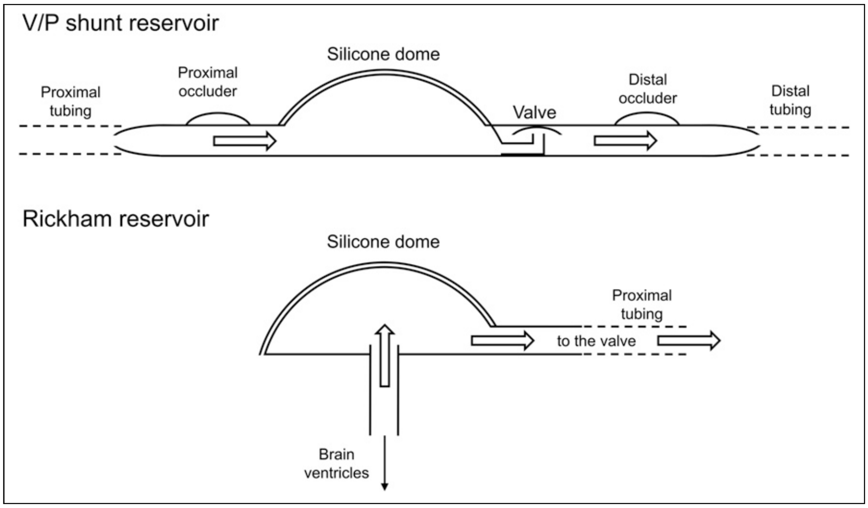


FIGURE 1. Ventriculoperitoneal shunt valve, usually implanted subcutaneously just behind ear. Proximal tubing connects to Rickham reservoir. Distal tubing goes to peritoneal cavity. Proximal and distal occluders can be pressed and held manually to occlude flow. Silicone dome is then pressed to force flow in one direction or other. Silicone dome is designed to be pierced by hypodermic needle for sampling or injection. Rickham reservoir is placed beneath skin at top of head and provides connection between catheter into ventricles and proximal shunt tubing. Either silicone dome can be accessed for ventriculoperitoneal shunt study.

1970s (*2*). Conceptually, it is a simple test that involves injecting a small volume of radionuclide into the shunt reservoir and then observing its disappearance using dynamic γ-camera imaging. The sequence of events is shown in Figure 2A.

Although the procedure seems to be quite straightforward, in actual practice it is not quite so simple. It is like a recipe for a cake. You can follow all the steps carefully, but your result will not be nearly as good as if an experienced chef makes it. The reality is that several small details have been left out of the recipe that are intuitive to the chef and make a significant difference in the outcome. The same is true for CSF ventriculoperitoneal studies. The discussion below reveals many of these details and should help in conducting useful studies. It is likely that there are subtle differences in how the procedure is done at different institutions. The details discussed below reflect the methodology I have successfully used at the University of Washington and at the University of Iowa over the past 40 y.

CHART REVIEW

A very important point in the history is whether the patient's symptoms are postural. It may take discussion with the patient to determine this. A common mode of failure of ventriculoperitoneal shunts is to fail in the wide-open position. This results in syphoning (or overdrainage) of CSF from the ventricles into the peritoneum, particularly when the patient is upright. This, in turn, results in negative ventricular CSF pressure, which causes the symptoms. Typically, the patient feels well in the morning but develops symptoms an hour or two after getting up. This is important to know before starting, so you can be prepared for a negative opening pressure. Review the radiographs or CT images of the skull to identify the location of the reservoir. Sometimes patients have 1 or 2 failed shunts still in place. Make sure you are injecting the correct one.

PATIENT PREPARATION

The patient should be lying supine on a flat table. Typically, this is a wheeled gurney that has the capability to raise the thorax and head. Lying flat means no pillow or other support, except for the knees. Ideally the patient should be lying flat for an hour before starting, although this is often not feasible. The problem with shorter durations is that, if patients have overdrainage and were recently upright, they will have a negative opening pressure when they lie down that will gradually increase with time. This can lead to a misleading value of the opening pressure.

STERILE PREPARATION

Sterile preparation is more rigorous than our usual prep for an intravenous injection because of the potential disastrous problems that can result from meningeal infection. Some institutions allow only neurosurgery residents and staff to access ventriculoperitoneal shunts. If that is the case, then the neurosurgeon needs to be supervised to ensure that the study is done properly. The neurosurgeon knows how to access shunts but not how to do a radionuclide shuntogram.

Before starting, make sure that all the necessary supplies are immediately available. Usually, they are set out on a nearby table. A list of necessary supplies is shown in Figure 2B.

Usually the valve, along with an integral silastic reservoir, is located behind the ear. The reservoir is designed to be punctured, but some neurosurgeons prefer to puncture the Rickham reservoir. This reservoir is usually located near the vertex of the scalp and provides a connection between the proximal tubing and a catheter into the ventricles. Either reservoir can be punctured for the study, although it is often more difficult to puncture the Rickham reservoir.

Before puncturing the reservoir, it is essential to connect a small syringe (typically 3 mL) to the distal Luer fitting of the butterfly catheter. This is in case there is a negative opening pressure. Once the reservoir is punctured, withdraw the syringe to see CSF in the tubing. Disconnect the syringe to see if the pressure is positive. If CSF starts to go back, immediately reconnect the syringe and do not attempt to measure the opening pressure. The opening pressure is measured in centimeters of water (cm water), using a ruler held vertically with one end adjacent to the ventriculoperitoneal

A

Radionuclide CSF V/P Shunt Evaluation

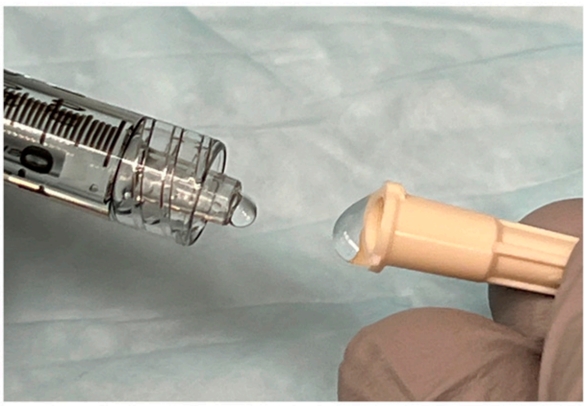
1. Shave hair over the shunt reservoir.
2. Clean skin with iodine or chlorhexidine-based solution.
3. Put on sterile gloves.
4. Place a fenestrated sterile drape over the area.
5. Puncture reservoir with a 23-gauge butterfly needle.
6. Measure opening pressure.
7. Inject 37 MBq (1.0 mCi) Tc-99m pertechnetate in 0.1 mL saline into the reservoir.
8. Withdraw needle and put a bandage on the site.
9. Begin gamma camera dynamic imaging at 10 sec/frame for 20 min.
10. Sit subject semi-upright when activity over reservoir is at half of starting value or at 10 min, whichever comes first.

B

Supply setup for V/P Shunt study

1. Four chlorhexidine or iodine prep swabs in sterile package
2. Two 23-gauge butterfly IV sets in sterile package
3. Sterile fenestrated plastic drape in sterile package
4. Three mL syringe in sterile package
5. Surgical gloves in sterile package (several sizes)
6. Four 2×2 gauze pads in sterile packages
7. Adhesive bandage (Band-Aid™)
8. 30 cm ruler with centimeter markings
9. Hair clipper or razor
10. Hemostat
11. Radiotracer dose (1.0 mCi pertechnetate - 0.1 mL in 1.0 mL syringe)

C



D

Diagnosis	Opening pressure	Flow rate	Change when semi-upright
Normal	6-12 cm water	$T_{1/2}$ = 2-4 min	No change
Proximal obstruction	Low or negative	Low	No change
Distal obstruction	High	Low	No change
Over-drainage	Low or negative	Variable	Speeds up

FIGURE 2. (A) Radionuclide CSF ventriculoperitoneal shunt evaluation. (B) Supply setup for ventriculoperitoneal shunt study. (C) Injection syringe (left) and distal connection to butterfly catheter (right). It is important that connection is fluid to fluid, so that no air is injected into valve. Menisci are seen at both sides immediately before connection. (D) Most common outcomes of radionuclide ventriculoperitoneal shunt studies.

reservoir. This assumes that CSF has the same density as water. The disconnected butterfly tubing is held vertically, and the level of CSF in the tubing is determined with the ruler. During the pressure measurement, it is important not to contaminate the sterile field. The measurement does not have to be precise. It will be low (<6 cm water), normal (6–12 cm water), or high (>12 cm water). If the pressure is positive, generally spontaneous flow will be seen if the distal end of the butterfly tubing is held lower than the reservoir. Once a meniscus is seen, the catheter is connected to the injection syringe and the tracer can be injected (Fig. 2C).

If the pressure is negative, then CSF has to be withdrawn into the catheter to the distal fitting. It is useful to have a hemostat available to clamp the tubing while the 3-mL syringe is being disconnected and the injection syringe is being connected. Sometimes the entire tubing needs to be compressed to get a meniscus at the catheter Luer fitting. This can be accomplished by tightly wrapping a portion of the tubing around a pencil or a 1-mL syringe. Once a meniscus is seen, the catheter is connected to the injection syringe and the tracer can be injected.

The tracer used in all the original studies was pertechnetate. In the recent past, some sites have used diethylenetriamine-pentaacetic acid (DTPA); however, the only type currently available is a form that strongly chelates calcium and magnesium and has caused adverse reactions when administered intrathecally (*3*). Since a small amount of the injectate often gets into the ventricles, DTPA acid is now contraindicated.

The activity (1.0 mCi of ^{99m}Tc-pertechnetate) in 0.1 mL is drawn into a 1-mL syringe. The volume is kept small to avoid changing the pressure in the valve, since that might affect the results. The syringe plunger is drawn back to approximately 0.7 mL, and the liquid is gently shaken down to the tip. After connection (meniscus to meniscus) with the distal butterfly Luer fitting, the activity is slowly injected, using the air behind the 0.1 mL to push it all the way to the needle (Fig. 2C). This is called the air-piston technique. Be careful not to inject any air into the reservoir, since an air bubble can temporarily obstruct the outflow of the valve.

IMAGING

Once the injection is complete, the needle is removed. If there is any persistent bleeding, it should be controlled with light pressure with a gauze pad. Do not push on the reservoir. It is essential to start imaging as soon as possible after the injection. Hemostasis is not critical, so put an adhesive bandage on it, even if it is still bleeding. Sometimes, the CSF flow is very rapid and all the activity can wash out of the reservoir in the first minute.

At this point in the procedure, most of the people in the room walk out, trusting that the tech knows what to do. This is a mistake, since there is a continuing need for careful oversight.

The acquisition is set up for 10-s frames for 20 min. Acquisition should start as soon as the reservoir is seen on the persistence scope. Do not wait until the positioning is perfect. It is essential that the head remain still during the imaging. This is because, with the camera positioned horizontally and the injection site on the side of the head, a small change in the left–right tilt of the head will cause a significant change in attenuation. Accordingly, it is optimal to have the head tilted so that the shunt is better seen by the camera. A cooperative patient can be instructed to hold the head still, but if the patient is less cooperative, someone (usually a parent if the patient is a child) should hold the head.

Occasionally, the problem with the shunt is positional kinking of tubing in the neck. This may be the case if the opening pressure is normal but there is no flow (activity remains in the reservoir but is not seen in the efferent tubing). This can be tested by having the patient turn the head to the left for 1 min and then to the right for 1 min, which may result in an increase in flow.

Most γ-camera systems allow real-time depiction of activity in a region of interest. If feasible, this should be set up while the study is under way, with a region of interest around the reservoir. If the activity is dropping slowly, then the patient should be shifted to a semiupright position at 10 min. If the activity is dropping faster, then shift to semiupright when the activity is halfway down. If the activity suddenly stops dropping, this indicates probable kinking. Have the patient turn the head to one side and then to the other side.

After the dynamic imaging, a static image of the abdomen is acquired. The primary use of this image is to identify or rule out a CSF-oma. If a site of intense focal uptake is seen, SPECT/CT should be done immediately to locate the site precisely. This is quite rare but can be a cause of distal obstruction. If activity has definitely reached the distal tubing in the abdomen and there is no focal uptake, then there is adequate dispersion. The pertechnetate is absorbed quite rapidly by the peritoneum, and wide dispersion may not be seen.

INTERPRETATION

A summary of the most common outcomes of radionuclide ventriculoperitoneal shunt studies is shown in Figure 2D.

Normal (Fig. 3A)

For a normal study, the opening pressure should be 6–12 cm water. Half-time ($T_{1/2}$) should be 2–4 min. The static abdomen image at the end of the study should show good dispersion. Programable shunts can be reset externally using magnets. This allows them to be set to very low pressures (1–1.5 cm water). In this case, the study can look like overdrainage. If there is any question, find out what pressure the valve is set to.

Overdrainage (Syphoning) (Fig. 3B)

Overdrainage is the most common mode of failure of ventriculoperitoneal shunts. The valve fails in the wide-open position. When the patient is upright, CSF is syphoned from

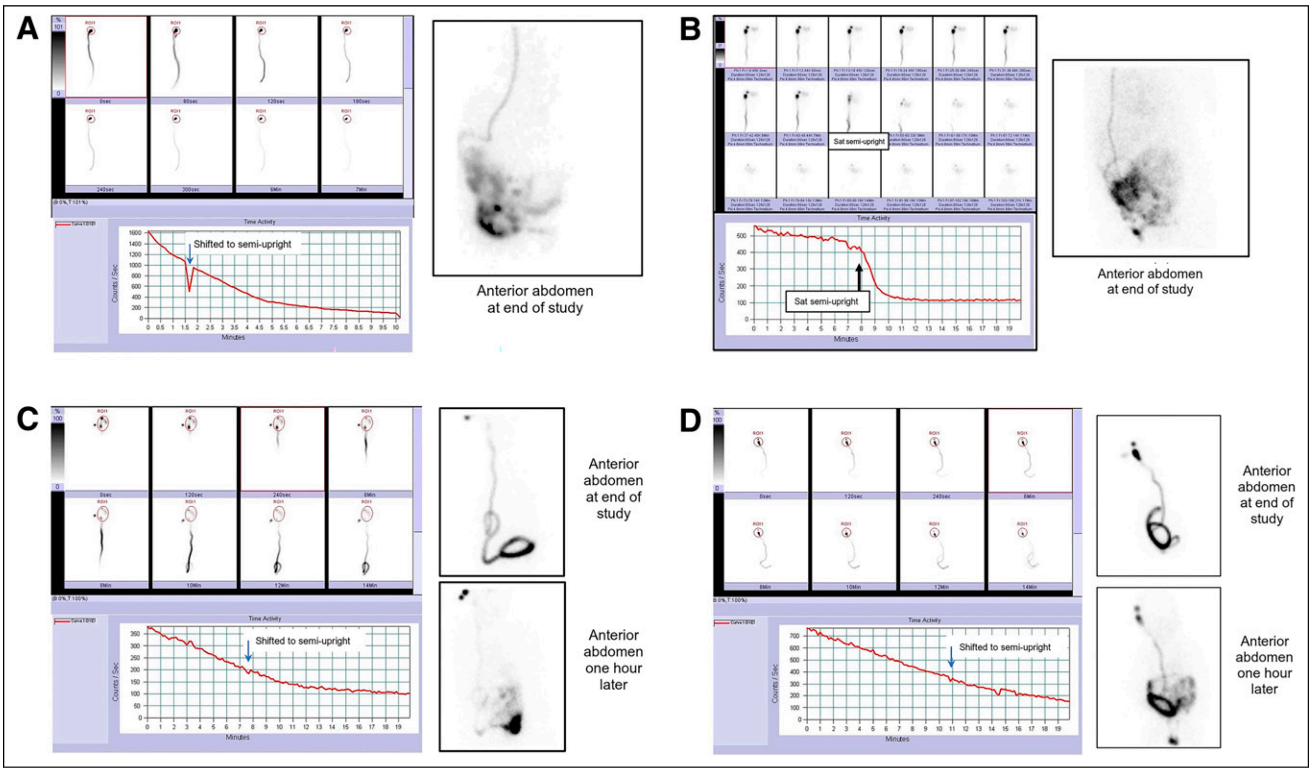


FIGURE 3. (A) Normal study (normal opening pressure; normal $T_{1/2}$) in 72-y-old woman with history of normal-pressure hydrocephalus, now with gait instability and worsening symptoms. Opening pressure was 7 cm water with $T_{1/2}$ of 2.5 min. Anterior abdomen image shows good dispersion. (B) Overdrainage (or syphoning) (normal or low opening pressure; increase of flow when positioned semiupright) in 50-y-old man with ventriculoperitoneal shunt placed for subarachnoid hemorrhage 6 y ago, now with worsening somnolence. Opening pressure was 10 cm water, with initial $T_{1/2}$ of 20 min, increasing to 1 min after patient sat semiupright. Anterior abdomen image shows good dispersion. (C) Distal obstruction (high opening pressure; slow flow) in 12-y-old girl with ventriculoperitoneal shunt placed for congenital hydrocephalus, now with lethargy, nausea, and vomiting. Opening pressure was 29 cm, with $T_{1/2}$ of 10 min. Anterior abdomen image shows good dispersion in delayed imaging. (D) Proximal obstruction (low opening pressure; slow flow) in 4-mo-old boy with congenital hydrocephalus, now with periodic spells of apnea. Opening pressure was 1 cm, with $T_{1/2}$ of 10 min.

the ventricles into the peritoneum. This results in collapse of the ventricles, with significant symptomatology. It also results in a negative CSF pressure. When patients present for the ventriculoperitoneal study, they are likely to have been upright for some time and will have negative CSF pressure. After they lie supine, flow through the tubing will slow or cease, and the pressure will slowly increase. This creates some uncertainty in how to interpret the opening pressure. It may be negative or low normal. If it is negative, make sure to take precautions to avoid letting air enter the system. The key finding in the reservoir time–activity curve is that there is a major increase in the downslope of the curve when the patient is shifted to a semiupright position.

Distal Obstruction (With or Without CSF-oma) (Fig. 3C)

For distal obstruction, the opening pressure should be high (>12 cm water). Flow should be slow (generally $T_{1/2} > 10$ min). It may speed up slightly when the patient is shifted to a semiupright position. Distal obstruction is often associated with an abdominal CSF-oma.

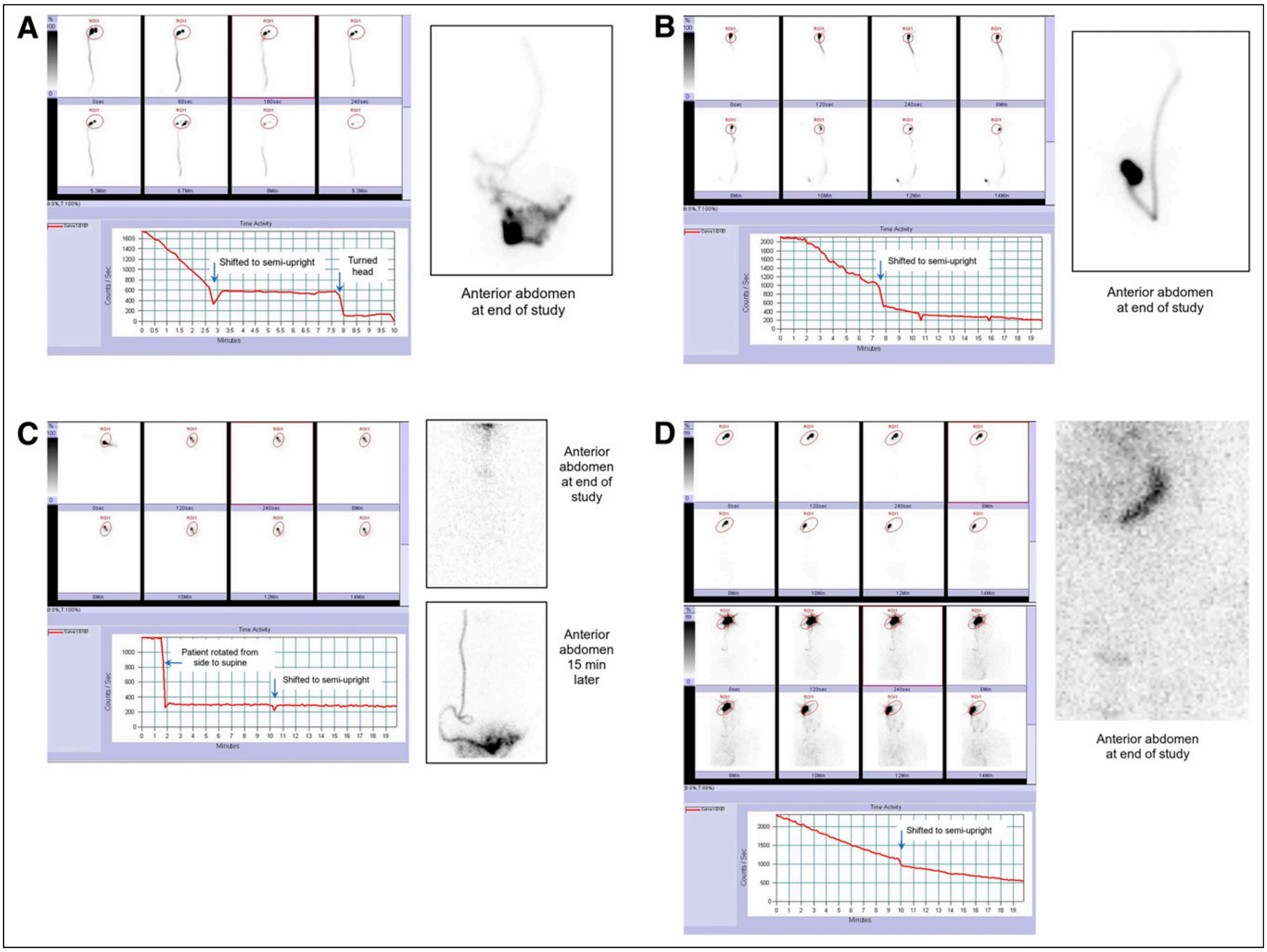


FIGURE 4. (A) Kinking (normal flow with abrupt cessation of flow with change in position) in 80-y-old woman with history of normal-pressure hydrocephalus. Ventriculoperitoneal shunt was placed 13 y previously. Patient was now having increasing trouble with balance and urinary control. Opening pressure was 6 cm, with initial $T_{1/2}$ of 2 min. Flow stopped when patient sat semiupright and resumed after she turned her head. (B) CSF-oma (pattern of distal obstruction but with focal uptake in abdomen) in 32-y-old man with history of childhood brain tumor that had been resected and ventriculoperitoneal shunt placed. Patient now had 1- to 2-wk history of headache. Opening pressure was 14 cm, with initial $T_{1/2}$ of 5 min. Anterior abdomen image shows loculation. (C) Inadvertent air in system in 64-y-old man with history of normal-pressure hydrocephalus and recent head injury, now experiencing worsening problems with balance and memory. Opening pressure was negative. Butterfly catheter was left open for about 1 min. Air entered system and caused temporary blocking of flow. Activity was seen in abdomen after 15 min of ambulation, showing that flow had restarted. Diagnosis is probable overdrainage. (D) Perivalvular injection in 47-y-old woman with history of ventriculoperitoneal shunt placement in 1990 for idiopathic intracranial hypertension. Opening pressure was 0 cm, with initial $T_{1/2}$ of 8 min. Important point in this study is that efferent tubing is not visualized, even on lower set of dynamic images, with intensity increased. Faint activity seen in left neck may be diffusion along tract of tubing. We confirmed that this was not ventriculoatrial shunt, since tubing was seen in abdomen on recent radiograph. Activity over injection site is decreasing because of diffusion into neighboring tissue. Stomach activity is seen at end because pertechnetate diffuses into bloodstream and is taken up by gastric mucosa.

Proximal Obstruction (Fig. 3D)

For proximal obstruction, the opening pressure should be low (<6 cm water). It is often either zero or slightly negative. Flow should be slow (generally $T_{1/2} > 10$ min). It may speed up slightly when the patient is shifted to a semiupright position.

Kinking (Fig. 4A)

Kinking is usually intermittent, most commonly occurs in the neck, and is caused by turning the head to one side or the other. If kinking is suspected, have the patient turn the head to one side for at least 1 min and then turn the other way. If the shunt is working properly, there should be no change in the slope of the curve. Kinking will cause an abrupt cessation of flow, and the curve will become flat. Because turning the head will cause a shift in attenuation between the reservoir and the camera, changes in the absolute value of the curve are not meaningful.

CSF-oma (Fig. 4B)

One of the causes of distal obstruction is a CSF-oma at the end of the distal tubing in the abdomen. The distal tubing has several side holes to try to avoid this problem; however, it still occurs occasionally. The definitive evidence is a focal collection in the abdomen that disperses very slowly. When feasible, it is useful to obtain a SPECT/CT image of the abdomen, both to document the CSF-oma and to demonstrate its location.

Inadvertent Air (Fig. 4C)

It is important to avoid injecting any air into the valve during the procedure. Air will temporarily block CSF flow, because of surface tension. There is also a small risk of infection because of microbes in the air. It is most likely to occur when there is negative CSF pressure, usually when there is overdrainage. The time–activity curve will be flat, indicating no flow. If accidental air injection is suspected and there is no flow, it is useful to obtain delayed imaging of the abdomen. Flow will usually resume in 15–30 min, and activity will be seen in the abdomen. A negative opening pressure and initial lack of flow but with delayed activity seen in the abdomen is likely inadvertent air in the system combined with overdrainage.

Perireservoir Injection (Fig. 4D)

Sometimes the butterfly needle can slip out of the reservoir after the opening pressure is measured, and the injection of tracer is into tissue adjacent to the reservoir. If this occurs, the distal shunt tubing will not be visualized (although sometimes faint activity can be seen along the tubing since activity can diffuse more easily along the tract of the tubing). No activity will be seen in the abdomen. The activity in a region of interest placed over the injection site will slowly decrease, typically with a $T_{1/2}$ of 10–20 min. If the activity remains constant, the activity was injected into the reservoir and the system is completely obstructed. If it slowly decreases without visualization of efferent tubing, it is a perireservoir injection.

CONCLUSION

The nuclear medicine shuntogram for the evaluation of ventriculoperitoneal shunts is a deceptively simple procedure. If done properly, it provides essential information to determine how to manage shunt malfunction. However, there are several details where errors can occur that make the results uninterpretable or misleading. This can happen because of inexperience in accessing the reservoir, injecting the tracer, acquiring the data, or interpretating the results. The above detailed description of the procedure should help ensure that the outcome is useful.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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