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Evaluation of shunt function in hydrocephalic patients with the radionuclide ^{99m}Tc-pertechnetate

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Abstract In most cases of shunted hydrocephalus, shunt malfunction is evaluated by clinical examination and neuro-imaging. However if there is a discrepancy between neurological examination and imaging, additional shuntography can be helpful in the evaluation of the shunt function. In our clinic, radionuclide-imaging shuntography using ^{99m}technetium-pertechnetate was performed in 85 children between 1992 and 1995. The results of shuntography were evaluated visually and from time-activity curves. Shuntography had a sensitivity of 96%, a specificity of 89%, and an accuracy of 93%, proved either by surgery or by clinical follow-up for 2–5 years. Corresponding to these results, we recommend the use of shuntography in cases with an uncertain shunt function before surgical revision.

Key words Shuntography · Central nervous system · Radionuclide · Hydrocephalus

Introduction

In the era of computed tomography (CT) and magnetic resonance imaging (MRI), most cases of malfunction of the shunt in hydrocephalic patients can be diagnosed by these non-invasive methods. Manual compression of the valve unit also belongs to the non-invasive techniques. Nevertheless, in some cases it remains difficult to decide whether surgery is indicated or to confirm that there is normal shunt function. Diagnostic accuracy can be greatly improved by shuntography, since both anatomical and functional information can be obtained.

Contrast medium can be injected into the antechamber [1, 5, 12], and plain radiographs or serial CT scans can then visualize the distribution of the contrast medium. Disadvantages of this method are the high radiation exposure to the patient, owing to serial CT scans, along with possible damage to the valve unit because of the high viscosity of the contrast medium, the risk of bacterial contamination; and inconvenience to the patient. There are also thermosensitive methods for the determination of obstructed sites of shunts [3]. The advantages of this method are that there is no risk of infection, no discomfort for the patient, and no radiation exposure. However, it can only be used for ventriculoperitoneal (VP) shunts, and additional equipment is needed. Shunt patency can also be determined by ultrasound flowmeters [7].

Owing to the disadvantages associated with the occlusion of the valve by contrast medium along with flow assessment only by visualization and the high technical expenditure of the ultrasound flowmetric method, we use radionuclide shuntography as an additional diagnostic method to evaluate shunt function in certain cases. The injection of radionuclide substances was first described by Di Chiro and Grove in 1966 [6]. Since that time, the procedure has been improved [8–11, 14] and has not only been used to ascertain shunt obstructions but also, for example, to diagnose patients who have become independent of the shunt apparatus or to find an optimal position for the antisiphon device [14].

In our cases, shuntography with radionuclide was used to evaluate shunt function when there had been a discrepancy between clinical symptoms and the size of the ventricles in CT or MRI. This paper describes the method and the interpretation of the results in view of the follow-up findings in the patients and gives guidelines for radionuclide shuntography.

Patients and methods

Patients

From 1992 to 1995, 85 children with shunted hydrocephalus internus underwent radionuclide ^{99m}technetium-pertechnetate (^{99m}Tc-pertechnetate) shuntography. Hydrocephalus was caused by obstruction or stenosis of the aqueduct (idiopathic, or caused by infection, hemorrhage or tumor) by Arnold-Chiari deformity, Dandy-Walker syndrome, or communicating hydrocephalus. Indications for shuntography were:

1. Discrepancy between the clinical symptoms of a shunt malformation and CT or MRI findings
2. Unspecific symptoms in retarded children (subtle changes in daily activity), small children (malaise, vomiting, and irritability are often secondary to non-specific viral infection), or patients in a vegetative state with no visible change of the ventricles in an atrophic enlarged ventricular system
3. Children with a low compliance of the brain, where the clinical symptoms of a shunt malfunction appear before CT shows differences in the size of the ventricles
4. Need for additional information for the surgical strategy of the shunt revision

The 85 patients were hydrocephalic children and adolescents between 1 month and 18 years of age. There were 41 female and 44 male patients.

Sixty-three patients had a VP shunt, 18 a ventriculoatrial (VA), 2 a ventriculomastoidal, and 2 a ventriculospinal shunt. Eight had an additional catheter deriving either from the contralateral ventricle or from a separated IV ventricle. They were connected via a Y-piece to the peritoneal or atrial catheter before the valve.

Usually Cordis-Hakim valves were used, but Medos-Hakim valves or shunt systems without a valve were also used in some cases. In the latter cases, there was only a reservoir to tap the system.

Method

The patient was positioned under the large-field gamma camera (DIACAM, Siemens Cooperation) in a supine position, with the head turned to the contralateral side so that the antechamber or Rickham reservoir and valve unit were placed in the direction of the head of the camera at least 5 min prior to injection of the tracer. In the two cases with a ventriculospinal shunt, the patient was brought into a prone position. Sometimes sedation was necessary in small or retarded children.

In 84 cases, approximately 0.4 cc of the radionuclide ^{99m}Tc-pertechnetate (3–4 MBq) was injected into the antechamber or the Rickham reservoir using a 27-gauge needle (3–4 MBq is a small dose of radioactivity, but is sufficient not only for infants but also for adolescents).

One patient with a VP shunt did not have an antechamber or a reservoir, therefore, the radionuclide had to be injected into the valve unit. Only in one case had cerebrospinal fluid (CSF) been taken prior to the injection of the isotope.

Sterile handling of the radionuclide and sterile injection were mandatory. Therefore, the scalp over the antechamber or Rickham reservoir or valve unit had to be shaved and disinfected with ethanol.

The dynamic study (one frame per minute over 10 min) was started immediately after injection. With the exception of adolescents with a VP shunt, the whole shunt system was in the field of view. After the first 5 min of spontaneous flow, the valve unit was pumped manually for 10–15 s. Finally, one or two additional static recordings of the head and/or abdomen were taken.

The results of shuntography were obtained both visually and from time-activity curves from the regions of interest such as the antechamber, supratentorial ventricles, cystic IV ventricle, distal catheter, and in VP shunts also the abdominal cavity. Shuntographies were considered to be normal only if there was retrograde flow of the radionuclide into the ventricles and spontaneous flow of the radionuclide to the distal part of the shunt system (Fig. 1). Additionally, in the VP shunts a free distribution of the radionuclide in the abdominal cavity was required (Fig. 2).

The results of shuntography were checked either by surgical revision, by continuous intracranial pressure (ICP)-monitoring, or by clinical follow-up for 2–5 years. Sensitivity, specificity, and accuracy were determined as shown in Table 1.

Table 1 Estimation of sensitivity, specificity, and accuracy (*TP* true positive, *TN* true negative, *FP* false positive, *FN* false negative)

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP}+\text{FN}} \times 100\%$$

$$\text{Specificity} = \frac{\text{TN}}{\text{TN}+\text{FN}} \times 100\%$$

$$\text{Accuracy} = \frac{\text{TP}+\text{TN}}{\text{TP}+\text{FP}+\text{TN}+\text{FN}} \times 100\%$$

Results

Normal shuntographies

Thirty-five of the shuntographies (Table 2) showed normal results. Thirty-one patients did not have to undergo surgery and had a normal clinical follow-up. In two cases (6% of the normal shuntographies), normal shunt function had been verified in the surgical revision, but the valve was changed to a lower-pressure valve because of the clinical symptomatology. In the two other cases where surgery had been performed, CSF flow could also be verified by surgery, but in one case the valve was working only partially and in the other the ventricular catheter was partially occluded.

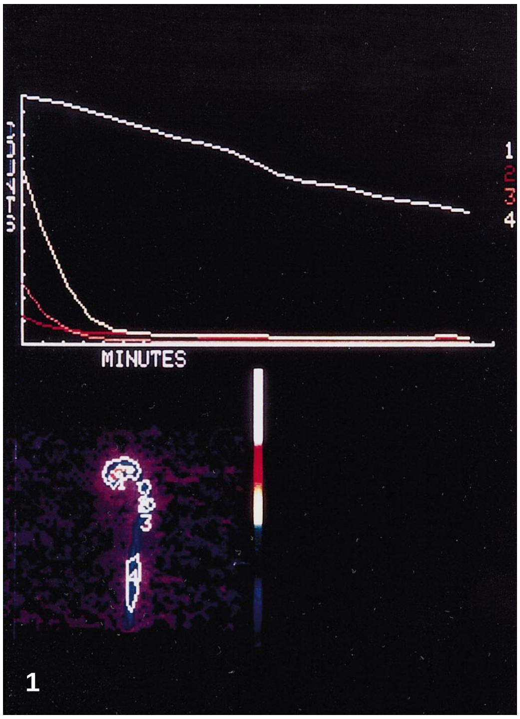

Fig. 1 ^{99m}Tc-pertechnetate image of normal shunt function (*1* ventricle, *2* injection site, *3* and *4* distal parts of the shunt). The shunt was not pumped, because of good continuous spontaneous flow. *Above*: radioactivity in counts per minute in the different regions of interest as marked *below*, confirming normal shunt function

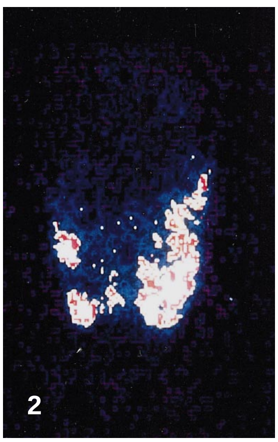

Fig. 2 ^{99m}Tc-pertechnetate image of a normal distribution of the radionuclide in the abdominal cavity in a ventriculoperitoneal shunt

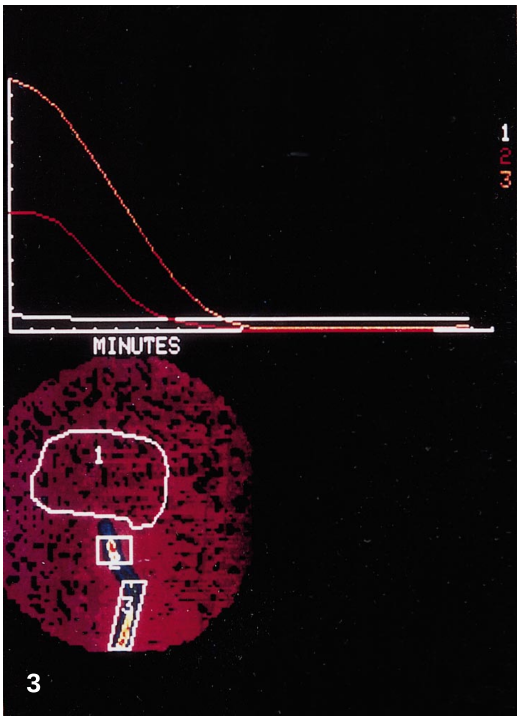

Fig. 3 ^{99m}Tc-pertechnetate image with missed retrograde flow of the tracer but quick distal flow function (*1* ventricle, *2* injection site, *3* distal part of the shunt). *Above*: radioactivity in counts per minute in the different regions of interest as marked *below*, confirming no retrograde flow and quick distal flow

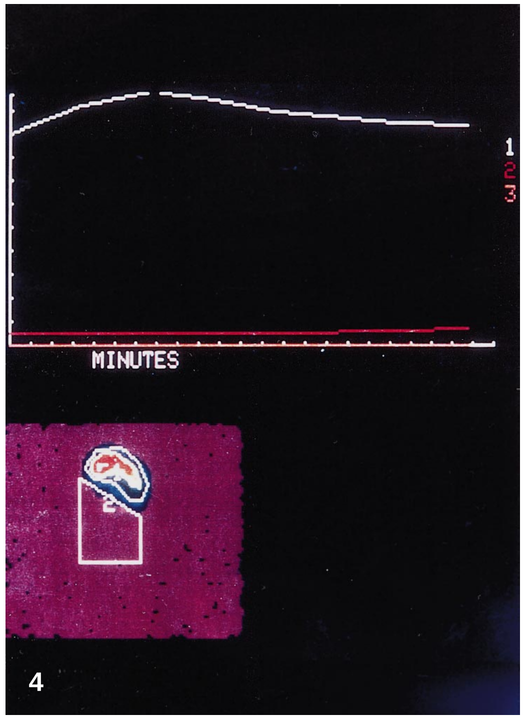

Fig. 4 ^{99m}Tc-pertechnetate image of complete stop of flow: absent retrograde flow to the ventricle (*1*); tracer in the injection site (*2*), and distal part (*3*) of the shunt only after pumping of the valve. *Above*: radioactivity in counts per minute in the different regions of interest as marked on the image (*below*), confirming no retrograde flow and no distal flow

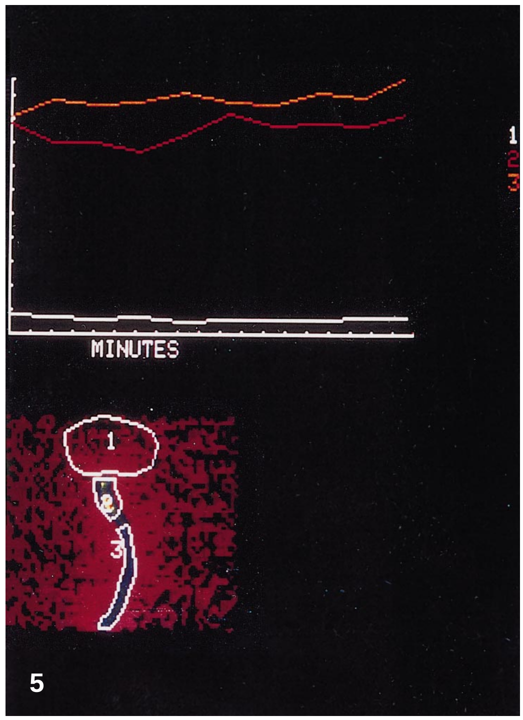

Fig. 5 ^{99m}Tc-pertechnetate image of a complete caudal blockage: ventricle and injection site (*1*), distal part (*2*) of the shunt. *Above*: radioactivity in counts per minute in the two regions of interest as marked on the image (*below*), confirming a complete caudal blockade

Table 2 Results of shuntographies and clinical follow-up in 85 patients (46 with true-positive results, 33 with true-negative results, 2 with false-negative results, 4 with false-positive results) (*ICP* intracranial pressure, *CSF* cerebrospinal fluid)

	Normal clinical follow-up	ICP monitoring (normal ICP)	Surgical revision with pathological results
Normal shuntographies (35 cases)	33		2
Pathological shuntographies (total: 50 cases)			
No retrograde flow (8 cases)	1[a]		7
Intraperitoneal cyst (6 cases)			6
Complete distal block (10 cases)			10
No spontaneous flow, but flow during manual pumping of the shunt (26 cases)	1[b], 1	1	23

[a] No retrograde flow was expected, because the tracer had to be injected into the valve unit
[b] No spontaneous flow was expected, because 2 ml CSF had been aspirated before injection of the tracer

Pathological shuntographies

There were 50 shuntographies (Table 2) with pathological findings. In 8 cases there was no retrograde flow (Fig. 3); however, in 1 of these the radionuclide had to be injected into the valve unit, so that no retrograde flow could have been expected.

In the other 7 cases, an obstructed ventricular catheter was verified at surgery. One of these patients had a complete stop in either direction, as also already expected by shuntography (Fig. 4).

Six other cases showed a cystic depot of the radionuclide in projection of the abdomen. All patients underwent surgery, which revealed either an extra-abdominal location of the catheter tip or an intraperitoneal cyst around the tip of the catheter. In all 13 cases, the surgical strategy could be planned in advance after shuntography.

In 10 cases, there was a complete stop of the radionuclide distal to the injection site (Fig. 5), and in all cases an obstruction of the tip of the distal catheter had been seen at surgery.

In 26 cases, there was no spontaneous flow of the radionuclide, but rapid flow after pumping the valve unit. In 1 of these cases, 2 ml of CSF had been taken for diagnostic reasons before shuntography, so that there was not enough pressure, and no revision was performed. In the other 25 cases, neurological symptoms and CT were reviewed again. One of these cases was clinically followed over 3–4 years without surgery. One underwent ICP monitoring, and in 23 patients a shunt revision was done. The ICP values of the monitored patient were normal. Shunt revisions in the other 23 patients showed either a defective valve unit or insufficiency of the distal catheter.

In summary, surgery was performed in 47 of the 50 patients with a pathological shuntography.

Sensitivity, specificity, and accuracy

No complete obstruction escaped detection, but in 2 cases with normal shuntography, partial obstruction of the ventricular catheter and partial dysfunction of the valve unit were seen. Therefore, the method has a sensitivity of detection of total or partial obstruction of the catheter or dysfunction of the valve unit of 96%. In 4 cases without spontaneous flow of the radionuclide, a normal shunt system was found following ICP monitoring or in the clinical follow-up without surgical revision. Therefore, the specificity of the method is 89%. Accuracy was 93%.

Complications of shuntography

No complications were noted with the procedure. There was no case where the tracer was injected outside the shunt tubing. However, in 2 children an infection was seen, but it could not be determined whether it was due to shuntography or to several shunt revisions within a short interval before and after shuntography.

Discussion

For shuntography, we used the radionuclide ^{99m}Tc-pertechnetate, because of the short half-life. However, in the literature other tracers such as ^{111}In-diethylenetriaminepentaacetic acid have also been also proposed [2].

It is mandatory to inject a small volume (0.4 cc) of the radionuclide, but also to prohibit the loss of CSF by taking CSF for diagnostic reasons or puncturing only with a needle before connecting to the syringe in order to keep the original fluid balance. Radiation exposure is minimal.

In the literature, almost all authors evaluated the results of shuntography only visually [6, 8, 9, 13], except in one report where the results were expressed in counts per hour for the lateral ventricle over a period of 24 h [10]. A new aspect of the present paper is the dynamic evaluation of the results.

From our experience, we propose that if a normal shunt function is expected after shuntography, but clinical data indicate raised ICP, a shunt revision should be performed. Either the opening pressure of the valve needs to be decreased or the replacement of a partially functioning valve or catheters is necessary.

In all cases where no retrograde flow of the radionuclide was seen but radionuclide was injected into the antechamber or the Rickham reservoir, a complete or partial

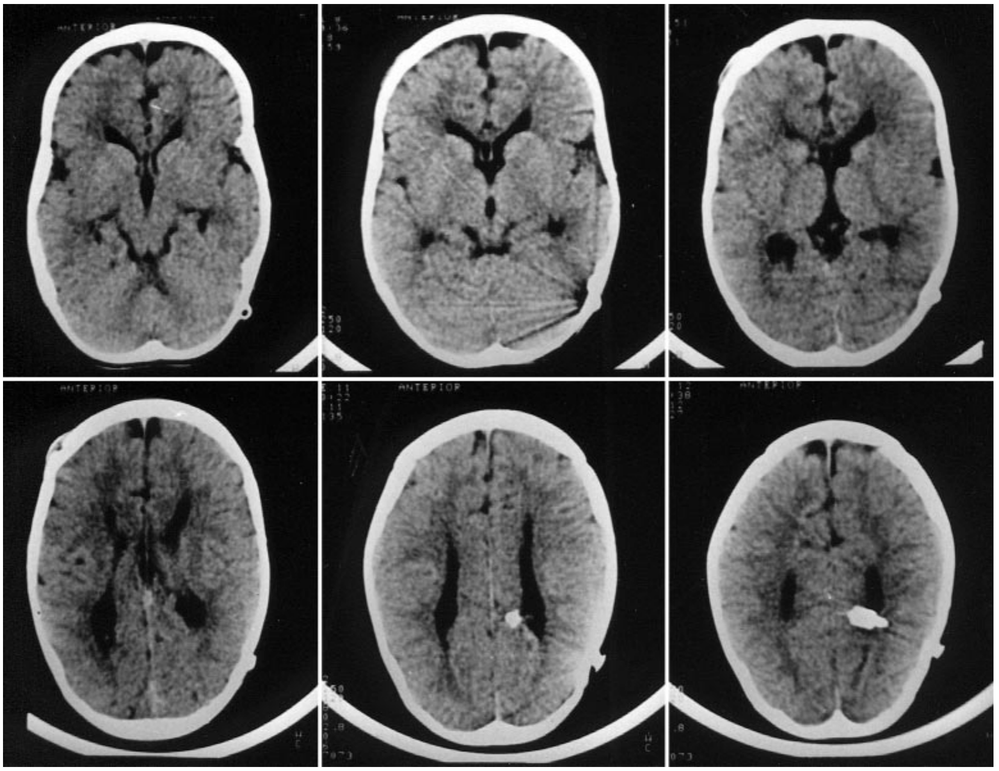

Fig. 6 CT scans of a patient with symptoms of raised intracranial pressure, showing no visual dilatation of the ventricular system. The scans were taken some minutes before shuntography in the same patient (see Fig. 3), in whom no retrograde flow had been seen

obstruction of the ventricular catheter was verified at surgery. All cases with cystic depots of the radionuclide in projection of the abdomen were also verified at surgery, showing an insufficiency of the distal outlet of the distal tube. Either the tip of the catheter was located in the abdominal wall or it was draining into a cyst. If there was a complete stop distal to the injection site, an obstruction was always found. Difficult to interpret was a missed spontaneous distal flow of the radionuclide, but a rapid flow after pumping the valve unit. In those cases, clinical symptoms, CT scans and shuntography needed to be reviewed again, and if there was any suspicion of a shunt malformation, surgical revision or ICP monitoring was performed. In 23 cases of surgical revision, either a partial dysfunction of the valve unit or partial distal occlusion was seen at surgery.

In patients with a low compliance of the brain, CT scans do not show dilatation of the CSF system at the beginning of the clinical symptoms of shunt dysfunction. However, shuntography is more sensitive at that early time point. Figure 6 shows CT scans taken some minutes before shuntography (Fig. 3) of the same patient. While shuntography gives the indication for surgical revision, CT scans are not convincing of a shunt dysfunction.

Shuntography is not only important for indicating surgery or changing the opening pressure of the valve unit, but also gives valuable information that can be used to decide on the strategy at surgical revision.

Limitations of shuntography for indicating essential surgery are encountered in the presence of partially obstructed ventricular catheters and partially working valve units, because in those cases the elevated ICP overcomes partially working parts of the shunt. Also, if the operating pressure of the valve has been chosen too high for a particular patient, there is no abnormality of the shuntography. If there is no antechamber or Rickham reservoir and the radionuclide needs to be injected into the valve unit, only partial information about the function of the ventricular catheter can be obtained. Shuntography can also provide additional information to identify those patients who become independent of their shunt if the shuntography is pathological but no symptoms and no enlargement of the ventricles occur.

It is very important to perform an additional X-ray examination, because patent fibrous tracts may mask disconnections or outgrowth of the distal catheter and can show normal shuntographies [4].

The present paper confirms the specificity, sensitivity, and accuracy of previous reports of shunt pressure measurement combined with radionuclide shuntography [13] or of radionuclide shuntography itself [9].

In summary, shuntography gives additional valuable information about the general shunt function, but also about the localization of the dysfunction in the era of CT and MRI. However, in all cases the results of shuntography need to be discussed together with the clinical symptoms, X-rays, CT scans, and the type of the shunt system itself, especially with a dynamic evaluation of the results.

Guidelines for shuntography

1. Sterile handling is mandatory, not only for the injection but also for the production and handling of the radioactive solution.
2. The patient should be placed in a horizontal relaxed position at least 5 min before the procedure is to be started.
3. No CSF should be aspirated before injection of the radionuclide.
4. If possible, there should be no injection into the valve unit, as otherwise only partial information about the function of the ventricular catheter can be obtained.
5. Scanning should be started as soon as possible after injection.
6. Normal shuntography requires retrograde flow and spontaneous distal flow.
7. In normal shuntographies the possibility of a too-high opening pressure of the valve should be considered.
8. No retrograde flow of the radionuclide into the ventricles or cyst always shows an obstructed or partially obstructed ventricular catheter.
9. Absent distal flow always shows an obstruction of the distal catheter.
10. Absence of any spontaneous flow of the radionuclide towards the distal end should always be considered to be pathological, but all data about the patient should be reviewed again before revision.
11. In VP shunts, free distribution of the radionuclide in the abdominal cavity is required.

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