Radionuclide Tests of Cerebral Fluid Shunt Patency

The article by Chervu et al. (1) that appears in this issue is most gratifying since it answers a question that arose many years ago (2) and has continued to disturb us: Why are some patients with severe obstructive hydrocephalus adequately compensated and clinically well with cerebrospinal fluid (CSF) shunt flow rates measuring as low as 0.005 ml/min? If normal CSF production is about 0.4 ml/min (3), absorption rates lower by almost two orders of magnitude do not adequately account for the restorative effects of CSF shunting. Chervu et al. have shown us that the addition of a downstream valve system changes the clearance characteristics of the injected reservoir, thereby invalidating the assumptions made in the calculations.

The measurement of CSF shunt flow, F, using the relationship

\[ F = \lambda V \]  

where \( \lambda = \frac{0.693}{T_{1/2}} \), and \( V \) = the physical volume injected, assumes first-order kinetics wherein the CSF flowing into the reservoir is completely mixed with the tracer injected into the reservoir. The concentration entering the reservoir is zero and the concentration leaving is assumed to equal the mean concentration within the reservoir.

The above formula is easily derived from the differential equation describing the rate of clearance of the injected activity, \( \frac{dA_t}{dt} \):

\[ \frac{dA_t}{dt} = -\frac{F}{V} A_t + \frac{2}{V} I_1 \]  

Integrating and taking the exponential, the general equation for the ratio of remaining to initial activity at time \( t \) is obtained:

\[ \frac{A_t}{A_0} = e - \frac{F}{V} t, \]  

and at \( t_{1/2} \):

\[ \frac{A_{t_{1/2}}}{A_0} = \frac{1}{2} = e - \frac{F}{V} t_{1/2}. \]

and

\[ \ln 1 - \ln 2 = -\frac{F}{V} t_{1/2}. \]

or

\[ F = \ln \frac{2}{t_{1/2}} V. \]

Since \( \lambda \) is defined as \( (\ln 2)/t_{1/2} \):

\[ F = \lambda V \]

If incomplete mixing occurs, the usual result is to reduce the effective volume of the reservoir. Consider the example shown in Fig. 1 in which counter currents within the reservoir prevent complete mixing of CSF flowing into the reservoir. If we assume that some fraction \( (k) \) of the volume is expanded or contracted by the mixing process, then Eq. (4) becomes:

\[ \frac{A_{t_{1/2}}}{A_0} = e - \frac{F}{V(k)} t_{1/2} \]
We have chosen to define $V(k) = V_{exp}$ because the volume involved is unknown and must be determined experimentally (2). Equation (1) then becomes:

$$F = \lambda V_{exp}$$

The alternative—that selected by Chervu et al.—is to plot the clearance constant values against several predetermined rates of flow. The latter method requires a graph for each reservoir and valve-reservoir combination.

While it is obviously the clearance constant ($\lambda$) that changes with different degrees of mixing, it is easier to adjust the values of $V(V_{exp})$ because they can be tabulated easily. We have provided these $V_{exp}$ values for several valves and reservoir systems (2). Complex currents apparently exist in most reservoir-and-valve systems because the values of $V_{exp}$ required to estimate flow correctly from experimentally determined clearance rates using the above equation are seldom the same as the physical volumes of the injected chamber (2). $V_{exp}$ is usually smaller than the physical volume, reflecting the increased value of $\lambda$ caused by incomplete mixing. Fortunately $V_{exp}$ is constant in most shunt systems over the range of CSF flow rates encountered in physiologic conditions. The Mischler flat-bottom reservoir is an exception; unpredictable values of $V_{exp}$ occur at different flow rates.

We noted in 1974 that the clearance from multicompartment reservoirs often differed greatly depending upon the chamber injected. In all such cases we gave the $V_{exp}$ assuming injection into the most distal chamber. Knowing this, it should have been apparent that the addition of downstream valves would change the flow characteristics from the proximal reservoir. Nevertheless, that did not occur to us, and elucidating this point is the central value of Chervu’s study.

Combinations of shunt devices are becoming increasingly common. The use of antisiphon valves in combination with low- and medium-resistance differential pressure valves in infantile hydrocephalus helps prevent complications such as slit ventricles and subdural hematomas (4). These devices add to the overall resistance of the shunt system and always displace the pressure-flow curve upward (5). It is now clear that they also alter the clearance characteristics of the reservoir system to which they are connected immediately downstream. To quantitate CSF flow from clearance measurements, each combination must be individually bench tested to derive an accurate value of $V_{exp}$ or the relationship between clearance constant and flow.

Clinicians should be aware that a radionuclide shunt flow study tests patency only at the time of study and even then may not reflect the functional adequacy of the shunt system, chiefly because the pressure: flow relationships are not assessed.

Changes in hydration, intrathoracic pressure, and ambient CSF pressure can greatly affect CSF flow at any particular moment. Position (i.e. hydrostatic pressure), struggling or crying (increased intracranial pressure), and pCO$_2$ (altered CSF formation) can all affect CSF shunt flow. Often the most useful information that can be provided is to determine the circumstances under which flow can be demonstrated or altered. Since simultaneous measurements of intracranial pressure are usually not possible, the shunt flow characteristics must be estimated on clinical grounds.
In a recent analysis of 76 radionuclide shunt patency studies, French and Swanson found no errors in diagnosing 19 cases of shunt obstruction (6). In fact, misleading information was found only in patients with patent but inadequately functioning shunts. Such problems are the most difficult to diagnose clinically and by other nonfunctional tests. Nevertheless, since serial TCT images have largely replaced other methods of evaluating CSF shunt function, the difficult problems are all the more likely to be encountered in the nuclear medicine laboratory.

Inadequate shunt function can usually be identified by carefully considering the presenting complaints, the physical findings, and results of ancillary diagnostic tests, and by performing a few essential maneuvers as a part of the radionuclide shunt-patency study:

1. Patients in whom CSF flow varies little between the upright and supine position are likely to have a partial obstruction, either in the ventricular or in the efferent catheter. The best means of measuring postural CSF flow changes is by the quantitative shunt patency test.
2. A reservoir that requires pumping to initiate flow or in which resistance is encountered when injecting tracer into the chamber, should always be considered faulty despite patency.
3. A patient that has been struggling or crying before or during injection may be expected to have reduced CSF flow until CSF pressure returns to steady-state levels. Serial flow studies may be useful.
4. A reservoir that fails to empty even with manual pumping should be reinjected and the reservoir barbotaged slightly before concluding complete obstruction. Subgaleal injections are usually apparent by diffusion of tracer around the reservoir or by the presence of renal activity, but these may not become apparent until several minutes following injection.
5. Plain radiographs usually detect disconnections, and these are confirmed by leakage of tracer at the site. Imaging the entire course of the shunt is therefore essential.
6. Failure of radionuclide to disperse within the abdomen (encystment) generally raises the opening pressure and requires replacement of the distal tubing.
7. Patent shunts associated with slit ventricles on TCT imaging usually indicate too low an opening pressure and the need for increased valve resistance. CSF shunt flow in such cases is usually normal unless coaptation of the ventricular walls occludes the ventricular catheter.

A final technical comment might be appropriate. Investigators must realize that Rickham reservoirs are available in more than one size and design shape, and from more than one manufacturer. When performing CSF flow studies as described in the Chervu article, the exact type and model number of the reservoir should be specified so that the flow characteristics can be related precisely to the clinical testing problem.

JOHN C. HARBERT
DAVID C. MCCULLOUGH
Georgetown University Hospital
Childrens Hospital National Medical Center
Washington, D.C.

REFERENCES