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Control of Hydrocephalus by Valve-Regulated Shunt

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The operative procedure for control of hydrocephalus by use of the Holter valve appears on first glance to be one of the simplest in neurosurgery. Experience has shown, however, that strict adherence to minute technical details and careful aseptic precautions are imperative; otherwise the procedure may be doomed to ultimate failure even though this may not become apparent for several years. The technical points we have emphasized are based on our experience with complications which will be described in another publication.

Good preoperative pneumoencephalography is essential to define the etiology of the hydrocephalus and eliminate the possibility of a lesion which could be treated by more specific surgery.

Risk from air embolism is unlikely, even in a small infant when the venous shunt has to be established while ventricular air is still present. If excessive amounts of air are required to delineate the etiology of the hydrocephalus, carbon dioxide may be used.

Bacterial contamination of the cerebrospinal fluid, either through an open myelomeningocele or from repeated ventricular taps, is another hazard. When such a possibility is recognized, an initial temporizing shunt into the peritoneal or pleural cavity may be advisable since it carries less risk.

Operative Procedure

Anesthesia and Positioning. We prefer general anesthesia with intubation. This permits the use of positive pressure during venous catheterization as a safeguard against air embolism, and x-ray procedures are facilitated by the ability to control anesthesia from a distance. In situations of poor risk, however, the operation can be accomplished under local anesthesia. There is usually no need for a separate intravenous infusion since the surgeon’s first maneuver will be catheterization of the jugular vein through which fluids can be easily introduced. Monitoring of temperature is important in the small infant where an unexpected degree of hypothermia can endanger cardiorespiratory function.

The best position of the patient for both surgical exposure and x-ray study is as follows: The head is placed with the right side upward in a true lateral plane. Folded sheets raise the shoulders to extend the neck for surgical accessibility. The chest lies in a neutral supine position unless avoidance of pressure on a myelomeningocele requires oblique rotation. A cassette holder is placed under both the head and the chest. In small infants, a non-opaque warming unit is interposed.

The Holter Apparatus. Fig. 1 illustrates the components of the Holter apparatus. The barium-impregnated silicone-rubber venous catheter (A) usually employed has an external diameter of 2.5 mm. The rigid connector (C) fits within the tubing to permit solid anchoring. A modified catheter (B) is preferred by some surgeons on the theory that this stepped-down filamentous end could rest low in the heart without danger of endocarditis, but we prefer the proven safety of higher placement of the (A) catheter described later. The paired-valve assembly (D) incorporates check valves available at three different grades of resistance. They are designated as normal pressure (70 mm of re-
Valve-Regulated Shunt Control of Hydrocephalus

usually a medium pressure valve is chosen for the initial procedure. The manufacturer provides instructions for testing both the check and resistance characteristics of the valves at the operating table. The valves are reliably sterilized by the manufacturer because improper operating room autoclaving could alter their properties. The valve assembly is purposely made bulky so that it can be tested by palpation in its subcutaneous location; easy compression assures distal patency, and prompt refill demonstrates free proximal inflow from the ventricle. The introducer (E) can be threaded into the proximal adapter of the valve assembly and, with its leading cone, will facilitate threading of the apparatus through a small subcutaneous tunnel. The ventricular catheter (F), also made of barium-impregnated silicone rubber, has a blind end which will hold a stylette. Multiple, tiny, side perforations extend over the distal 15-mm segment of the catheter. The Rickham reservoir (G) is a useful addition whose incorporation in the standard shunt arrangement permits access to the ventricular catheter by subcutaneous puncture with a hypodermic needle.

Fig. 1. The Holter equipment: A. Standard venous catheter; B. Modification of venous catheter, connector incorporated, with step-down termination; C. Connector to permit fixation of venous catheter; D. Paired valve assembly; E. Introducer for placement of valve; F. Ventricular catheter with stylette for insertion; G. Rickham reservoir modification.
Marking Incisions. The scheme for head and neck incisions is shown in Fig. 2. These must be drawn on the prepared skin before draping obscures landmarks. The incision for inserting the venous catheter extends transversely in a skin fold just below the angle of the jaw. The scalp flap is outlined to cover both the site for the burr hole and the proximal valve apparatus.

Fig. 2. Plan for incisions: Trephine (x) is located 3 cm above, 3 cm behind tip of ear. Scalp flap will cover field needed for trephine and fixation of valve assembly. Neck incision placed just below angle of jaw.
Insertion of Venous Catheter. After draping the patient and checking the equipment, the first surgical step (Fig. 3) is to expose the internal jugular vein through the previously outlined incision in the neck. Preservation of its continuity is only useful when entrance through a tributary vein, such as the common facial, lingual, or superior thyroid, is easy. The rigid connector is threaded into the catheter with the help of a stylette. The length of tubing that will extend intravenously beyond the connector is purposely over-estimated by 1 to 2 cm, since the first placement is never sufficiently accurate and it is technically easier to shorten the catheter (and readjust the connector) than to lengthen it. With the aid of the preoperative roentgenogram of the chest, a length is chosen so that the catheter tip will lie near the level of the seventh thoracic vertebral body. Before its introduction, the catheter is filled with saline solution and connected above with a closed stopcock syringe system which includes a manometer for verification of low or negative venous pressure at the intrathoracic catheter tip. The tributary vein is then ligated above the proposed point of insertion and opened after placement of a check or proximal sling ligature and establishment of positive intrathoracic pressure. The catheter is introduced and advanced into the jugular vein until its indwelling connector lies at the venous orifice. Since its position must be modified later, back-bleeding and air embolism are prevented by a temporary closure of the check ligature.

After venous pressure measurement and irrigation, which can include infusion of fluids if required in a small infant, 2 cc of 50% Hypaque are injected and the catheter is clamped. An anteroposterior x-ray of the chest is then taken, centered at T-6.
Fig. 4. Initial x-ray shows a preliminary placement of the catheter tip purposely introduced too low (at T-7). De- lineation was assisted by instilling 2 cc of 50% Hypaque.

Fig. 5. Corrected final placement (low T-6). Catheter was withdrawn 7 mm and the connector advanced 7 mm farther into the catheter.
When this x-ray has shown the position of the distal catheter, attention is turned to the neck wound to secure final placement of the venous catheter. Fig. 4 shows the catheter tip opposite the seventh thoracic vertebral body. Since ideal placement is at the level of the lower part of the sixth thoracic vertebral body, correction is accomplished by measured withdrawal of the catheter and a corresponding advancement of the connector by stylette (7 mm in this instance). To be certain of correct position a second chest film is obtained. Fig. 5 shows correct final placement at the low T-6 level. Permanent fixation can now be achieved by ligating the wall of the tributary vein around the segment of catheter held rigid by the indwelling connector.

**Skull Opening.** While awaiting the x-ray film, the scalp flap is reflected in the subgaleal plane and the pericranium incised vertically (Fig. 6). A burr hole is made 3 cm above and 3 cm behind the superior tip of the ear. This high posterior placement permits direct access to the lateral ventricle and facilitates later placement of a new ventricular catheter in the frontal horn of a ventricle that may be appreciably smaller. Furthermore, this allows for location of the valve assembly well behind the mastoid prominence. Sufficient bone is removed below the burr hole to contain the proximal valve assembly. A heavy 2-0 silk ligature is threaded into two twist-drill openings in the skull and arranged for later fixation of the valve mechanism to the skull, as shown.

**Fig. 6.** Scalp flap elevated. Skull defect extended below burr hole to hold proximal valve assembly and connecting ventricular catheter. Cross section shows plan for later fixation of valve assembly by 2-0 silk threaded through two skull perforations by twist drill.
Subcutaneous Passage of Valve Introducer.
The medium pressure Holter valve is now placed outside the scalp over its anticipated final subcutaneous location, and the venous catheter is brought alongside to estimate the correct length from the point of venous ligature to the distal valve adapter. It is well to allow moderate slack. After valve and catheter have been irrigated with saline solution, the catheter is cut to proper length and secured to the distal valve adapter with two 3-0 silk ligatures. Silk of smaller size tends to cut the silicone tubing. A uterine forceps, advanced subcutaneously from scalp to neck wound in a line from the skull defect to the point of venous catheter fixation, grasps the valve introducer and draws it toward the scalp wound. When only a short length of introducer remains projecting from the neck wound, it can be threaded

**Fig. 7.** A long clamp, previously tunneled subcutaneously from scalp to neck incision, has partially pulled through the introducer, threaded to the valve assembly. The valve is attached to the required length of tubing by two ligatures.
into the countthreaded proximal valve adapter. Fig. 7 shows the arrangement of introducer, protective cone, and valve assembly as the apparatus is pulled toward its final positions.

Placing the Ventricular Catheter. The ventricular catheter is inserted by stylette through a dural opening snug enough to permit its passage but prevent cerebrospinal fluid leak. A length sufficient to carry the catheter tip to the frontal horn at the level of the coronal suture and to permit its final connection to the valve assembly has been estimated from previous skull x-rays or pneumoencephalograms. As the catheter is advanced in a parasagittal plane, cerebrospinal fluid will leak around the stylette when the ventricle is entered and should continue as full insertion is accomplished. With removal of the stylette, free flow of cerebrospinal fluid should occur. Fig. 8 shows the position of the extracranial portion of the ventricular catheter and emphasizes the important maneuver of repeated flushing with 1-cc amounts of normal saline solution to clear its tiny distal openings. The catheter is then clamped to await final connection with the valve assembly.

Fig. 8. The ventricular catheter is introduced by stylette through a tight fitting dural opening. It should drain freely and must be irrigated vigorously to clear it of possible debris.
A lateral skull roentgenogram is now obtained. While awaiting the result, the valve assembly is irrigated, using a temporary connecting tube (Fig. 9). Closure of the neck wound can be started.

Fig. 9. While awaiting a skull x-ray, the valves and distal tubing are irrigated using a temporary connecting tube.
The lateral skull roentgenogram (Fig. 10) shows the catheter in ideal position with its tip and 1.5 cm of its draining surface projecting just past the coronal suture and foramen of Monro. As the ventricles subsequently become more normal in size, this position will prevent occlusion by the choroid plexus.

Fig. 10. The lateral skull film shows the catheter in ideal position projecting forward to the level of the coronal suture so that its tip is anterior to the foramen of Monro.
Attachment of Ventricular Catheter to Valve Adapter. Final attachment of the apparatus is completed (Fig. 11). The proximal valve-housing is sutured to the skull to prevent mobility. The catheter is held securely to the valve adapter with two 3-0 silk ligatures. The arrangement must allow no sharp angulation of the soft ventricular catheter. Closure of wounds is then completed.

Rickham Reservoir. The elective incorporation of a Rickham reservoir (routine in our clinic since early 1965) is illustrated in Fig. 12. The reservoir must be so recessed in the bone that it will be barely palpable through the scalp. Its plastic cap can be entered through the overlying scalp with a No. 24 Huber needle without subsequent leak from the puncture site. This will permit later ventriculography as well as irrigation of the ventricular catheter in case of block.

Since postoperative morbidity is minimal with prompt resumption of oral intake, no special measures are required other than the routine use of a humidity tent following tracheal intubation in infants. The use of prophylactic antibiotics will be described in another publication.

Technique for Surgical Revisions

Advancing the Venous Catheter. Even with ideal placement and fixation of the shunt apparatus, growth of the infant will require revisions to lengthen the venous catheter. We believe that the risk of late postoperative endocarditis and septicemia can be avoided by placing the catheter tip above T-7. Usually it will become occluded when factors related to chest growth bring it above T-4. Appropriately-timed follow-up chest x-rays permit prediction of occlusion and the revision can thus be accomplished before there has been a recurrence of increased intracranial pressure. Lengthening of the venous catheter is technically simple under these circumstances. The point of entrance of the catheter into the vein is exposed, the anchoring suture released, and the tubing sectioned a distance above the connector corresponding to the new length required. If blood is aspirated there will be no obstruction to advancing the catheter.
downward into the vena cava as far as necessary. The position is verified by another roentgenogram after 2 cc of 50% Hypaque have been injected into the distal tube. An extra length of tubing utilizing connectors then restores continuity of the shunt apparatus.

Replacing the Venous Catheter. If the catheter tip has been allowed to ascend higher and to become obstructed, blood cannot be aspirated and saline solution injected into the tube will flow reflexly around the catheter. In this event the catheter must be removed, with care being taken to preserve the orifice into the venous lumen which can be re-entered with a dull ventricular cannula. Firm resistance will be encountered at the point of fibrous obstruction corresponding to the previous position of the catheter tip. With gentle pressure the cannula can be advanced past this thin but firm membrane, at which point blood can be aspirated. This channel to the free venous reservoir in the superior cava must then be dilated with No. 7, 8, and 9 ureteral catheters. Finally, a new venous catheter can be passed to the T-6 level with the help of a stylette. Occasionally, recatheterization cannot be effected, but entry through the subclavian vein is possible. Rarely, thoracotomy, or a left jugular approach, has been used to re-establish caval shunts in older children.

Replacing the Ventricular Catheter. Replacement of the ventricular catheter in the frontal horn can be difficult in older, well-controlled hydrocephalic patients who have acquired small ventricles. Insertion of the catheter through a new frontal burr-hole may carry the best possibility for success. To avoid these technical difficulties, the position of the ventricular catheter is checked by x-ray at the time of “routine” revision of the venous catheter and, if not in ideal position, replaced in the frontal horn during the surgical procedure performed primarily to advance the venous portion of the shunt.

Valve Assembly. A revision designed to replace the valve assembly with one of lower resistance occasionally will be indicated early if head growth and a full fontanelle persist and there is no evidence of shunt obstruction. If a severely depressed
fontanelle indicates overdrainage, a change to a valve of higher resistance may be required. A late change in the resistance properties of the valve assembly will occur only when there has been obstruction at the ventricular catheter tip. Both catheter and valve assembly may acquire solid detritus in an amount that will account for the increased resistance.

**Advantage of Holter Valve**

This technical description has been confined to placement of the Holter valve and shunt apparatus. We prefer the easily-accessible subcutaneous location of paired valves with a palpable connecting tube. Shunt function can be checked by palpation and by direct needling, if necessary, either to aspirate ventricular fluid or to inject a radiopaque medium suitable for intravenous use in the study of venous drainage. There is a choice of valve resistances for the patient who requires either more or less assistance in cerebrospinal fluid "absorption" than the average patient, and valves can be changed without disturbing the venous catheter. Occlusion of the entire apparatus by barium impregnation becomes of major assistance in long-term management, since all shunt dysfunctions are explainable by x-ray studies which will demonstrate the changing anatomical position of catheter tips with growth, or more rarely the migration of separation of components in the apparatus. Furthermore, this capacity for visualization by x-ray permits anticipation of shunt dysfunction before it occurs and the accomplishment of a technically simple elective revision, thus avoiding further pressure insult to the developing brain.

The most important point in the placement of this prosthesis is to establish the tips of the catheters in positions that will guarantee the longest possible duration of shunt function. The optimal venous tip position is at a low sixth thoracic vertebral body level; the best ventricular tip position is in the frontal horn, anterior to the foramen of Munro and coronal suture. The correlation of original position with duration of function is so striking that roentgenographic guidance to ideal placement becomes essential.

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