Cerebrospinal Fluid Shunts to Treat Hydrocephalus and Idiopathic Intracranial Hypertension

Surgical Techniques and Complication Avoidance

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KEYWORDS

• Cerebrospinal fluid shunts • Idiopathic intracranial hypertension • Neuronavigation • Shunt laparoscopy • Infection control protocols

KEY POINTS

- Stereotactic neuro-navigation and laparoscopic techniques improve cerebrospinal fluid shunt placement precision, reducing complications and enhancing outcomes in hydrocephalus and idiopathic intracranial hypertension management.
- Detailed procedural guidance is provided for proximal and distal catheter placements, including ventricular, lumbar, peritoneal, atrial, and pleural sites, with evidence-based strategies for surgical optimization.
- Strategies to minimize shunt complications emphasize infection prevention bundles, appropriate valve selection, and meticulous adherence to sterile surgical protocols.
- Comparative analyses of ventriculo-peritoneal, ventriculo-atrial, ventriculo-pleural, and lumbo-peritoneal shunts offer patient-specific recommendations, addressing anatomic and pathological considerations for optimal outcomes.

INTRODUCTION

Hydrocephalus is predominantly treated with cerebrospinal fluid (CSF) diversion via shunt systems or endoscopic third ventriculostomy. In idiopathic intracranial hypertension (IIH), shunting becomes necessary when pharmacologic treatments and temporary lumbar drainage fail. CSF shunt systems comprise 3 main components: a proximal catheter placed in the ventricle or lumbar cistern, a flow-regulating valve, and a distal catheter directing CSF to an absorptive site, typically the peritoneal cavity but occasionally the right atrium, pleural cavity, or other spaces. Some

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Neurosurg Clin N Am 36 (2025) 255–268
https://doi.org/10.1016/j.nec.2024.12.004
1042-3680/25/

Abbreviations	
AIC	antibiotic-impregnated catheter
CAJ	cavo-atrial junction
COPD	chronic obstructive pulmonary disease
CSF	cerebrospinal fluid
CT	computed tomography
EVD	external ventricular drains
HCRN	Hydrocephalus Clinical Research Network
IIH	idiopathic intracranial hypertension
iNPH	idiopathic normal pressure hydrocephalus
IVH	intraventricular hemmorage
LP	lumbo-peritoneal
VA	ventriculo-atrial
VP	ventriculoperitoneal
VPL	ventriculo-pleural

configurations include a Rickham reservoir for diagnostic or therapeutic access without disturbing the valve.

Global variations in shunting approaches reflect differences in preferences and regulatory factors. Ventriculoperitoneal (VP) shunts are most common in North America, whereas lumbo-peritoneal (LP) shunts are preferred in Japan and other Asian countries, particularly for idiopathic normal pressure hydrocephalus (iNPH). In parts of South America, ventriculo-atrial (VA) shunts are often a first-line choice. Additionally, the choice of valve types is influenced by local markets and regulatory landscapes. Despite these differences, no single shunt design has shown universal superiority in clinical outcomes.

VP shunting is one of the most frequently performed neurosurgical procedures, with an estimated 30,000 operations annually in the United States.[1] However, failure rates remain significant, with 15% to 25% of new VP shunts failing within 6 months in adults and up to 50% failing in high-risk populations.[2] These failures necessitate revision surgeries, which increase perioperative risks, patient distress, and health care costs.[3–9] Hospital stays related to shunt malfunction average 8 days, with a reported mortality rate of 1% to 3%.[10] These challenges have driven advancements in surgical techniques and perioperative protocols to minimize complications such as infection, catheter misplacement, and mechanical failures.[11–13]

This article reviews the surgical principles and techniques for shunt insertion, focusing on VP, VA, ventriculo-pleural (VPL), and LP shunts. It highlights strategies for addressing complications and recent innovations aimed at optimizing outcomes and reducing failure rates.

DISCUSSION

Historical Perspective

The concept of CSF diversion dates back to 1898, when Ferguson introduced an early LP shunt. This rudimentary approach involved drilling a burr hole in the fifth lumbar vertebra and threading a silver wire from the spinal canal to the peritoneal cavity.[14] In 1905, the first true VP shunt was attempted using a rubber tube to redirect CSF from the lateral ventricle to the peritoneal cavity. However, this pioneering effort was short-lived, as the patient survived only a few hours postoperatively.[15] Incremental improvements followed, such as the use of silver wires to wick CSF, but it was the introduction of silicone catheters in the 1950s that revolutionized the field, establishing VP shunting as the standard treatment for hydrocephalus.[16]

Although VP shunting remains the most widely adopted method for managing both pediatric and adult hydrocephalus, alternative distal catheter sites are sometimes necessary. Venous shunting was first explored in 1907, when Erwin Payr used an autologous saphenous vein to divert CSF into the superior sagittal sinus in a child.[17] In 1909, McClure successfully shunted CSF into the neck veins, achieving extracranial venous drainage.[16] However, these early efforts were hindered by complications such as thrombotic occlusion and retrograde blood migration into the proximal catheter. The development of the Seldinger technique in the 1960s revolutionized VA shunting by enabling precise catheter placement into the right atrium, significantly improving its reliability.[18]

The evolution of VP shunting paralleled advancements in surgical methods. Initially, ventricular catheter placement relied solely on anatomic landmarks, while peritoneal catheter insertion required open surgical techniques. Modern innovations, including neuro-navigation, endoscopic visualization, and laparoscopic approaches, have enhanced the precision and safety of shunt placement.[12] However, their adoption varies across institutions, reflecting differences in resources, neurosurgical training, and access to collaborative surgical teams, such as general surgery.

Surgical Risks in Adult Patients Undergoing Shunt Surgery

CSF shunting in adults, particularly elderly patients, presents unique challenges due to the prevalence of comorbidities, frailty, and functional limitations.[19,20] Careful patient assessment and tailored risk mitigation strategies are essential to optimize outcomes and minimize complications.

Frailty, advanced age, and surgical risk

Elderly patients often exhibit reduced physiological reserve, or frailty, which increases their vulnerability to perioperative complications. Frail individuals are approximately 2.5 times more likely to experience adverse surgical outcomes than their non-frail counterparts.[21] Frailty assessment tools, such as the Frailty Index, are valuable for evaluating surgical candidacy, but application in hydrocephalus patients requires caution, as reversible hydrocephalus-related symptoms like gait impairment and functional decline may overestimate frailty.[21–25] Individualized assessments are vital for identifying patients who may benefit from preoperative optimization.[26]

Chronologic age alone is not a contraindication for shunt surgery in adults.[21,27] Studies consistently shows that appropriately selected elderly patients tolerate shunting well, with the benefits of clinical improvements often outweighing procedural risks.[24,26,28–30] Multidisciplinary discussions should focus on overall health status, functional reserve, and specific risk factors rather than age as the primary determinant of surgical candidacy.

Comorbid conditions

Adult shunt candidates, especially the elderly, frequently present with comorbidities, which increases perioperative risks.[30] Cardiovascular complications, affecting 2% to 5% of patients, are common in those with a history of cardiac disease.[31–33] Preoperative cardiovascular optimization and intraoperative monitoring are critical for minimizing adverse events. Pulmonary conditions, such as chronic obstructive pulmonary disease and obstructive sleep apnea, elevate the risks of pneumonia, pulmonary embolism, and respiratory failure. Pulmonary complications can occur in up to 7% of elderly patients and require proactive management.[34,35] Diabetes further complicate surgical outcomes, predisposing patients to infections, hypoglycemia, and cardiovascular events.[36–38] Preoperative glucose optimization reduces these risks and improves outcomes.

Anticoagulation and bleeding risks

A substantial proportion of elderly shunt candidates are on anticoagulant or antiplatelet therapy, which heightens the risk of perioperative bleeding.[39–41] Shunt surgery, particularly in iNPH patients, is typically elective, allowing time for careful management of anticoagulation.[41,42] Current guidelines recommend pausing anticoagulants or antiplatelets 5 to 7 days before surgery, while considering each patient's thromboembolic risk, such as those with mechanical heart valves, who may require bridging therapy with heparin to minimize thrombotic events.[41] Postoperatively, anticoagulation should be restarted judiciously, balancing the risks of thrombosis and bleeding.

Surgical Techniques for Shunt Insertion

General surgical principles

Effective CSF shunting requires adherence to standardized protocols to optimize outcomes and minimize complications. This section outlines essential practices in preoperative preparation, sterile techniques, infection prevention, and postoperative care. A comparison of VP, VA, VPL, and LP shunts is provided as a quick reference for tailoring shunt selection to individual patient needs (Table 1).

Preoperative preparation Thorough preoperative planning is essential to minimize surgical risks. Patients with temporary CSF diversion devices, such as external ventricular drains (EVDs), must have negative CSF cultures before shunt placement to reduce infection risk. Elevated CSF protein levels (greater than 100 mg/dL) and cell counts should also be addressed, as these factors increase the likelihood of catheter occlusion and early shunt failure. Imaging studies are reviewed preoperatively to assess ventricular size, identify anatomic landmarks, and detect potential obstructions.

Proper positioning is critical for surgical accessibility. Most patients are positioned supine with the head rotated contralaterally and supported by a donut or horseshoe headrest. In cases of limited cervical mobility, a longitudinal bump under the ipsilateral hemi-body can improve positioning. Cranial fixation, such as the Mayfield clamp, may be required in complex cases to ensure stability, but rarely necessary.

When neuronavigation is utilized, its setup is customized to the type of system. Electromagnetic navigation systems like AxIEM are ideal for non-fixed head positioning, whereas optical systems are used when the head is stabilized in a Mayfield clamp. Prophylactic antibiotics, typically cefazolin or clindamycin for penicillin-allergic patients, are administered 30 minutes before the incision.

Sterile protocols and infection prevention bundles Infection prevention starts with meticulous preparation of the sterile field. Hair at incision sites is trimmed with clippers, marked, and scrubbed using alcohol or chlorhexidine gluconate. Antiseptic solutions, such as ChloraPrep and DuraPrep, containing, respectively, 70% and 74% isopropyl alcohol are applied, followed by sterile povidone-iodine-impregnated adhesive drapes to maintain sterility. Double gloving is used

Table 1
Comparative table of shunt systems

Shunt Type	Advantages	Disadvantages	Ideal Use Cases
VP Shunts	High absorptive capacity; widely used; suitable for all ages.	Abdominal complications (pseudocysts, migration); infection risks.	General hydrocephalus management; first-line option.
VA Shunts	Effective for patients with abdominal contraindications; avoids peritoneal risks.	Cardiac complications (thrombosis, arrhythmias); requires precise cavo-atrial positioning.	Patients with abdominal contraindications or VP failures.
VPL Shunts	Viable alternative when VP and VA shunts are unsuitable.	High risk of pleural effusion, hydrothorax, pneumothorax.	Last-resort option; patients with no significant pulmonary disease.
LP Shunts	Avoids intracranial risks; effective for IIH and communicating hydrocephalus.	High risk of overdrainage complications; challenging malfunction evaluation.	IIH or communicating hydrocephalus; failed pharmacologic therapy.

throughout the procedure to minimize contamination risks and the outer layer of gloves is changed after draping is finished. Afterward, local anesthesia is administered.

Evidence supports infection prevention bundles as an effective strategy to lower postoperative infection rates.[43] Key components include maintaining normothermia, proper antibiotic prophylaxis, and minimizing catheter handling during placement.

Postoperative care and imaging Post-operative care focuses on confirming catheter placement and monitoring for complications. Imaging, including a cranial computed tomography (CT) scan, verifies ventricular catheter positioning, while an X-ray shunt series confirms the trajectory and location of the distal catheter. Patients are typically monitored overnight in a neurosurgical unit to detect early complications such as overdrainage, shunt malfunction, or bleeding.

High-risk populations require tailored follow-up care, including additional imaging and clinical evaluations to identify and address potential issues. Proactive management and regular assessments help ensure long-term shunt functionality and minimize the need for revisions.

Proximal catheter placement

Ventricular catheter Effective placement of the ventricular catheter is critical for the functionality and longevity of the shunt system. Proper technique minimizes the risks of malpositioning, obstruction, and early shunt failure.

Surgical procedure The procedure begins with a skin incision, followed by dissection through the subcutaneous fat and galea using monopolar cautery. The pericranium is preserved to secure the valve or reservoir. A subgaleal pocket is created distal to the incision to house the valve. A high-speed drill is used to create a burr hole at the desired site. Neuro-navigation can be used to both select and confirm the location of the burr hole. The dura is opened in a cruciate fashion and leaflets are cauterized, followed by coagulation of the pia-arachnoid layer to facilitate smooth catheter insertion. An alternative technique is to use needle monopolar cautery to simultaneously create a small, catheter-sized hole, in both the dura and pia arachnoid.

The catheter is inserted freehand or with stereotactic guidance (Fig. 1). Once CSF flow is confirmed, the catheter is secured with bulldog clamps, and the proximal catheter is attached to the valve and previously tunneled peritoneal catheter using silk ties.

Technical considerations

Entry site and location of proximal catheter tip The choice of entry site is influenced by patient anatomy, pathology, and surgeon preference. The frontal and parieto-occipital approaches are the most common.[44]

- *Frontal Approach*: Targets Kocher's point, located ∼1 cm anterior to the coronal suture and 3 cm lateral to midline, directing the catheter into the frontal horn of the lateral ventricle while avoiding the choroid plexus and ventricular wall. This approach often uses a curvilinear incision and a retroauricular skip incision for continuous distal catheter tunneling.

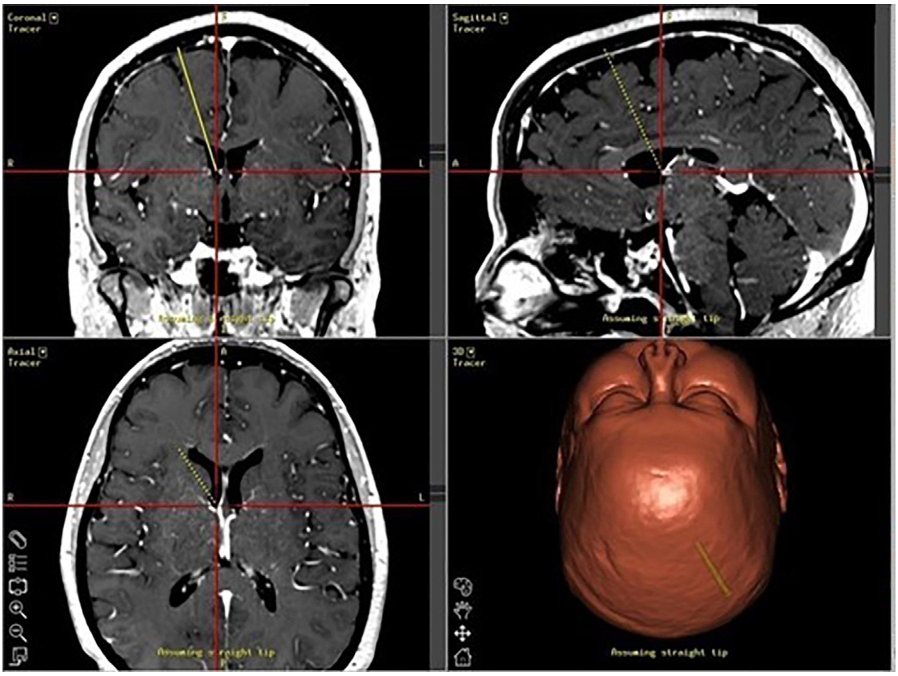

Fig. 1. Use of stereotactic neuro-navigation to insert a ventricular catheter in a patient with relatively small ventricle size.

- *Parieto-Occipital Approach*: Targets Frazier's point (~6 cm above the inion and 4 cm lateral to midline) to access the frontal horn of the lateral ventricle.
- *Parietal Approach*: Targets the atrium of the lateral ventricle via Keen's point (~3 cm posterior to the bregma and 2.5 cm lateral to midline). This approach is reserved for unique anatomic scenarios or when other approaches are contraindicated.

Evidence on the optimal entry site is mixed.[45,46] Some studies suggest the frontal approach provides better catheter tip positioning compared to parieto-occipital approaches, though a randomized trial by the Hydrocephalus Clinical Research Network (HCRN) found no significant differences in outcomes between anterior and posterior placements.[47] However, shunt survival was reduced when surgeons were randomized to an approach contrary to their preference, suggesting that surgeon expertise and familiarity play a critical role in outcomes.[47–49] Proper catheter tip positioning is crucial, as tips free-floating in CSF show a failure rate of ~20%, compared to 33% when in partial contact with brain tissue.[45]

Role of neuro-navigation and endoscopic visualization Stereotactic neuro-navigation significantly enhances ventricular catheter placement accuracy, particularly in patients with complex ventricular anatomy or slit ventricles, such as those seen in IIH (Fig. 2).[50,51] Endoscopic visualization provides direct anatomic views, further reducing malposition risks.[52] Combining neuro-navigation with endoscopy offers an added layer of precision, with the potential to decrease the rate of shunt failure.

Shunt revisions Proximal catheter occlusion by choroid plexus tissue is the leading cause of proximal shunt malfunction. Removal of an occluded catheter poses risks, including intraventricular hemorrhage (IVH). To minimize these risks, a Bug-Bee electrode or low-energy monopolar cautery with a metal stylet can be used to gently release the catheter. In cases of IVH, copious irrigation is recommended, and an EVD may be placed until the blood clears adequately.

Lumbar catheter LP shunts offer an alternative proximal access point, particularly for patients with communicating hydrocephalus or refractory IIH. LP shunts eliminate the need for intracranial entry, reducing risks such as ventriculostomy-associated hemorrhage.[53] However, they are contraindicated in obstructive hydrocephalus. Although recent studies show no significant differences in outcomes between VP and LP shunts for IIH or hydrocephalus, regional preferences play a key role. VP shunts are preferred in Europe and North America, while LP shunts dominate in

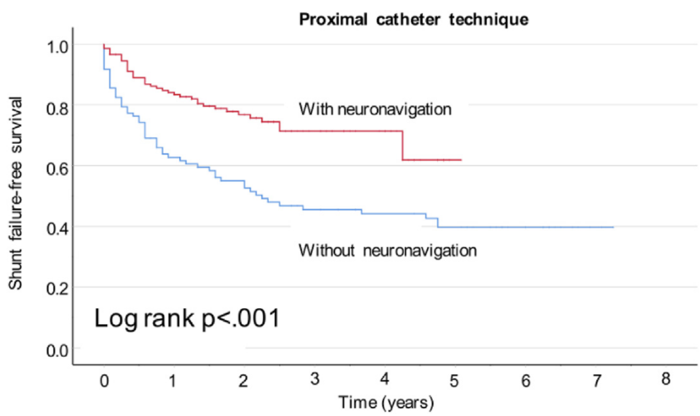

Fig. 2. Kaplan-Meier analysis from Isaacs and colleagues, 2021 demonstrating the beneficial effects of the use of neuro-navigation for proximal catheter placement on rates of shunt failure. (Isaacs, A. M. et al. Reducing the risks of proximal and distal shunt failure in adult hydrocephalus: a shunt outcomes quality improvement study. J Neurosurg 136, 877-886, doi:10.3171/2021.2.JNS202970 (2022). An Open Access or Creative Commons publishing model conveys no rights to use this material in any format without written permission from the JNS Publishing Group.)

Japan, where studies demonstrate non-inferior treatment efficacy in certain patient subgroups.[54]

Surgical procedure The procedure begins with the patient in the lateral decubitus position. After standard sterile preparation and draping, a 3 to 4 cm midline incision is made at the L3-4 interspinous space to expose the lumbar fascia. A Touhy needle is used to access the subarachnoid space, confirmed by CSF return. The lumbar catheter is advanced cephalad approximately 5 cm into the spinal canal after the stylet is removed, and the needle is withdrawn. The catheter is anchored to the lumbar fascia to prevent dislodgement.

A second incision is made in the flank to house the valve, and a third incision is created in the abdomen for peritoneal cavity access. Posterior-to-anterior tunneling is performed, and all catheter connections are secured with silk ties. Once the system is secured, all surgical sites are closed in layers.

Technical considerations

Overdrainage concerns A major risk of LP shunting is overdrainage, which can result in intracranial hypotension, subdural hematomas, and Chiari type I malformations, with or without syringomyelia (Fig. 3). Proper valve selection, particularly valves with adjustable resistance settings and siphon guards, is critical in mitigating these complications. In cases where overdrainage persists, management may include occluding or removing the shunt or converting to a VP shunt system.

Challenges of shunt interrogation Diagnosing and managing LP shunt malfunctions is more challenging than with VP shunts. LP shunts are often difficult to access due to thick subcutaneous tissue, and ventricular size changes are typically unreliable markers of malfunction in IIH patients, as ventricles often remain slit-like or unchanged in iNPH patients regardless of shunt function. Consequently, diagnosing LP shunt malfunctions often requires invasive methods such as fluoroscopy-guided access or shunt exploration.

Distal catheter placements

Peritoneal catheters The peritoneal cavity is the most common destination for distal catheter placement due to its large absorptive surface area and relatively straightforward access. Distal catheter insertion can be performed using 1 of 3 primary techniques: mini laparotomy, split trocar, or laparoscopic placement, with the choice potentially tailored to patient-specific factors such as body habitus and surgical complexity.

Surgical procedures

Mini-laparotomy The mini-laparotomy appr oach remains a widely used method of accessing the peritoneal cavity. The choice of location for the incision is varied. In one example, a diagonal incision is made in the right upper quadrant, approximately 2 to 3 fingerbreadths below the rib cage. Sequential dissection of the subcutaneous layers, including Camper's and Scarpa's fascia, is performed. The external oblique, internal oblique, and transversus abdominis muscles are bluntly separated to expose the transversalis fascia. A small incision is made in the transversalis fascia and carried through to the parietal peritoneum. Intra-peritoneal positioning is confirmed by observing bowel peristalsis or using a blunt instrument, such as a Penfield 4, to ensure unobstructed passage. The distal catheter is advanced into the peritoneal cavity and may be secured with a purse-string suture at the transversalis fascia to maintain its position.

Split trocar This method expedites catheter placement and is suitable for cases with favorable

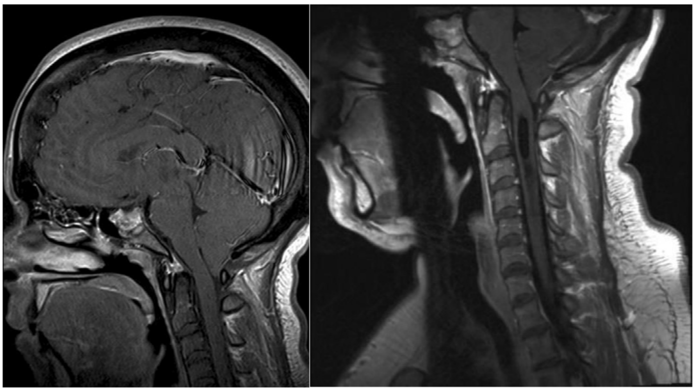

Fig. 3. Demonstration of idiopathic intracranial hypertension patient status prior to lumbo-peritoneal shunt insertion (*left*); after lumbo-peritoneal shunt insertion with subsequent Chiari 1 malformation and syringomyelia (*right*).

anatomy. A small periumbilical abdominal incision is made, and the anterior abdominal wall is held taut. The trocar is advanced at an angle toward the contralateral iliac crest until the peritoneal cavity is entered, denoted by a characteristic "*pop*". Once the stylet is removed, the catheter is passed through the trocar into the peritoneal cavity. However, the split trocar method is less effective in patients with high body mass index due to reduced tactile feedback and difficulty navigating thicker abdominal walls.

Laparoscopic The laparoscopic technique offers the advantage of direct visualization, reducing risks of catheter mispositioning and migration.[50] A curvilinear periumbilical incision is made, and blunt dissection exposes the fascia. A Hasson trocar is inserted to insufflate the peritoneal cavity with CO_2, creating adequate working space. A 30° laparoscope provides direct visualization, and a secondary port is introduced laparoscopically, typically on the left side unless adhesions dictate otherwise. Adhesiolysis is performed if necessary. The catheter is tunneled subcutaneously to a proximal abdominal incision and advanced into the peritoneal cavity using a peel-away sheath.[50] Spontaneous CSF flow is confirmed, and the abdomen is gradually deflated to prevent catheter migration before instruments are removed.

Technical considerations

Benefits of laparoscopy In adults, distal catheter failure is more common than proximal failure, with primary causes including mispositioning, migration, and occlusion by omental tissue, bowel loops, or adhesions.[55–59] The laparoscopic approach offers significant advantages over open techniques, providing direct visualization to optimize catheter placement and minimize these complications (Fig. 4).[50,51] Studies have shown that laparoscopic placement significantly reduces shunt malfunction rates by enabling precise positioning in regions less prone to obstruction or adhesion formation. Further modifications, such as directing the catheter into specific peritoneal spaces, further reduce risks of migration and occlusion.[12,60]

Falciform ligament anchoring An innovative modification of the laparoscopic approach involves anchoring the distal catheter to the falciform ligament and positioning it in the perihepatic space. This approach reduces the risk of catheter migration and obstruction by avoiding omental entanglement. The perihepatic space also minimizes the risk of abdominal pseudocyst formation and re-adhesion due to its relative lack of omental tissue.[12,50,61] In the *falciform technique*, a small hole is created in the falciform ligament under laparoscopic guidance, and the catheter is passed through it into the perihepatic space. The liver's right posterior sector is mobilized medially for precise positioning, with the catheter tip trimmed to rest above the liver's inferior margin and below the diaphragm. This placement reduces complications associated with catheter migration and occlusion while preserving catheter functionality.[12,50,62]

Atrial catheters VA shunts are a valuable alternative for CSF diversion when VP shunts are not ideal or have repeated distal failures. They are often preferred for patients with abdominal pathologies, infections, extensive scarring, or other anatomic challenges that render the peritoneal cavity unsuitable.[63–66] In some centers, VA shunts are used as a first-line option.

Surgical procedure The patient is placed in a slight Trendelenburg position to minimize the risk of air embolism. Under ultrasound guidance, the right internal jugular vein is visualized, and a seeker needle is inserted. Once blood return confirms proper vessel access, a guidewire is advanced,

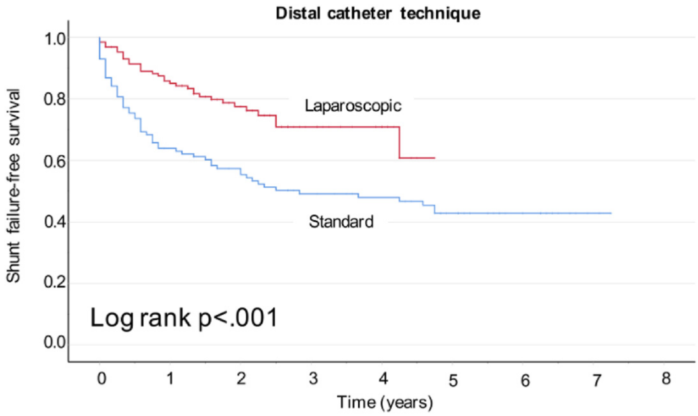

Fig. 4. Kaplan-Meier analysis from Isaacs and colleagues, 2021 demonstrating the beneficial effects of the use of laparoscopy for distal peritoneal catheter placement on rates of shunt failure. (Isaacs, A. M. et al. Reducing the risks of proximal and distal shunt failure in adult hydrocephalus: a shunt outcomes quality improvement study. J Neurosurg 136, 877-886, doi:10.3171/2021.2.JNS202970 (2022). An Open Access or Creative Commons publishing model conveys no rights to use this material in any format without written permission from the JNS Publishing Group.)

and the vessel is dilated using the Seldinger technique. The distal catheter is inserted over the guidewire and advanced to the cavo-atrial junction (CAJ), with its position confirmed using intraoperative X-ray fluoroscopy. The CAJ is where the superior vena cava meets the superior border of the right atrium, and is generally visualized 2 vertebral bodies below the carina or at the intersection of the bronchus intermedius with the right heart border.[13,67] Once successfully placed, the proximal and distal catheters are connected with a valve, which is then secured in place.

Technical considerations

Catheter length and distal terminus Preoperative vascular imaging, such as CT angiography or vascular ultrasound, is recommended to evaluate vessel patency and identify anatomic variants that may influence catheter placement. Patient-specific anatomic variability can complicate placement and increase the likelihood of mispositioning.[68,69] Proper catheter length is also critical to avoiding complications. A catheter that is too short can lead to fibrous capsule formation, resulting in vessel thrombosis or catheter occlusion. Conversely, an excessively long catheter may cause rare but severe complications, such as congestive heart failure.[70,71] As such, accurate distal catheter placement at the CAJ is essential to minimize risks such as arrhythmias, microembolization, pulmonary hypertension, catheter coiling, and shunt failure.[66,68] Postoperatively a shunt series X-rays to confirm the final position of the catheter.

Transesophageal echocardiography transesophageal echocardiography (TEE)-guided placement While X-ray fluoroscopy is traditionally used to guide catheter placement, it has limitations, including poor visualization of anatomic landmarks of the CAJ, exposure to radiation and potential contrast agent reactions.[72–74] Transesophageal echocardiography (TEE)-guided VA shunt placement has emerged as a superior alternative, offering real-time, high-resolution visualization of cardiovascular anatomy.[13,67,75–77] This technique allows for precise catheter adjustments without the risks associated with radiation or contrast agents and has been shown to reduce complications.

Upon anesthesia induction, a standard TEE probe is inserted and maintained in position throughout the shunt surgery. A mid-esophageal bicaval view is utilized to guide the advancement of the catheter and determine the appropriate insertion depth. Additional TEE views, such as the 4-chamber and right ventricular inflow-outflow views, are employed to ensure that the catheter does not disrupt tricuspid valve function (**Fig. 5**).[13] Agitated saline injections can confirm catheter patency via bubble visualization. However, the procedure should ideally be performed in collaboration with an anesthesiologist experienced in echocardiography.

Pleural catheters VPL shunting is the least common option for distal catheter placement due to its associated risks and complications, such as hydrothorax, pleural effusions, and pneumothorax.[70] Despite these challenges, VPL shunting is considered in patients where both the peritoneal and atrial cavities are unsuitable.

Surgical procedure The procedure begins with a curvilinear incision along the anterior axillary line, following the course of the seventh rib. After the skin and subcutaneous layers are incised, the external, intermediate, and internal intercostal muscle layers are carefully detached from the anterior rib margin. Once the pleural cavity is visualized, care is taken to avoid injury to underlying structures. The distal catheter is inserted into the pleural space under direct vision to ensure proper placement. The incision is then closed in layers to

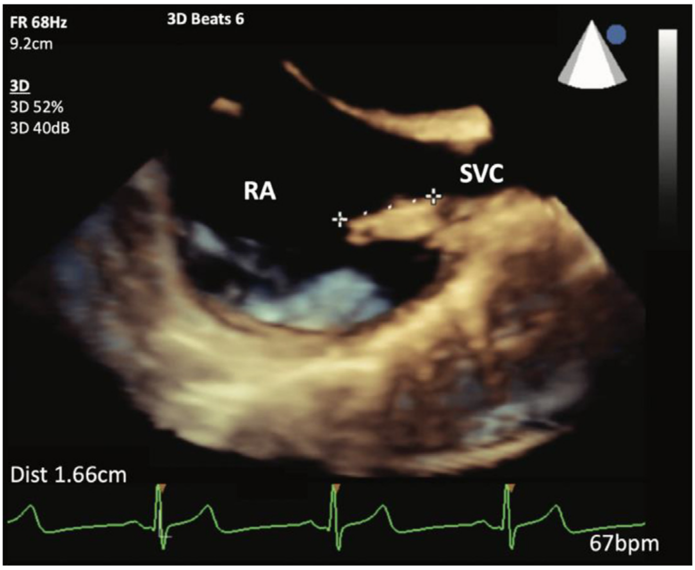

Fig. 5. Three-dimensional bicaval view of a 22-year-old male demonstrating the distal portion of a ventriculoatrial shunt catheter (*dotted line*) coursing through the superior vena cava (SVC) and situated 1.6 cm past the cavo-atrial junction into the right atrium (RA).[13]

create a watertight seal and minimize the risk of air leakage or pneumothorax.

Technical considerations The most frequent complication of VPL shunting is pleural effusion, which occurs due to the negative intrapleural pressure creating a siphoning effect and leading to CSF overdrainage.[78] To address this issue, an antisiphon device can be incorporated into the shunt system.[79] Additional strategies, such as the use of acetazolamide to decrease CSF production and the placement of bilateral pleural catheters to equalize pleural pressures, have been investigated.[80] However, they have primarily been studied in small cohorts and lack sufficient long-term follow-up to support widespread adoption.

Shunt Infections

Shunt infections represent a significant complication of both initial shunt implantation and subsequent revisions. In adults, the risk of infection during the first post-operative year ranges from 5% to 15%, leading to substantial morbidity, mortality, and financial burdens.[81–83]

Shunt infection prevention bundles

Standardized shunt infection prevention bundles are the most effective approach to reducing shunt infections. These bundles integrate evidence-based practices to optimize preoperative preparation, ensure operative sterility, and standardize the handling of shunt components. A single-center prospective study by Muram and colleagues reported a dramatic reduction in adult shunt infection rates from 6% to 0% over 6 years following the implementation of such a bundle. The bundle focused on 4 key areas: preoperative optimization, sterile precautions for the operative field, sterile precautions for the surgical team, and meticulous handling of the shunt system (**Fig. 6**).[43]

The success of infection prevention bundles is multifactorial. Standardized practices promote behavioral consistency and ensure adherence to evidence-based techniques. Individual components of these bundles have demonstrated strong efficacy. For example, chlorhexidine gluconate/alcohol skin scrubs or preoperative baths are consistently effective in reducing postoperative infection rates across multiple surgical fields.[84,85] Prophylactic antibiotics and intraoperative normothermia are critical to infection prevention, with evidence showing that administering antibiotics at least 30 minutes before the skin incision and maintaining normothermia throughout the procedure significantly lower infection rates.[12,54,86]

The use of iodine-impregnated adhesive drapes, such as Ioban, further enhances outcomes by minimizing skin contact with shunt components and securing the surgical field.[87] A study by Bejko and colleagues in cardiovascular surgery patients demonstrated a significant reduction in surgical site infections from 7% to 2% when using Ioban compared to non-iodine drapes.[87] Double gloving has also been shown to significantly reduce shunt infection rates. In a study by Tulipan and colleagues involving 863 patients undergoing CSF diversion procedures, infection rates were approximately 7% in the double-glove group compared to 15% in the single-glove group.[88] Additional research by Kulkarni and colleagues

1.	**Preoperative optimization**	Avoidance of hypothermia or hyperglycemia	Administer prophylactic antibiotics at least 30 minutes prior to first skin incision[a]	Limit operating room traffic[b]
2.	**Operating field sterile precautions**	Use alcohol-based chlorhexidine solution for prepping surgical field	Wait 3 minutes for prep to dry before applying drapes	Ioban applied to surgical field
3.	**Operating staff sterile precautions**	Full standard hand scrub required by all participants	All participants double glove for procedure	Outer gloves of all participants changed after draping completed
4.	**Shunt system**	Each shunt implant packaging only opened when needed	Avoid contacting the shunt device with the drapes	Ensure minimal shunt device handling

Fig. 6. Demonstrative diagram of the components of the Calgary Adult Shunt Infection Prevention Protocol (CA-SIPP), utilized by the University of Calgary neurosurgery group to successfully reduce their rate of shunt infections from 5.8% to 0% over the course of 2 years. [a]Cefazolin 2g IV is recommended as first line agent. Clindamycin 500 mg IV may be used if patient has cefazolin allergy. [b]Only essential staff in operating room. Ideally no more than 7 persons and avoid unnecessary traffic in/out of operating theater. (Muram, S. et al. A standardized infection prevention bundle for reduction of CSF shunt infections in adult ventriculoperitoneal shunt surgery performed without antibiotic-impregnated catheters. J Neurosurg 138, 494-502, doi:10.3171/2022.5.JNS22430 (2023). An Open Access or Creative Commons publishing model conveys no rights to use this material in any format without written permission from the JNS Publishing Group).

identified breached gloves as a significant predictor of shunt infections, underscoring the importance of this simple yet effective intervention.[89]

Antibiotic-impregnated catheters

The use of antibiotic-impregnated catheters (AICs) has been extensively studied as a potential method to reduce shunt infection rates. However, evidence for their efficacy remains inconclusive.[11,82,90] A 2016 report by the HCRN found no significant reduction in infection rates with AICs.[90] Moreover, a 2015 study raised concerns about an increased incidence of infections caused by antibiotic-resistant organisms, including methicillin-resistant *Staphylococcus aureus* and gram-negative bacilli, in association with AICs.[91] These findings suggest that while AICs may provide benefits in specific populations, their routine use in adult shunt surgeries is not recommended due to limited efficacy and concerns over promoting antibiotic resistance.

SUMMARY

CSF shunting remains effective in the management of hydrocephalus and IIH symptoms despite its associated challenges. Advances in surgical techniques, including the use of neuro-navigation, endoscopic visualization, and laparoscopic approaches, have significantly improved the precision and safety of shunt placement. Standardized infection prevention bundles have reduced infection rates, while innovations such as programmable valves and TEE offer new strategies to minimize complications and optimize outcomes.

Tailoring shunt selection, catheter placement, and the use of adjunct technologies to individual patient factors is critical for achieving optimal results. However, gaps in evidence highlight the need for ongoing research. Collaborative efforts among surgeons, researchers, and engineers will be vital to refine shunting systems, reduce revision rates, and improve the quality-of-life for patients requiring these essential procedures.

CLINICS CARE POINTS

- Neuro-navigation improves proximal catheter placement accuracy, reducing revision rates, especially in patients with small or distorted ventricles. In its absence, outcomes rely on surgeon expertise and familiarity with the selected approach.
- Laparoscopic placement of distal peritoneal catheters enhances precision and reduces risks of migration, obstruction, and adhesion-related complications, offering improved outcomes over traditional approaches.

- VP shunts are the preferred first-line option for most patients due to their ease of placement and high absorptive capacity. Clinicians must remain vigilant for abdominal complications, such as pseudocysts. VA shunts are suitable for patients with abdominal contraindications but require precise CAJ placement. LP shunts are effective for IIH and communicating hydrocephalus but carry higher risks of overdrainage-related complications.
- Infection prevention bundles, incorporating chlorhexidine/alcohol preparation, double gloving, and iodine-impregnated drapes, significantly lower infection rates. The routine use of AICs in adults remains inconclusive.
- Adjustable pressure and anti-siphon valves reduce overdrainage risks and allow for non-invasive postoperative pressure adjustments, improving long-term outcomes.
- Postoperative imaging ensures proper shunt catheter placement and identifies immediate complications.
- Early detection of complications is critical. Clinicians should monitor for overdrainage, shunt malfunction, and infection.

DISCLOSURES

The authors have nothing to disclose.

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