

Ventriculosternal Shunting for the Management of Hydrocephalus: Case Report of A Novel Technique

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BACKGROUND: Conventional cerebrospinal fluid diversion such as ventriculoperitoneal or ventriculoatrial shunting for the management of hydrocephalus is one of the commonest neurosurgical procedures. However, in selected patients, surgical options are limited when relative contraindications for these operations exist. A patient who underwent ventriculosternal shunting, a novel procedure, is presented with durable and successful outcomes.

OBJECTIVE: To demonstrate the feasibility, durability, and safety of ventriculosternal shunting for the management of hydrocephalus.

METHODS: A patient with end-stage renal failure and heart failure with recurrent pleural effusion suffered from post-subarachnoid hemorrhage communicating hydrocephalus. Because of the need for continuous ambulatory peritoneal dialysis and the risk of introducing excessive cardiac preloading, conventional shunting was relatively contraindicated. Ventriculosternal shunting was performed by adopting the cancellous matrix of the sternum as the anatomic receptacle for intraosseous cerebrospinal fluid absorption. After placement of the ventricular catheter in the usual manner, the distal end was inserted into the sternum.

RESULTS: There was demonstrable clinical and radiological improvement in hydrocephalus by ventriculosternal shunting. Cerebrospinal fluid intraosseous absorption by this novel procedure translated into both physical and cognitive recovery. The procedure was tolerable, effective, and durable, with the patient suffering no complications 3 years after the procedure.

CONCLUSION: Ventriculosternal shunting for the management of hydrocephalus is a feasible, safe, and durable surgical treatment option for selected patients when conventional procedures are contraindicated.

KEY WORDS: Cerebrospinal fluid shunting, Hydrocephalus, Intraosseous infusion, Ventriculoatrial shunting, Ventriculoperitoneal shunting

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Cerebrospinal fluid (CSF) diversion for the management of hydrocephalus is one of the commonest of operations performed in daily neurosurgical practice. Despite the increasing popularity of endoscopic third ventriculostomy, ventriculoperitoneal shunting remains as a mainstay procedure. Surgical techniques and perioperative management have reduced the incidence of shunt failure, but the procedure is still fraught with potential complications such as infection, blockage, disconnection, overdrainage, and malabsorption of CSF at the implantation site.^{1,2} Almost a third of adult patients (29%) experience shunt

failure within the first year, and up to 59% of patients require shunt revision during their lifetime.^{2,3} When the peritoneal cavity is compromised, for example, by infection or adhesions, the surgeon is obligated to use alternative locations such as the right atrium or the pleural cavity. When contraindications to these anatomic repositories exist, the sternum has been described as an alternative for distal shunt implantation.⁴ Sternal intraosseous fluid infusion is an established method for vascular access in adults, and on the basis of this practice, Tubbs et al^{4,5} described the site for CSF diversion in a proof-of-concept study. We report a patient with a ventriculosternal (VS) shunt that was successfully implanted for the

ABBREVIATION: VS, ventriculosternal

management of communicating hydrocephalus. In addition to describing this novel surgical technique, we demonstrate its feasibility and long-term safety for selected patients.

CASE REPORT AND SURGICAL TECHNIQUE

Case Presentation

A 54-year-old woman with diabetic chronic end-stage nephropathy (glomerular filtration rate, $<15 \text{ mL} \cdot \text{min}^{-1} \cdot 1.73 \text{ m}^{-2}$) who was receiving continuous ambulatory peritoneal dialysis and had a history of heart failure with subacute bacterial endocarditis treated 6 months beforehand was admitted for subarachnoid hemorrhage. On admission, the patient was fully conscious with a grade 1 World Federation of Neurological Societies score. A computed tomography (CT) brain scan showed a modified Fisher grade III subarachnoid hemorrhage, and a subsequent catheter angiogram confirmed a ruptured right posterior communicating artery aneurysm. Primary coil embolization of the aneurysm was performed with complete obliteration with 105 mL of the nonionic, iso-osmolar contrast medium Iodixanol (Visipaque, Nycomed Amersham, New Jersey). Postoperative serum creatinine and urea values were stable at 212 to 253 $\mu\text{mol/L}$ and 11 to 13 mg/dL , respectively (after dialysis). By day 15, the patient remained drowsy with a Glasgow Coma Score of 14 of 15 and

a Montreal Cognitive Assessment score of 17 of 30. The patient was diagnosed with communicating hydrocephalus on CT scan (Figure 1A). Lumbar puncture opening pressure was 21 mm Hg. Preoperative echocardiography showed a left ventricular ejection fraction of 48% with no evidence of intracardiac valvular vegetations. The patient was considered at risk of developing ventriculoperitoneal shunt infection or peritonitis as a result of her continuous ambulatory peritoneal dialysis. There were also concerns that ventriculoatrial shunting could precipitate a recurrent episode of bacterial endocarditis. Ventriculopleural shunting was also considered, but her history of recurrent cardiogenic pleural effusion that required tapping meant placement was prohibitive. An alternative means of CSF diversion was therefore required. After consent was obtained, with the patient's full understanding of the novel nature of the procedure, implantation of a VS shunt was performed 3 weeks later.

Surgical Procedure

The patient was administered 2 g cefazolin intravenously and was positioned supine with her head rotated 15° contralateral to the side of shunt implantation. After skin preparation and draping, an L-shaped skin incision was made at the sternal notch with the longitudinal limb measuring 3 CN, parallel to the anterior border of the sternocleidomastoid muscle (Figures 2A-2C). The tendinous

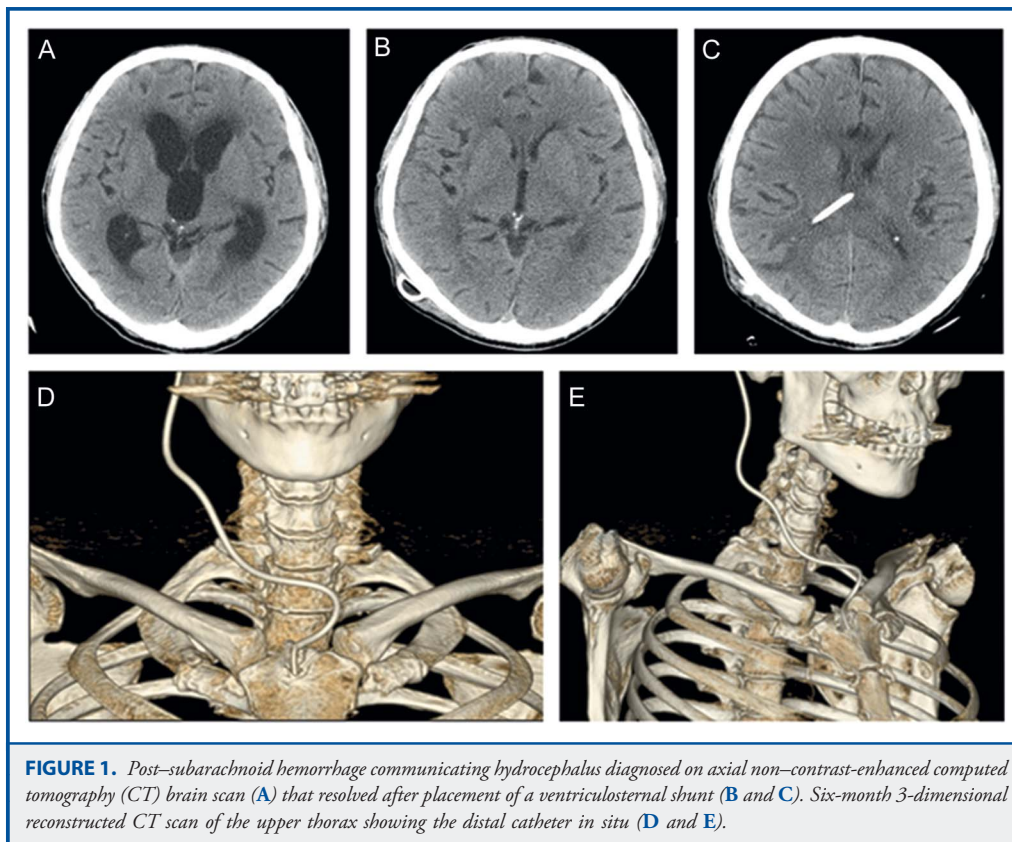
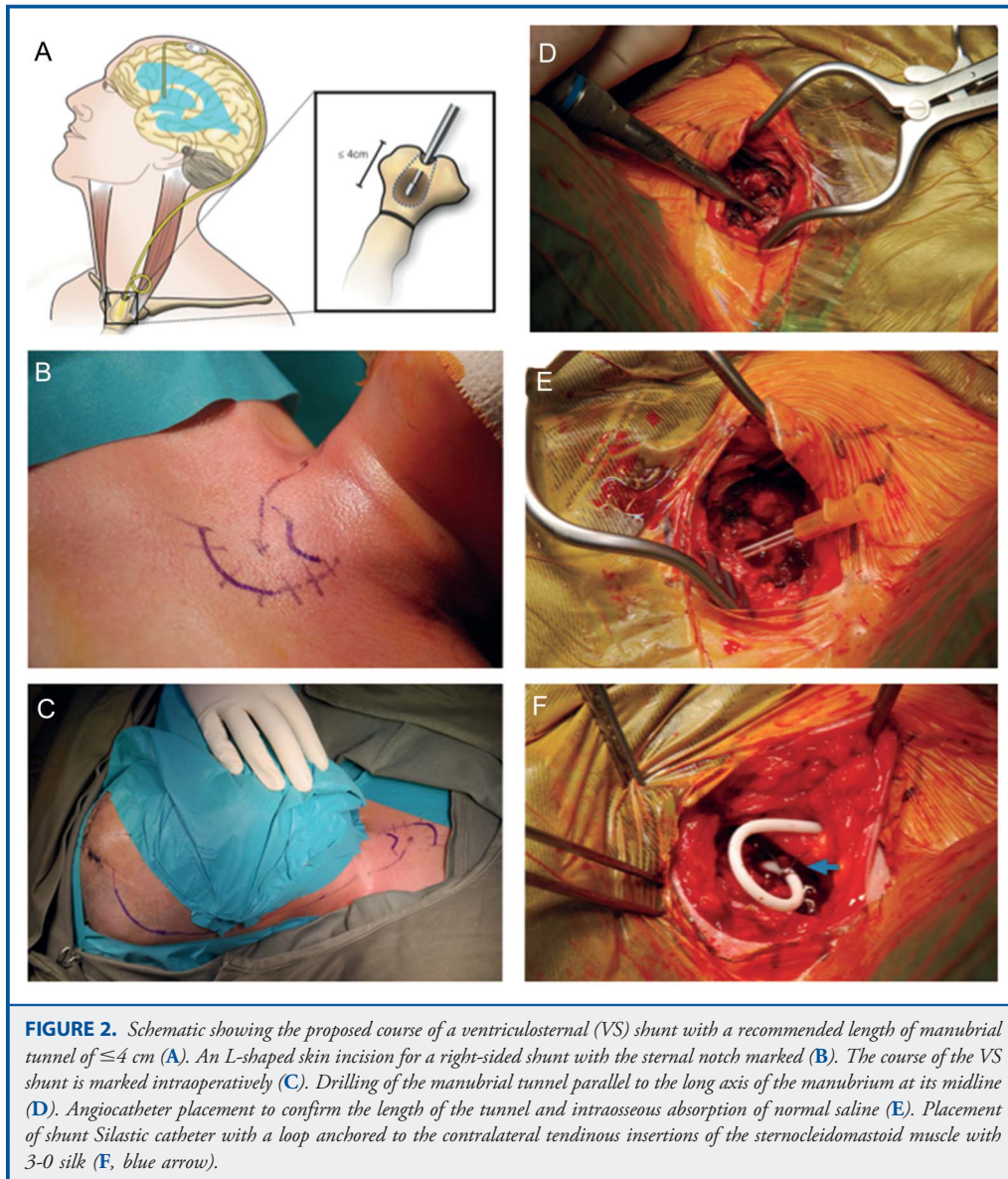


FIGURE 1. Post-subarachnoid hemorrhage communicating hydrocephalus diagnosed on axial non-contrast-enhanced computed tomography (CT) brain scan (A) that resolved after placement of a ventriculosternal shunt (B and C). Six-month 3-dimensional reconstructed CT scan of the upper thorax showing the distal catheter in situ (D and E).



insertions of the sternocleidomastoid muscle were displaced laterally to expose the superior border of the manubrium. An 8-mm-wide bore, 4-cm-deep tunnel through the cortical bone of the manubrium into its cancellous matrix was created with a high-speed drill (Midas Rex Legend, Medtronic, Minneapolis, Minnesota; Figures 2A, 2D, and 2E). A ventricular Silastic catheter (Medtronic Neurosurgery, Goleta, California) was inserted via a right parietal burr hole in the usual manner, and a subcutaneous tunnel was created from the scalp wound to the sternal notch wound. A programmable differential pressure valve (PS Medical Strata II, Medtronic Neurosurgery) was then connected to the ventricular catheter. Another Silastic catheter (3-mm outer diameter) with 3 side perforations was inserted into

the sternal tunnel and anchored to the tendinous insertions of the contralateral sternocleidomastoid muscle with nonabsorbable 3-0 silk sutures. Bone wax was used to seal the tunnel entrance to prevent CSF egress. The catheter was subsequently looped to accommodate lateral rotation neck movement (Figure 2F). Attaching the catheter to a syringe elevated 15 cm above the heart allowed 10 mL normal saline to be absorbed intraosseously over 3 minutes. The catheter was subsequently connected to the distal end of the shunt valve, with shunt patency confirmed when the valve reservoir refilled after compression. Both the scalp and sternal notch wounds were closed in layers with absorbable 3-0 polyglactin-910 (Vicryl, Ethicon, Somerville, New Jersey) and 3-0 nylon sutures.

Postoperative Course

The patient did not suffer any procedure-related complications. Her ambulatory ability improved, and she could walk with minimal assistance by postoperative day 5. A week after shunting, the patient's Montreal Cognitive Assessment score improved to 28 of 30. A CT scan showed a reduction in ventricular size and the sternal wound healed well without evidence of fluid collection, osteomyelitis, or keloid formation (Figures 1B and 1C). A postoperative 6-month CT thoracic scan showed that the distal catheter remained within the intraosseous tunnel without CSF accumulation in the mediastinal cavity (Figures 1D and 1E). There was also no evidence of osteomalacia, and bone architecture was preserved. Three years after VS shunt implantation, the patient continued to be free of shunt-related complications with no deterioration of cardiac function.

DISCUSSION

Our experience demonstrates that VS shunting can be a feasible, safe, and durable CSF diversionary procedure. The adoption of an intraosseous compartment for CSF absorption is not new. Ventriculomastoid shunting to the mastoid antrum, the Nosik⁶ operation, was proposed >60 years ago but failed to gain popularity because of its high rates of infection and CSF rhinorrhea. Researchers using swine and human cadaveric models recently proposed that the diploic space of the skull or the iliac crest could also be a potential osseous site, but their findings were not translated clinically.^{7,8} By adopting a similar theory of intraosseous fluid infusion, Tubbs et al⁴ first conceived the possibility of VS shunting.

Intraosseous fluid infusion in prehospital trauma and critical care settings is a time-tested procedure when peripheral venous access cannot be established.⁹ A variety of resuscitation fluids such as crystalloids, blood products, and medications can be successfully delivered to the vascular space by intraosseous means. The medullary cavity is a noncollapsible entry point into the systemic circulation. It contains a rich plexus of venous sinusoids that drain into longitudinal central haversian canals linked to one another by a system of Volkmann canals and exit bone via emissary or nutrient veins.⁹ From the numerous osseous entry sites available, the sternum is ideal for shunt implantation for several reasons. Its location is superficial and is surgically accessible. Its midline position and proximity to the skull render implantation less difficult and reduce the risk of shunt dislodgement compared with the humerus or the iliac crest.⁷ In adults, the sternum also retains a relatively large portion of vascular red marrow compared with the tibia or humerus, allowing better CSF absorption.⁹ Finally, the site is drained by the internal mammary and azygos veins, which have been shown to impart intraosseous pressures comparable to central venous pressure.¹⁰

An exploratory study describing the feasibility of VS shunting using human cadaveric, live rhesus monkey, and swine animal models concluded that the manubrium can be a viable CSF receptacle.⁴ Tubbs et al⁴ demonstrated that up to 30 L water

could be infused over an hour through the cannulated manubrium in 5 fresh human cadavers without noticeable fluid collections in the cranial, thoracic, or abdominal cavities. The group then performed sternal intraosseous normal saline infusions in live rhesus monkeys for 24 hours, and extravascular fluid accumulation could not be detected on subsequent magnetic resonance imaging.⁴ To verify the practicality of VS shunting in larger animals, Tubbs et al finally performed the procedure on 2 adult nonhydrocephalic pigs. At 2 weeks, both pigs were stable and did not display signs of infection. On autopsy, there was no evidence of osteomyelitis or CSF extravasation.⁴

The critical stages of VS shunt implantation are the tunneling of the manubrium and the final insertion of the distal catheter tip. Preparation of the manubrium was performed easily with a high-speed neurosurgical drill, but one should be cognizant of regional anatomy. The trapezoid-shaped adult manubrium has a mean length, breadth, and thickness of 5.3 ± 0.4 , 4.9 ± 0.6 , and 1.2 ± 0.1 cm, respectively.¹¹ We advise that the maximal length of the tunnel should be limited to 4 cm to avoid inadvertent penetration of the posterior cortex and entry into the superior mediastinum (Figure 2A). In that event, the procedure may need to be abandoned because CSF entering the mediastinal cavity could exert undue pressure on its contents.

The surgeon should also be aware that intraosseous vascular access has potential, although uncommon, complications with an overall rate of <1%.¹⁰ From a recent meta-analysis of 18 studies that adopted modern infusion devices, no infectious complications were described in >1300 procedures.¹⁰ Despite a high incidence of fat or marrow embolism, ranging from 89% to 100% observed in canine animal models, most embolisms were subclinical and rarely resulted in hemodynamic instability.¹² The lack of yellow, fat-laden bone marrow within the sternum makes this site less likely to be a source of embolism. There is also a risk of causing acute iatrogenic fractures or, with long-term infusion, osteomalacia and subsequent pathological fractures. However, such cases are rare, and animal studies have reported normal bone growth and marrow cellular differentiation.¹³ Prospective human radiographic studies also failed to detect delayed bone growth in pediatric patients with a history of tibial infusions.¹⁴ The VS shunt was implanted for 3 years, and the patient did not experience any complications. To the best of our knowledge, no other patient has been exposed to such longstanding intraosseous fluid infusion, which reflects the potential durability of this procedure. Inadvertent entry into the superior mediastinum could lead to brachiocephalic artery injury as a result of its more superficial and midline location. Other superficial structures at risk of injury include the brachiocephalic veins and vagus nerves, but they are often located beyond the lateral border of the manubrium. Another concern is keloid scarring, especially in young patients or those with a positive family history or darker skin complexions. Finally, as with conventional ventriculoatrial shunts, immune complex-mediated glomerulonephritis can also theoretically occur with VS shunts.

We propose that patients with tracheostomies, a previous history of sternal fractures or sternotomy, osseous abnormalities

such as severe osteoporosis or osteogenesis imperfecta, regional infection, evidence of right-to-left cardiac shunting (with a consequential risk of fat or marrow paradoxical embolism), and a history of shunt nephritis should not be considered for VS shunting.

CONCLUSION

VS shunting can be an effective alternative in treating selected adult patients with hydrocephalus when other conventional CSF shunt terminus sites are contraindicated. Although such clinical scenarios are uncommon, they are occasionally encountered in neurosurgical practice. We believe that wider adoption of this novel technique may confirm its role as a safe, durable CSF diversionary procedure.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors have taken the results of our original feasibility study and applied them clinically with good results. Additional target absorptive receptacles such as the sternum will broaden the options available to the neurosurgeon who treats hydrocephalus. Long-term studies in large cohorts are now necessary to investigate the application of this novel approach. Moreover, future comparison studies will direct the surgeon toward the best anatomic option for the terminal part of the cerebrospinal fluid diversionary shunt.

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The authors present an unusual shunting option in which the distal portion of the shunt was inserted into the manubrium. The case in question is the not uncommonly seen situation in which there are poor options for distal insertion. The authors present their logic and details of the manubrial shunting option and nicely describe the potential complications and patient outcome. Although commonplace use of this method is unlikely, it adds another option to the neurosurgeon's armamentarium in dealing with difficult shunting situations.

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