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REVIEW ARTICLE

Cerebral venous sinus stenting in idiopathic intracranial hypertension

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Abstract

Cerebral venous sinus stenting (CVSS) is a minimally invasive procedure using endovascular stent placement to relieve elevated intracranial pressure secondary to venous sinus stenosis. Increased venous sinus pressure secondary to stenosis is commonly associated with elevated intracranial pressure without intracranial lesions on imaging or idiopathic intracranial hypertension (IIH). While the etiology of IIH remains unknown, stenosis of one or more of the dural sinuses has been implicated as a possible underlying mechanism. The manifestations of IIH include headaches, transient vision loss, pulsatile tinnitus, and neck pain. In this review, we discuss the recent studies that have demonstrated the effectiveness of CVSS for patients with IIH and also the indications, technical challenges, potential complications, and emerging developments in CVSS.

Keywords: Cerebral venous sinus stenting; Idiopathic intracranial hypertension; Pulsatile tinnitus; Venous sinus stenosis

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1. Introduction

Dural venous sinuses are channels between the endosteum and dura mater that receive blood and cerebrospinal fluid (CSF) from the cerebral veins and arachnoid granulations, respectively. These sinuses drain through the internal jugular vein to the heart. The seven sinuses are the superior sagittal, inferior sagittal, straight, transverse, sigmoid, cavernous, and superior petrosal sinuses[1,2]. The narrowing of any of these vessels, causing an obstruction of blood flow and CSF reuptake, is known as cerebral venous stenosis[3]. Stenosis of one or more of these sinuses can result in hypertension proximal to the stenotic area and increased intracranial pressure (ICP). The increased ICP further elevates the pressure within the stenotic vessel in a positive feedback loop[3]. The placement of cerebral venous sinus stent (CVSS) to relieve pressure and interrupt this cycle is a viable treatment option for patients with idiopathic intracranial hypertension (IIH).

2. Epidemiology and pathophysiology of IIH

IIH, also known as pseudotumor cerebri and benign intracranial hypertension, is characterized by an increase in ICP without a secondary cause[4]. The prevalence of IIH

is around 1/100,000 and is most common in obese women of childbearing age. One study has compared the incidence of IIH in 2017 with that in 1990 and showed a correlation between the rise in IIH and that in obesity. The same study has shown that the incidence of IIH was higher in women (3.3/100,000) compared to men (0.3/100,000) and the incidence of IIH in all women between the ages of 15 and 44 was 6.8/100,000; in comparison, the incidence was higher at 22.0/100,000 in obese women within the same age group[5]. The prevalence of IIH in pediatric patients has increased, but it is not associated with obesity or the female sex, like in older patients[6,7]. Other potential risk factors associated with IIH include anemia, sleep apnea, amiodarone, hypovitaminosis A, hypothyroidism, systemic lupus erythematosus, and polycystic ovary syndrome. Further research is required to understand the underlying mechanisms of these associations[7].

The etiology of IIH is not fully understood. However, there is evidence showing a correlation between IIH and elevated ICP. Theories explaining this increase in ICP include increased CSF secretion, CSF outflow obstruction, and venous stenosis[8]. Controversy exists within literature on whether venous sinus stenosis causes IIH or is a consequence of the latter. A small study using magnetic resonance venography (MRV) has demonstrated that 93% of 29 patients with IIH had bilateral transverse venous sinus stenosis[9]. However, it is unknown if stenosis of the transverse sinus is a cause or a result of increased overall ICP (Figures 1 and 2). Some have theorized that patients with IIH have anatomically distinct dural venous sinuses[9]. Symptoms of IIH include headaches, migraines, pulse-synchronous tinnitus, transient vision loss, double vision, and neck pain. Most patients present with visual changes, but 10% of patients experience blindness[10].

3. Diagnosis and treatment

IHH is diagnosed after the exclusion of other conditions that lead to increased ICP, such as tumors, hemorrhage, increased CSF secretion, or inadequate CSF absorption. Once these pathologies have been excluded, a diagnosis of IIH can be made[11].

IIH is diagnosed using several criteria like the modified Dandy criteria or the diagnostic criteria for pseudotumor cerebri syndrome. The original Dandy criteria were first proposed in 1937 to diagnose IIH. The report described common symptoms of elevated ICP that were not brought on by secondary causes, such as tumors. In addition to typical symptoms of IIH, other manifestations such as abnormalities in the fundus of the eye, drowsiness, gait issues, and a buzzing sensation in the ears have been observed in these patients[12]. The most recently modified Dandy criteria were penned and proposed by Friedman *et al*. in 2013[13,14]. The modified Dandy criteria, which have been widely used, include signs and symptoms of elevated ICP, no signs of neurological deficits, with an exception for abducens nerve palsy, normal CSF with elevated ICP, a computed tomography (CT) scan that does not show etiology for elevated ICP, and no other known causes for intracranial hypertension[12].

CSF: Cerebrospinal fluid; CVSS: Cerebral venous sinus stent; DSV: Digital subtraction venography; IIH: Idiopathic intracranial hypertension; MRI: Magnetic resonance imaging; MRV: Magnetic resonance venography; PTCS: Pseudotumor cerebri syndrome.

Magnetic resonance imaging and MRV are two diagnostic imaging modalities that can aid in the diagnosis of IIH. Some common findings include an empty sella turcica, distension of the optic nerve sheath, and slit-like ventricles. These findings may aid in the diagnosis of IIH. However, their absence does not rule out IIH[15]. Digital subtraction angiography (DSA) is another imaging modality used in diagnosing and visualizing vascular pathologies in the cerebrum. DSA remains the gold standard for visualizing and diagnosing vasculature for several reasons, including its heightened spatial resolution and superior temporal imaging quality (Figure 3)[16].

Once a diagnosis of IIH is made, initial treatments such as weight loss, lumbar punctures, and diuretics, such as acetazolamide, are initiated[17]. Acetazolamide with weight loss and a low-sodium diet has resulted in modest improvements in the visual function of patients with IIH experiencing mild vision loss[18]. Repeated lumbar punctures have been reported to be less effective. A study has shown that repeated lumbar punctures in patients with bilateral transverse sinus stenosis for 6 years and subsequent CSF pressure normalization did not resolve the patients' IIH[19]. In a 2021 study (n = 79), patients who had higher lumbar puncture opening pressure before transverse sinus stent insertion showed a higher risk of failure. Other studies have also shown that a higher lumbar puncture opening pressure confers a risk to CVSS failure or the need to retreat[20].

The next step for those who failed conservative management is surgical intervention, including bariatric surgery for obesity, CVSS, or ventriculoperitoneal shunting (Table 1). For patients with severe optic neuropathy that may lead to permanent vision loss, optic nerve sheath fenestration (ONSF) is recommended before conservative treatment and CVSS[21]. ONSF is less effective at treating headaches, which is the most common symptom in IIH[13,19]. Moreover, compared with shunting, CVSS is more cost-effective because fewer revisions are needed

and infections are less likely although the average cost for stenting is higher[22].

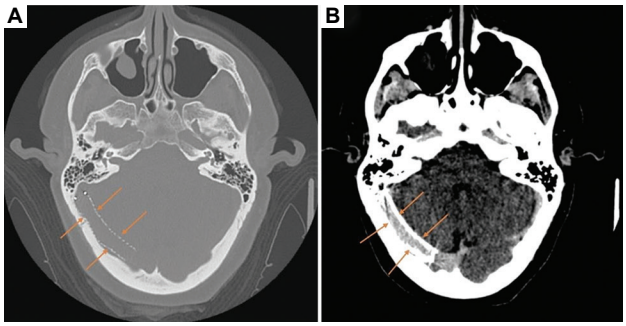

Figure 1. Computer tomography images on (A) bone and (B) soft tissue windows showing a right transverse sinus stent placed for management of cerebral venous sinus thrombosis.

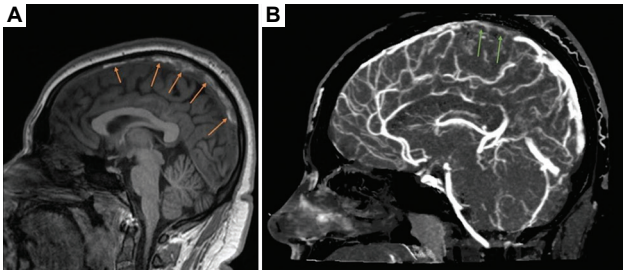

Figure 2. Magnetic resonance (MR) images demonstrating superior sagittal sinus thrombosis. (A) A T1-weighted sequence with a visible thrombus in the superior sagittal sinus. (B) An MR angiogram that confirms the presence of a thrombus by showing filling defects, where the contrast agent does not fill the superior sagittal sinus.

When IIH is refractory to management, several criteria must be met before performing CVSS. The major criteria include a pressure gradient of 8 mmHg or more across the stenosis, intracranial pressure of 22 mmHg or more, no contraindication to dual antiplatelet therapy (clopidogrel and aspirin), and the presence of one or more of the following symptoms: severely disabling headache, focal neurological deficit, papilledema, or visual changes[17] (Figure 3). The minor criteria include intolerance to repeated lumbar puncture/drain, dural sinus stenosis of 50% or more on CT or MRV, failed surgical intervention (like shunting or optic nerve fenestration), reduced pulsatility after the stenosis as detected by manometry, or patient preference[17]. If all five major criteria and at least one minor one is met, the patient may undergo CVSS[17].

4. History of CVSS

CVSS is performed to break the positive feedback loop involving stenosis and increase venous sinus pressure by treating the focal stenosis[21]. The goal of the procedure is to reduce IIH symptoms, such as headache, and prevent further visual deterioration[21]. Venous sinus stenosis was first characterized by King *et al.* in 1995 through manometry and cerebral venography. In the study, hypertension was consistently observed in the superior sagittal sinus and proximal transverse sinus with subsequent hypotension in the distal transverse sinus in nine patients with IIH[4,23]. Subsequent studies have revealed bilateral transverse stenosis in 30%–90% of patients with IIH compared to

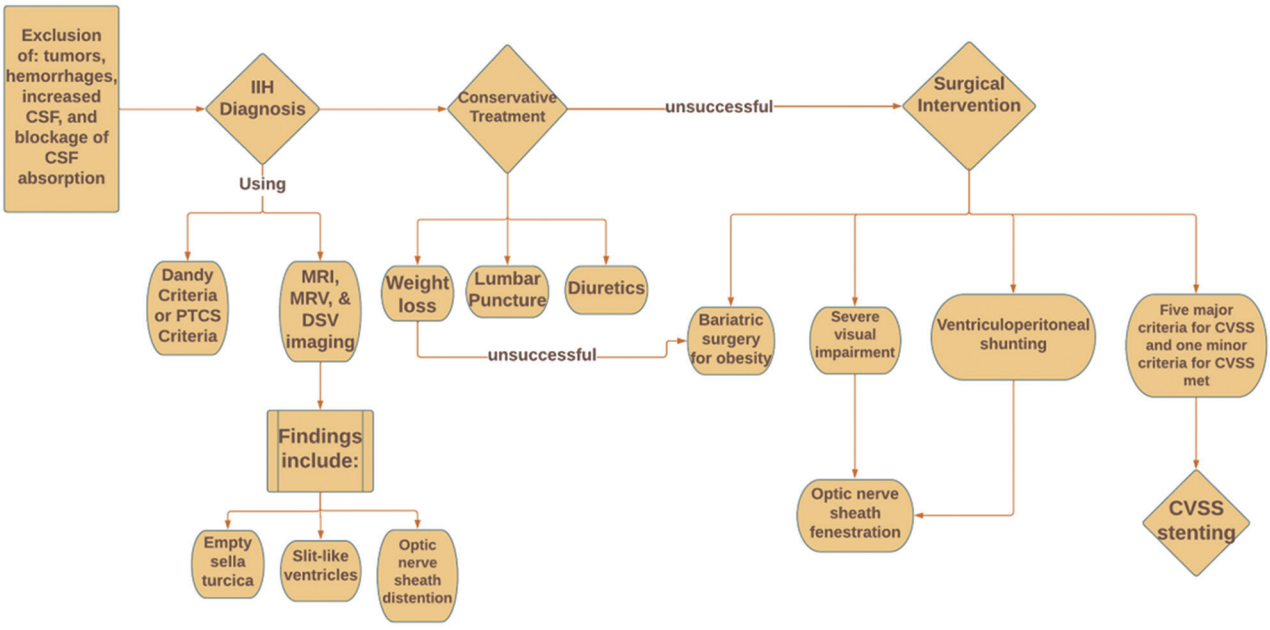

Figure 3. Proposed flowchart algorithm for indications of CVSS in the presence of IIH.

Table 1. Comparison of procedural alternatives to cerebral venous sinus stenting

Procedure	Advantages (compared to CVSS)	Disadvantages (compared to CVSS)
Repeated lumbar punctures	(i) Slight drop in IIH and headache immediately post-procedure[45] (ii) Normalizes CSF pressure[19]	(i) Rebound IIH with longer and more severe headache than before the procedure[45]
Bariatric surgery	(i) Significant reduction in headaches (90% reduction with bariatric surgery versus 70.2% reduction with CVSS), more than in CVSS[21,22] (ii)Comparable reductions in papilledema and tinnitus[21,41]	(i) Can only be used for IIH patients with obesity (ii) More pre-operative and post-operative care (iii) Variable cost but more expensive on average[42,43] (iv) Very little improvement in visual complaints[41] (v) Normally offered after failure of weight management interventions, thereby requiring a longer time before any improvement of IIH symptoms can be observed[43]
Optic nerve sheath fenestration	(i) Highly effective at treating visual impairment symptoms of IIH (such as decreasing papilledema grade and increasing visual field measured through kinetic perimetry)[47]	(i) Does not reduce headaches in IIH[47] (ii) Less improvement in visual acuity[44]
Shunting	(i) Better improvement in visual acuity than in repeated lumbar punctures, but not as significant as in ONSF or CVSS[44] (ii) Reduction in postoperative headaches, but not as significant as in CVSS[44]	(i) Less improvement in visual acuity and headaches[21] (ii) Moderate need for repeat procedures, making it more costly overall[21] (iii) More invasive[21] (iv) Significant complication rate as compared to CVSS[21]

CVSS: Cerebral venous sinus stenting; IIH: Idiopathic intracranial hypertension.

the general population, in which the incidence was only 6.8%[4]. By current standards, dural venous sinus stenosis can be described as extrinsic, intrinsic, or both[26]. Extrinsic stenosis can be related to scarring or elevated intracranial hypertension and presents as a long, smooth narrowing, whereas an intrinsic obstruction pattern consists of an arachnoid granulation defect that causes focal filling of the vein, which presents as a round or oval-shaped formation in the dural sinus wall[25].

The first venous stent was placed in 2002 by Higgens *et al*. In the study, a catheter was inserted into the internal jugular vein to direct a stent into the stenosed transverse sinus, which resulted in a decrease in the pressure gradient from 18 mmHg pre-procedure to 3 mmHg post-procedure[8,24]. The researchers described a significant improvement in symptoms after the placement of stent. In a meta-analysis by Mufti *et al*., 367 cases from 25 different publications were analyzed. Of these patients receiving one or more venous sinus stents, 78% experienced improvement in visual acuity and 77% had headache resolution; among the patients with papilledema, 84.5% showed resolution or improvement; and among the patients with pulsatile tinnitus, 88.7% had resolution after stent placement. CVSS has been shown to have high technical success, low relapse rates, and low major overall complication rates[26].

5. CVSS procedure

Before stenting, patients need to be screened for papilledema, their baseline visual acuity should be noted, and appropriate imaging such as magnetic resonance angiography or venography with manometry should be performed[4]. Once CVSS has been chosen as the course of action, aspirin and clopidogrel should be taken 3–4 days before stent placement and continued for 3–6 months after which only aspirin is used[21]. Although oral anticoagulants with single antiplatelet therapy may be better in preventing intra-stent thrombosis, dual antiplatelet therapy has been documented in literature as being more frequently used in CVSS[27].

Venous sinus stenting is done under general anesthesia, and a heparin bolus is given as soon as venous access is achieved to prevent clotting[4]. Although most stent surgeries use the femoral vein as an access site, upper extremity access through the brachial or basilic vein can also be used in CVSS[28]. Either the right or left internal jugular vein can be accessed using a right-arm approach[28]. Single arm access allows for earlier patient mobility, easier monitoring of healing, shorter procedure time, and reduction of femoral vein access site complications, such as retroperitoneal hemorrhage[26,28].

A microwire is guided through a micro catheter into the superior sagittal sinus and then past the point of stenosis[4]. Maximum venous pressures are reconfirmed at various spots in the dural venous sinus system (internal jugular, jugular bulb, bilateral transverse sinus, superior sagittal sinus, and sigmoid sinus) using venous manometry[4].

The access sheath system for the stent normally consists of three sheaths (7F, 9F, and 12F) of varying lengths (80–90 cm)[4]. Although most CVSS is performed using self-expanding stents, balloon-expanding stents may be considered as well[26]. Stents are placed across the stenosis, extending from 10 mm before the stenosis to 10 mm after the stenosis[4].

After stent placement, post-stenting venograms are performed to check for appropriate sinus drainage, followed by a CT to ensure the absence of intracranial hemorrhage[4]. Three months after stent placement, an angiogram should be repeated to check for complications[4].

6. Emerging developments in CVSS

As venous stenting has been introduced to patients as an acceptable form of treatment, the procedure has progressed through the advent of breakthroughs in treatment techniques. A newer technique, known to some as the "Cobra" technique, circumvents some of the difficulties encountered when placing stents in already-narrow vessels[29]. Navigating a catheter and stent around the narrowing is a difficult and taxing procedure, which can lead to complications if performed incorrectly. The Cobra technique, which is also referred to as "balloon-assisted tracking," uses a "gateway" 3.5 mm balloon shuttled through the catheter to reach the stenotic region[30]. The balloon is slightly inflated to a pressure slightly lower than its nominal pressure. The catheter and balloon are then jointly navigated to the venous sinus to allow stent delivery[29]. In some cases, the balloon may be deflated and reinflated to prevent tearing of vasculature through the razor effect (caused by the catheter) or vascular looping. These anomalies lead to challenges in catheterization or the need for alternate vascular access sites[31-34]. A study by Schwarz *et al.* has seen success in 30 cases, and Dalfino *et al.* also reported success using the same Cobra technique.

Some complications may arise from the Cobra technique. Venous sinus rupture may occur due to a significant level of force needed to inflate the balloon. This risk of injury must be evaluated before beginning the procedure. In addition, some studies have reported adverse events such as venous sinus and cortical vein injury appearing as venous sinus stenting becomes more common, although a rare occurrence[29]. Since the Cobra technique is relatively new, no significant long-term studies on post-operative complications were found.

Another breakthrough is the single-arm access venous sinus stenting (SAVeS) technique. This technique addresses the complications that arise when stenting from the femoral vein. The femoral vein is the most common venous access site in stenting procedures but it can be challenging to access in obese patients or in those with other medical indications[28]. SAVeS innovates using large upper-extremity veins such as the brachial and basilic veins for venous access instead.

In a study, a patient complained of numbness in the upper extremity after being treated using the SAVeS technique. It resolved two to 3 weeks after it was reported and was attributed to brachial plexus stretch when positioning the patient instead of venous injury[28].

CVSS has shown potential as a treatment option for patients with medically refractory IIH with an intrinsic cause of stenosis, such as brain encephaloceles[35]. In a study by Drocton *et al.* (n = 3), following venous sinus stent placement, one of the patients showed improvement in vision and had resolution of papilledema, while another patient had complete resolution of headache, blurred vision, and pulse-synchronous tinnitus[35]. Although CVSS is a promising technique for relieving symptoms of medically refractory IIH in patients with intrinsic stenosis, more vigorous research is required[35].

7. Complications of CVSS

While cerebral venous stenosis stenting has data supporting its efficacy as a minimally invasive procedure, there are noteworthy complications that may arise from the process. Complications following CVSS include restenosis, subdural hematoma, subarachnoid hemorrhage, intracerebral hemorrhage, intraventricular hemorrhage, in-stent thrombosis, retroperitoneal hemorrhage, and femoral pseudoaneurysm. Several studies have shown that the rate of minor and major complications is around 1–6%[3].

The most common complication from CVSS is headache ipsilateral to the stent. This headache may be oppressive in nature and may last for months[35-37]. In a study, 46% of patients experienced headaches described as mild, moderate, or severe in nature[36]. The cause of the headaches was hypothesized to be a consequence of the stretching of dura mater[8].

Furthermore, CVSS may affect the function of the vein of Labbé (VOL). The mechanism is poorly understood but is hypothesized to be secondary to coverage by stents placed across the transverse and sigmoid sinuses. The VOL, or inferior anastomotic vein, contributes to a channel forming between the superior sagittal and transverse sinuses and the superficial middle cerebral vein[38]. In several studies, CVSS has been shown to decrease VOL draining in certain patients. In a retrospective analysis, the data of 56 patients undergoing CVSS were examined, and 32 of these cases presented with VOL coverage that resulted in diminished vascular caliber, sluggish venous filling, and vessel occlusion[39]. Further consequences of VOL include cerebral edema, venous cerebral ischemia, and cerebral hemorrhage[8].

The inherent congestive nature of sinus stenosis implies that the passage of a catheter to access the sinus can result in complications, like hemorrhage[46].

In addition, serious complications include thrombus formation, subdural hemorrhages, and sinus wall injuries,

the combination of which can, in rare cases, lead to a *de novo* formation of dural arteriovenous fistula[40].

Restenosis is a common cause of failure in stenting and can occur in an existing stent or in an adjacent stent. However, the mechanism of which it occurs is unknown[8].

The long-term outcomes of CVSS are promising[48,49]. In a single-center real-world cohort study by Xu *et al*., 98.3% of patients showed improvements in papilledema and the headaches in 96% of patients (n = 62) resolved after 12~126 months (median 62 months). However, adverse effects such as optic disc atrophy and tent-interior thrombosis were reported in 8% of patients after 6.3 months[48].

8. Conclusion

Cerebral venous stent placement remains a viable option for patients experiencing symptoms of IIH, including headaches, vision loss, and pulsatile tinnitus. The clinical use of CVSS in the treatment of IIH and associated symptoms is promising; however, vigorous research is required to further evaluate to efficacy of this procedure. Developments such as the Cobra and SAVeS techniques present promising improvements to CVSS.

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Conflict of interest

The authors declare that they have no conflict of interest.

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