VASCULAR/INTERVENTIONAL CME

An Update on Programmable CSF Shunt Valves: Identification, MR Imaging Safety and Potential Pitfalls

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ABSTRACT

Programmable shunt valves are commonly used devices for the treatment of hydrocephalus. Unlike fixed shunt valves, programmable devices allow the operator to alter the amount of CSF drainage without the need for shunt revision or valve replacement. With their increased use, many different programmable shunt valves have been developed by various manufacturers; each programmable shunt valve has a distinct radiographic appearance and CSF drainage setting. Because of potential interactions with MR imaging scanners, which can alter programmable shunt valve function, understanding and accurately reporting these devices is essential.

Learning Objectives: Identify commonly used programmable shunt valves and understand their CSF drainage settings to enable the detection of device alterations after MR imaging scanning.

INTRODUCTION

Over the past decade, the use of programmable shunt valves (PSVs) for the treatment of hydrocephalus has increased dramatically.[1] Unlike traditional fixed shunt valves (FSVs), which have one specific CSF drainage setting, PSVs allow for noninvasive alteration in the amount of CSF drainage by using external tools that transmit a codified magnetic signal to the valve motor.[2] Although the clinical impact of PSV use remains controversial,[3] multiple studies demonstrated efficacy and decreased complication rates with PSVs compared with FSVs in the setting of complex or normal-pressure hydrocephalus.[4-10] Complex hydrocephalus includes multiple potential etiologies in which there is a need for long-term CSF drainage, often related to congenital malformations, such as Dandy-Walker syndrome or Chiari malformations. Also, because it is difficult to predict which cases will be complicated, some researchers advocate for PSV use in all patients in which CSF needs to be drained.[11]

Due to potential interactions of PSVs with MR imaging scanners, radiographic evaluation is routinely performed to assess CSF drainage settings before and after MR imaging examinations. Standard radiographs of the shunt valve and catheter tubing are also common for the assessment of suspected shunt dysfunction. Therefore, it is important for neuroradiologists to be familiar with the

ABBREVIATION KEY

FSV = fixed shunt valve
PSV = programmable shunt valve
SM8 = Sophysa Mini 8
SPV = Sophysa Polaris valve

Received August 3, 2019; accepted December 19, 2019.

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Previously presented at the American Society of Neuroradiology 56th Annual Meeting as an educational exhibit, June 2–7, 2018, Vancouver, British Columbia, Canada.

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http://dx.doi.org/10.3174/ng.1900030

Disclosures
Based on information received from the authors, *Neurographics* has determined that there are no Financial Disclosures or Conflicts of Interest to report.

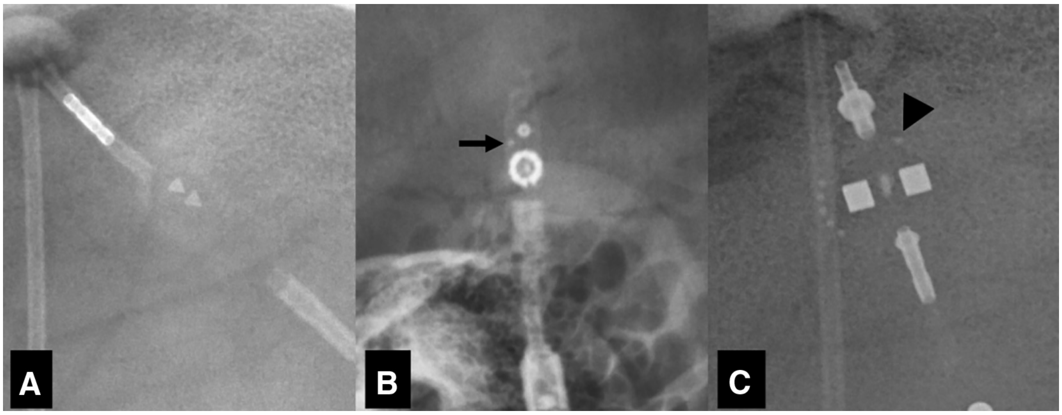

FIG 1. Radiographic appearance of FSVs and PSVs. *A*, Medtronic PS Medical Delta FSV. Note the absence of a radiopaque rotatory dial component. *B*, Codman Hakim PSV, with round rotatory valve dial and small radiopaque marker (*arrow*), denoting laterality of the valve. *C*, Sophysa Polaris PSV, with a square-shaped rotatory valve dial and small radiopaque marker (*arrowhead*), denoting valve version. Each valve version has different CSF drainage settings.

PSV radiographic appearance, CSF drainage settings, and potential pitfalls in radiographic interpretation.

PSVs

General Radiographic Features

The radiographic appearance of a PSV is unique among manufacturers and also varies among different PSV types or versions produced by the same manufacturer. However, in general, PSVs are distinguished from FSVs by the presence of a radiopaque rotatory component (Fig 1), which often contains a notch to determine the CSF drainage setting. Additional small radiopaque markers may be used to determine laterality or version of the PSV (Fig 1). Different versions of a PSV may have different CSF drainage settings, an example of which is the Sophysa (Orsay, France) Polaris valve (SPV).[12]

There are several components of PSVs (Fig 2). First, it is important to recognize that there can be a normal radiolucency at the calvarial entry site of the shunt catheter, which should not be misinterpreted as a catheter fracture or discontinuity. A circular radiopaque pumping reservoir is present just before the ventricular catheter and allows for catheter access and patency evaluation. Next, the adjustable valve is recognized through visualization of a radiopaque dial. Caudal to the PSV, an antisiphon device may be in place. The function of the antisiphon device is to prevent excessive drainage of CSF with large fluctuations in hydrostatic pressure, as can be encountered when standing.[13] The antisiphon device may have a round radiodense component and can potentially mimic the PSV dial.

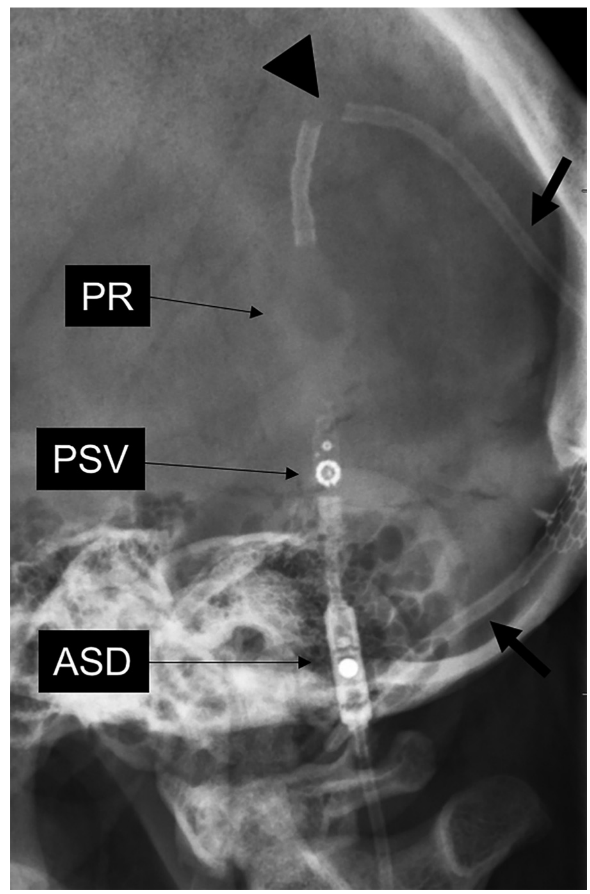

FIG 2. The general radiographic appearance of a PSV. Key components include the ventricular catheter (*arrows*), a normal radiolucent component of the shunt catheter at the calvarial insertion (*arrowhead*), pumping reservoir (PR), radiopaque dial of the PSV, and antisiphon device (ASD).

Codman

The Codman Hakim PSV (Johnson & Johnson, Wokingham, UK) is a commonly encountered PSV manufactured by Integra LifeSciences.[14] The Codman Hakim PSV (Fig 3) is recognized by its round radiopaque dial. A small radiolucent notch is located at the periphery of the valve dial, the position of which determines the CSF drainage setting. The Codman Hakim PSV drainage settings range from a valve opening pressure of 30 to 200 mm H_2O, and increase sequentially by increments of 10 mm H_2O. A central marker is seen along the cephalad portion of the valve. Adjacent to the central marker is a small round radiopaque marker, which is used to determine laterality of the valve and is important to prevent

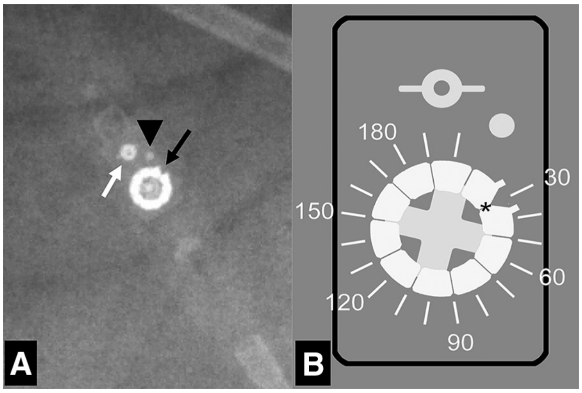

FIG 3. Codman Hakim PSV. *A*, The radiolucent notch denotes the shunt CSF drainage setting (*black arrow*). A small radiopaque marker determines the valve laterality (*arrowhead*). A central marker is also present at the cephalad aspect of the valve (*white arrow*). *B*, The current PSV setting is 30 mm H_2O (*).

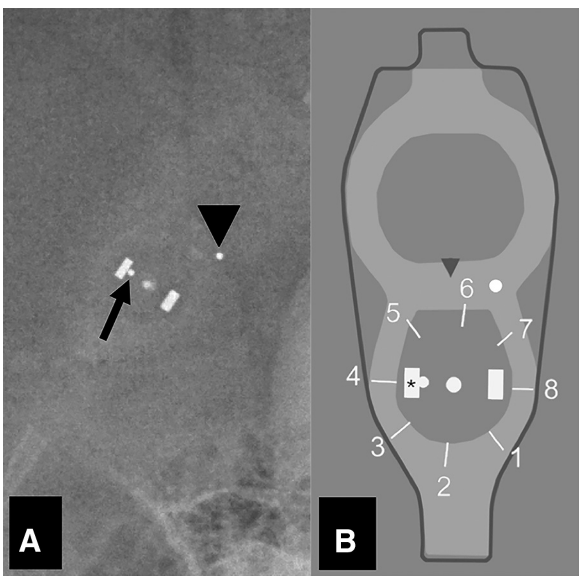

FIG 4. Codman Certas PSV. *A*, The small radiopaque marker along the inner margin of the PSV dial denotes the valve setting (*arrow*). An additional marker at the cephalad aspect of the valve determines laterality (*arrowhead*). *B*, The current PSV setting is performance level 4 (*).

misinterpretation of CSF drainage settings if the valve is flipped.

The Codman Certas is another PSV manufactured by Integra LifeSciences. This PSV was recalled in 2013, a voluntary class II FDA recall,[15] due to potential MR imaging interactions with the valve,[16] which were not indicated on the package insert. The recall was terminated in 2015, with the subsequent release of the Codman Certas Plus PSV (Integra LifeSciences),[17] which has an identical radiographic appearance and CSF drainage settings as the original Codman Certas PSV.

The Codman Certas PSV (Fig 4) is identified by 2 parallel radiopaque bars, which correspond to the valve dial. Along the inner margin of one of the radiopaque bars is a small, round radiopaque marker, which denotes the PSV CSF

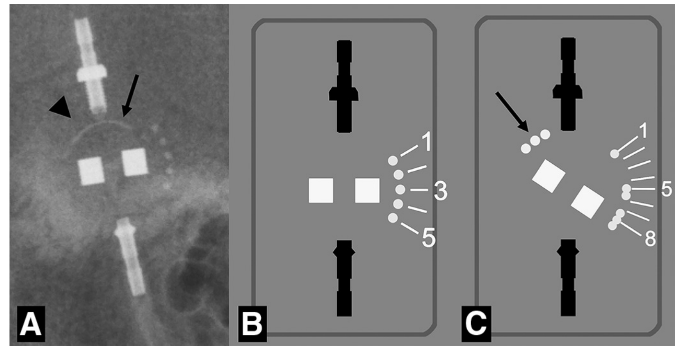

FIG 5. Sophysa PSVs. *A*, Sophysa Polaris PSV, with 5 possible performance settings, denoted by the round radiopaque markers on the side of the valve. A curvilinear line denotes the cephalad aspect of the valve (*black arrow*), with no adjacent markers (*arrowhead*), corresponding to the valve version SPV-140. *B*, The Polaris valve is set to position 3. *C*, SM8 set to position 8. Three markers at the cephalad aspect depict the valve version SM8-400 (*black arrow*).

drainage setting. Similar to the Codman Hakim PSV, there is an additional small, round radiopaque marker at the cephalad aspect of the valve used to determine laterality. The Codman Certas PSV has 8 performance settings (Fig 4). Positions 1 through 7 correspond to different ranges of CSF drainage, depending on the valve flow rate. At position 1, the CSF drainage will be set to a valve opening pressure of 25 mm H_2O ($\pm$20 mm H_2O, depending on the valve flow rate). Valve opening pressures will incrementally increase from positions 1 to 7. At position 8, the Codman Certas PSV is set to "virtual off," which allows minimal CSF flow through the valve. When interpreting the Codman Certas PSV, one should report at which of the 8 performance settings the valve dial is set.

Sophysa

The SPV is a commonly encountered PSV.[12,18] Similar to the Codman Certas PSV, the SPV (Fig 5) is recognized by 2 parallel radiopaque squares, which correspond to the valve dial. Five radiopaque markers are present on the side of the valve and determine the CSF drainage setting. Position 1 is at the cephalad aspect of the valve and the markers incrementally increase to position 5, toward the caudal aspect of the valve. A small curvilinear radiopaque line can be used to determine the cephalad portion of the valve.

Adjacent to the cephalad curvilinear line is the marker used to determine the PSV version, with each Sophysa Polaris version having different valve opening pressure ranges (Fig 5). If there is no marker, then this corresponds to the SPV-140, with a pressure range of 10 to 140 mm H_2O. One marker corresponds to a pressure range of 30 to 200 mm H_2O (SPV), 2 radiopaque markers correspond to a pressure range of 50 to 300 mm H_2O (SPV-300), and 3 radiopaque markers correspond to a pressure range of 80 to 400 mm H_2O (SPV-400). It is important for the neuroradiologist to recognize both the valve version and dial position.

A less common valve by Sophysa is the Sophysa Mini 8 (SM8) (Fig 5).[18,19] Similar to the Sophysa Polaris, the SM8 has radiopaque squares that denote the valve dial and 0 to 3

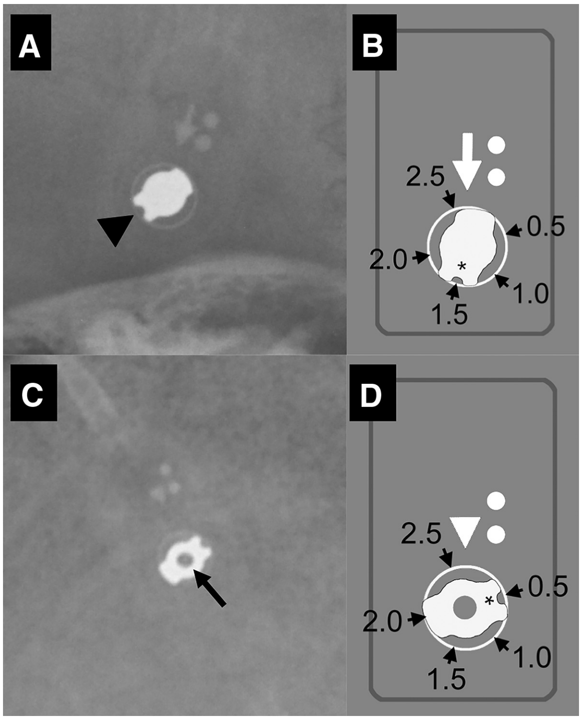

FIG 6. Medtronic Strata PSVs. *A*, Strata II PSV with specific valve markers (*radiopaque arrow* and *2 dots* to denote laterality) and unique valve dial shape. Radiolucent notch determines the valve setting (*black arrowhead*). *B*, The valve is set to a performance level of 1.5 (*). *C*, Strata II small, with specific valve markers (*radiopaque arrowhead* and *2 dots* to denote laterality) and a unique valve dial shape with central radiolucency (*black arrow*). *D*, The valve is set to a performance level of 0.5 (*).

markers at the cephalad aspect of the valve to determine the valve version. The valve version pressure ranges are identical (SM8-140, SM8, SM8-300, and SM8-400) to the Sophysa Polaris; however, there are 8 possible positions of the valve dial, determined by the position of the dial in relation to radiopaque markers at the left aspect of the valve.

Medtronic (Minneapolis, MN)

Three PSVs by Medtronic are currently used: the Strata II (Fig 6), Strata II small (Fig 6), and Strata NSC (Fig 7).[20] A fourth PSV by Medtronic, the Strata MR (Fig 7), is no longer used due to a design problem with the valve that may result in underdrainage of CSF (FDA class I recall).[21] Also, although still commonly used, the Strata II and Strata NSC PSVs were involved in a previous FDA class II recall,[22] similar to the Codman Certas, which was done to emphasize potential interactions with MR imaging scanners.

The Medtronic PSVs are identified by a unique radiopaque valve dial, which has a circular central component, with squared lateral margins (Figs 6 and 7). At one side of the dial is a small radiolucent notch, which points to the CSF drainage setting. For Medtronic PSVs, there are 5 valve performance levels, beginning at 0.5 and increasing by increments of 0.5 to a maximum valve setting of 2.5 (Figs 6 and 7). Each performance level corresponds to a range of valve opening pressures, which vary, depending on the valve flow rate and distal hydrostatic pressure. The distal hydrostatic pressure is determined by supine and upright positioning, and this valve feature prevents overdrainage of CSF when standing.[20]

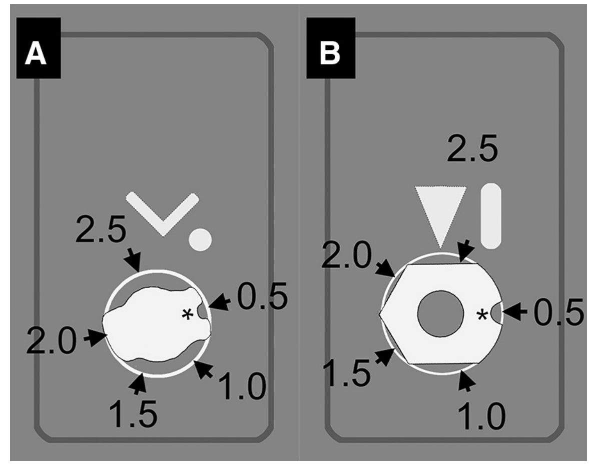

FIG 7. Medtronic Strata PSVs. *A*, Strata NSC PSV, with *radiopaque empty arrowhead* and laterality marker at the cephalad aspect of the valve. The valve dial shape is similar to that of the Strata II and Strata II small. The valve performance level is set to 0.5 (*). *B*, The Strata MR PSV is shown for reference and is not currently used due to an FDA class I recall.

The Strata II, Strata II small, and Strata NSC each have different radiopaque markers at the cephalad aspect of the valve dial (Figs 6 and 7). Additional small, round radiopaque markers are also present and determine valve laterality when interpreting the performance level. It is important for the neuroradiologist to report the Medtronic valve type and performance level.

Aesculap

There are 3 PSVs manufactured by Aesculap (Tuttlingen, Germany)[23]: proGAV, proGAV 2, and proSA PSVs. The proGAV PSV (Fig 8) is recognized by its valve dial shape, which is round centrally, with a squared and pointed margin on each side. The pointed side of the dial designates the PSV CSF drainage setting, which ranges from 0 to 20 cm H_2O valve opening pressure. After 1 cm H_2O, the valve opening pressure increases by increments of 3 cm H_2O. A flat radiolucent margin along the outer aspect of the PSV is used to determine valve laterality.

The proSA PSV (Fig 8) has a similar-appearing valve dial as the proGAV. The proSA CSF drainage settings range from 0 to 40 cm H_2O and increase by increments of 10 cm H_2O. A scalloped radiolucent margin is present along the inner aspect of the proSA to determine valve laterality. The proGAV 2 valve dial is unique in appearance compared with the proGAV and proSA, with a total of 6 radiopaque dots that form a triangular shape, which points toward the CSF drainage setting (Fig 8). The proGAV 2 CSF drainage settings range from 0 to 20 cm H_2O and increase by increments of 2 cm H_2O. A small saucer-shaped radiolucency on the side of the valve is used to determine laterality.

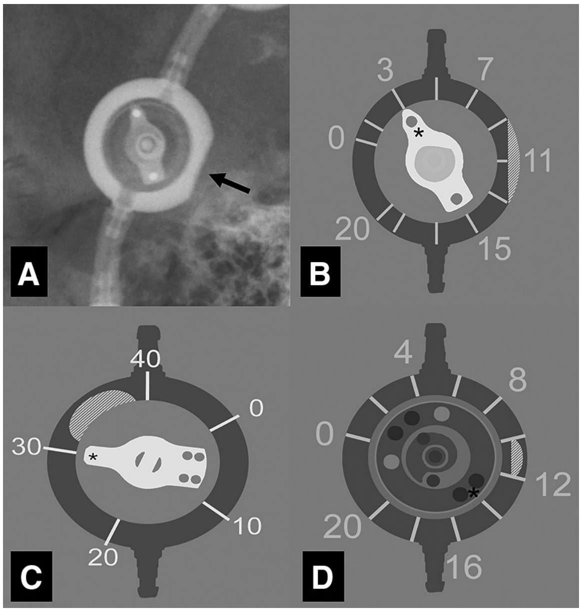

FIG 8. Aesculap PSVs. *A*, The proGAV PSV with a unique valve dial shape. The flat radiolucent outer margin (*arrow*) is used to determine laterality. *B*, The proGAV PSV is set to 3 cm H_2O (*). *C*, The proSA PSV with similar valve shape as proGAV. The radiolucent laterality marker (*white dashed lines*) distinguishes this valve type. This valve is set to 30 cm H_2O (*). *D*, The proGAV 2 PSV with 6 markers forming a triangular configuration, the tip of which determines the valve setting (*) of 14 cm H_2O. The radiolucent laterality marker is seen on the side of the valve (*white dashed lines*).

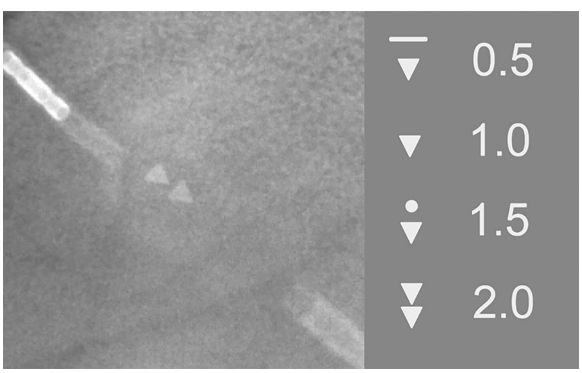

FIG 9. Medtronic PS Medical Delta FSV. There are 4 different versions, identified by the shape and number of the radiopaque markers (right diagram). Each version has a fixed performance level of 0.5 to 2.0. The depicted FSV version has a performance level of 2.0 (left image).

FSVs

FSVs are also commonly used for the treatment of hydrocephalus. Unlike PSVs, FSVs allow for a specific CSF drainage setting, which is not adjustable. FSVs are best differentiated from PSVs by a lack of a radiopaque dial component. Importantly, FSV CSF drainage settings are not affected by MR imaging interactions; therefore, screening radiographs are not needed before MR imaging scanning.

There are multiple FSVs produced by each of the major shunt manufacturers. Two commonly used FSVs by Medtronic are the PS Medical Delta (Fig 9) and CSF Flow-

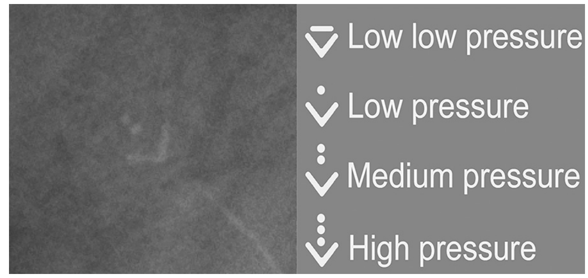

FIG 10. Medtronic CSF Flow-Control FSV. There are 4 different versions, identified by the shape and number of radiopaque markers (right diagram). Each version has a fixed performance level of low-low pressure to high pressure. The depicted FSV version has a medium pressure setting (left image).

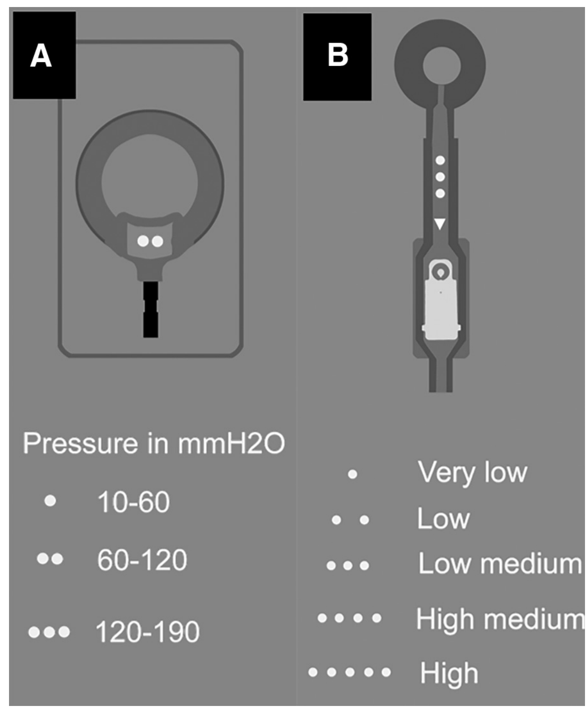

FIG 11. Representative Sophysa and Codman FSVs. *A*, The Sophysa Pulsar FSV has a valve pressure range of 10 to 190 mm H_2O, depending on the number of markers at the base. The depicted Sophysa Pulsar FSV version has a fixed pressure range of 60 to 120 mm H_2O. *B*, The Codman Hakim Precision In Line FSV has a performance level of very low to high. The depicted Codman Hakim Precision In Line FSV version has a performance level of low-medium.

Control (Fig 10) valves,[24] each of which has 4 versions with different CSF drainage settings. However, more importantly, the PS Medical Delta and CSF Flow-Control valves lack an adjustable dial (Fig 10) and should be readily differentiated from PSVs. Similar designs are demonstrated for Sophysa[25] and Codman[26] FSVs (Fig 11).

IMAGING PITFALLS

As previously emphasized, PSVs must be differentiated from FSVs to allow for appropriate MR imaging screening radiographs and correct interpretation of PSV settings. One FSV that can be misidentified as a PSV is the Aesculap Dual

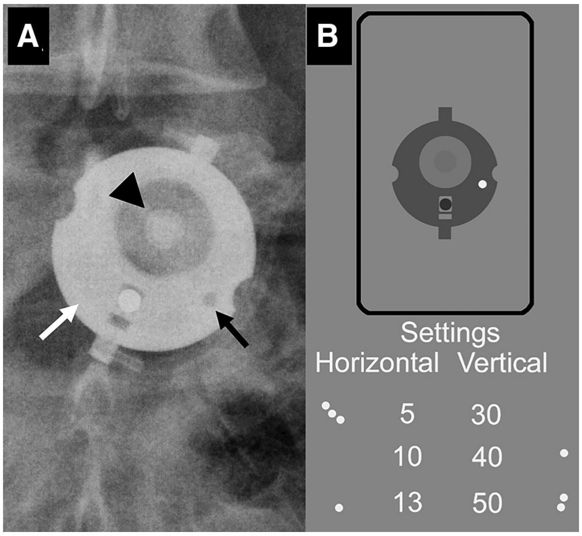

FIG 12. Aesculap Dual Switch lumboperitoneal FSV. ***A***, The central round radiopaque component can mimic a PSV dial (*arrowhead*); however, note that there is no associated notch, as seen in previous PSVs. The valve version is determined by the number of radiolucent dots at the right base (horizontal pressure [*white arrow*]) and left side (vertical pressure [*black arrow*]). ***B***, In this illustration, this valve version has a pressure setting of 10/40 cm H_2O.

Switch valve,[23] which has a central radiopaque component (Fig 12) that can be mistaken for a PSV dial. The number of radiolucent dots along the Aesculap Dual Switch FSV determines its version and CSF drainage settings (Fig 12).

Two programmable shunts that can also be misidentified are the Sophysa Polaris and Codman Certas. Because the adjustable dials on these PSVs are similar in appearance, the neuroradiologist must be aware of their radiographic differences. The Codman Certas has a more rectangular-shaped dial, with a small radiopaque dot on one side to determine the dial position (Fig 4). The Sophysa Polaris valve dial is more square in shaped (Fig 5) and has only 5 potential shunt settings on the side of the valve, compared with 8 circumferential settings for the Codman Certas.

Lastly, PSV radiographs should be interpreted with a centered anterior-posterior or posterior-anterior projection. If images are obtained with obliquity, then the valve dial can appear to be at an inaccurate position (Fig 13). Also, oblique images, depending on the PSV type, can make it impossible to determine the position of the laterality marker (Fig 14). If obtained with obliquity, radiographs should be repeated to avoid misinterpretation of CSF drainage settings.

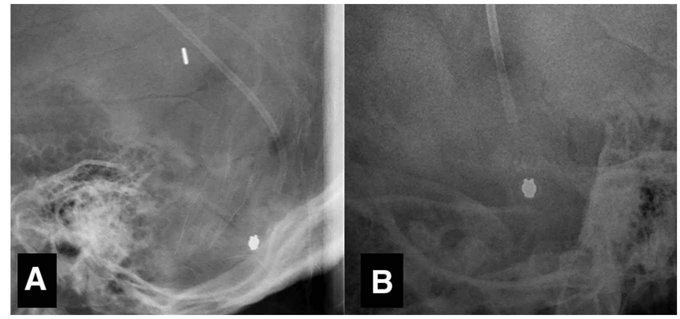

FIG 13. Potential imaging interpretation pitfall. ***A***, Due to obliquity of initial images, it is difficult to determine the version or setting of this Medtronic PSV. ***B***, Repeated coned images with decreased obliquity, demonstrating a Medtronic Strata II PSV set to a performance level of 2.5.

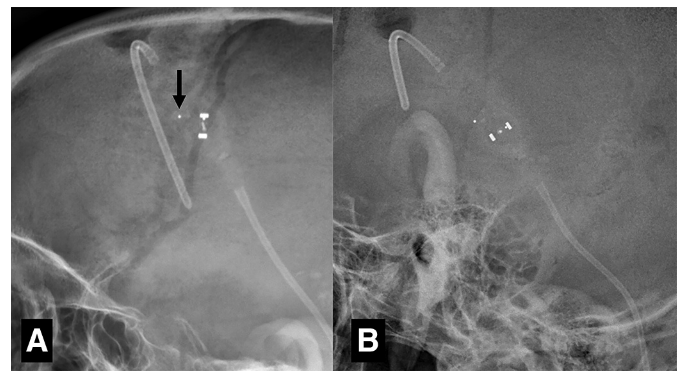

FIG 14. Potential imaging interpretation pitfall. ***A***, On initial radiographic evaluation, it is impossible to determine the side of the laterality marker (*arrow*) of this Codman Certas PSV. ***B***, A repeated image with decreased obliquity, clearly demonstrating the position of the laterality marker and the CSF drainage setting, which is set to a performance level of 4.

MR IMAGING SAFETY CONSIDERATIONS

The Codman Hakim, Codman Certas, Medtronic Strata II, and Medtronic Strata NSC programmable valves are MR imaging conditional for scanners up to 3T magnet strength.[14,17,24] The manufacturers recognize the potential for MR imaging scanners to alter PSV drainage settings and recommend that these valves be screened with radiographs before and after MR imaging scanning. The highest spatial gradient magnetic field for these PSVs is 720 gauss/cm. The recommended specific absorption rate for Codman Hakim, Strata II, and Strata NSC is 3 W/kg for 15 minutes.

Aesculap PSVs are also MR imaging conditional and are able to be scanned up to 3T magnet strength.[23] Although the manufacturers state that there is no impact on the performance of the valves by MR imaging scanners up to 3T, they also warn that, when using a magnetic field and simultaneously pressing on the valve, an adjustment of the valve cannot be excluded. The highest spatial gradient magnetic fields for the proGAV, proSA, and proGAV 2 are 430, 720, and 1400 gauss/cm, respectively. The maximum whole-body specific absorption rate for 15 minutes of scanning is 2.9 W/kg for proGAV and 4 W/kg for proSA or proGAV 2. No local transmit coils should be placed over the valves.

The SPV is MR imaging conditional up to 3T magnet strength.[25] The researchers indicate that, because of the "magnetic lock" mechanism of the valve, there is no effect of high magnetic field strength on valve performance. However, the SM8 does not have this valve mechanism and can be altered by magnetic fields.[25] Currently, the SM8 is MR imaging conditional at 1.5T magnet strength only.

Fixed valves vary in their MR imaging safety profile but are generally MR imaging conditional at 1.5T and 3T magnetic field strengths. For example, the Medtronic PS Medical Delta FSV is conditional up to 3T, whereas the Medtronic CSF Flow-Control valve is conditional at 1.5T only.[24] Importantly, FSV performance is not affected by magnetic fields, and these devices do not need screening radiographs after MR imaging scanning.

CONCLUSIONS

PSVs are effective devices for the treatment of complex hydrocephalus. Because PSV performance settings can be altered by MR imaging interactions, it is important to be familiar with the radiographic interpretation of CSF drainage settings and potential imaging pitfalls.

REFERENCES

1. Smith G, Pace J, Scoco A, et al. **Shunt devices for neurointensivists: complications and management.** *Neurocrit Care* 2017;27:265–75. 10.1007/s12028-016-0366-3
2. Lollis SS, Mamourian AC, Vaccaro TJ, et al. **Programmable CSF shunt valves: radiographic identification and interpretation.** *AJNR Am J Neuroradiol* 2010;31:1343–46. 10.3174/ajnr.A1997
3. Tomei KL. **The evolution of cerebrospinal fluid shunts: advances in technology and technique.** *Pediatr Neurosurg* 2017;52:369–80. 10.1159/000477174
4. Zemack G, Bellner J, Siesjö P, et al. **Clinical experience with the use of a shunt with an adjustable valve in children with hydrocephalus.** *J Neurosurg* 2003;98:471–76. 10.3171/jns.2003.98.3.0471
5. Arnell K, Eriksson E, Olsen L. **The programmable adult Codman Hakim valve is useful even in very small children with hydrocephalus. A 7-year retrospective study with special focus on cost/benefit analysis.** *Eur J Pediatr Surg* 2006;16:1–7. 10.1055/s-2006-923904
6. Gallia GL, Rigamonti D, Williams MA. **The diagnosis and treatment of idiopathic normal pressure hydrocephalus.** *Nat Clin Pract Neurol* 2006;2:375–81. 10.1038/ncpneuro0237
7. Zemack G, Romner B. **Adjustable valves in normal-pressure hydrocephalus: a retrospective study of 218 patients.** *Neurosurgery* 2008;62(Suppl 2):677–87. 10.1227/01.neu.0000316272.28209.af
8. Mpakopoulou M, Brotis AG, Gatos H, et al. **Ten years of clinical experience in the use of fixed-pressure versus programmable valves: a retrospective study of 159 patients.** *Acta Neurochir Suppl* 2012;113:25–28. 10.1007/978-3-7091-0923-6_5
9. Serarslan Y, Yilmaz A, Cakir M, et al. **Use of programmable versus nonprogrammable shunts in the management of normal pressure hydrocephalus: a multicenter retrospective study with cost–benefit analysis in Turkey.** *Medicine (Baltimore)* 2017;96:e8185. 10.1097/MD.0000000000008185
10. Li M, Wang H, Ouyang Y, et al. **Efficacy and safety of programmable shunt valves for hydrocephalus: a meta-analysis.** *Int J Surg* 2017;44:139–46. 10.1016/j.ijsu.2017.06.078
11. Zemack G, Romner B. **Seven years of clinical experience with the programmable Codman Hakim valve: a retrospective study of 583 patients.** *J Neurosurg* 2000;92:941–48. 10.3171/jns.2000.92.6.0941
12. Sophysa. Manufacturer guide. Polaris valve introduction. http://www.sophysa.com/en/page/valve-introduction. *Accessed July 3, 2019*.
13. Tokoro K, Chiba Y, Abe H, et al. **Importance of anti-siphon devices in the treatment of pediatric hydrocephalus.** *Childs Nerv Syst* 1994;10:236–38. 10.1007/BF00301160
14. Codman. **Procedure guide. Codman Hakim program-mable valves.** https://www.integralife.com/file/general/1537989306.pdf. *Accessed July 3, 2019*.
15. FDA. **Recalls, corrections and removals (devices).** https://www.fda.gov/medical-devices/postmarket-requirements-devices/recalls-corrections-and-removals-devices. *Accessed July 3, 2019*.
16. FDA. **Class 2 device recall Codman Certas programmable valve.** https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfres/res.cfm?id=118139. *Accessed July 3, 2019*.
17. Codman. **Manufacturer guide. Codman Certas Plus programable valve.** https://www.integralife.com/file/general/1549983654.pdf. *Accessed July 3, 2019*.
18. Martinez-Lage JF, Almagro MJ, Del Rincón IS, et al. **Management of neonatal hydrocephalus: feasibility of use of two programmable (Sophy and Polaris) valves.** *Childs Nerv Syst* 2008;24:549–56. 10.1007/s00381-007-0512-5
19. Sophysa. **Manufacturer guide. Sophy Mini SM8 – valve introduction.** http://www.sophysa.com/en/page/valve-introduction-2. *Accessed July 3, 2019*.
20. Strata. **Products catalog. CSF management, critical care, cranial repair, and neuroendoscopy.** https://www.medtronic.com/content/dam/medtronic-com/products/neurological/documents/catalog_csfmgt_criticalcare_cranialrepair_neuroendoscopy_uc201709479EN.pdf. *Accessed July 3, 2019*.
21. FDA. **Medtronic recalls StrataMR adjustable valves and shunts which may cause fluid buildup in the brain.** https://www.fda.gov/medical-devices/medical-device-recalls/medtronic-recalls-stratamr-adjustable-valves-and-shunts-which-may-cause-fluid-buildup-brain. *Accessed July 3, 2019*.
22. FDA. **Class 2 device recall Strata II/Strata NSC valves.** https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfRes/res.cfm?ID=152582. *Accessed July 3, 2019*.
23. Aesculap. **Manufacturer website. Hydrocephalus shunts.** https://www.aesculapusa.com/products/neurosurgery/hydrocephalus-shunts. *Accessed July 3, 2019*.
24. Medtronic. **Manufacturer website. Shunts for hydrocephalus.** https://www.medtronic.com/us-en/patients/treatments-therapies/hydrocephalus-shunt.html. *Accessed July 3, 2019*.
25. Sophysa. **Manufacturer guide. Pulsar valve introduction.** https://www.sophysa.com/en/page/valve-introduction-3. *Accessed July 3, 2019*.
26. Codman. **Manufacturer website. Fixed pressure valves.** https://www.integralife.com/fixed-pressure-valves/category/hydrocephalus-fixed-pressure-valves. *Accessed July 3, 2019*.