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3T magnetic resonance imaging testing of externally programmable shunt valves

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Abstract

Background: Exposure of externally programmable shunt-valves (EPS-valves) to magnetic resonance imaging (MRI) may lead to unexpected changes in shunt settings, or affect the ability to reprogram the valve. We undertook this study to examine the effect of exposure to a 3T MRI on a group of widely used EPS-valves.

Methods: Evaluations were performed on first generation EPS-valves (those without a locking mechanism to prevent changes in shunt settings by external magnets other than the programmer) and second generation EPS-valves (those with a locking mechanisms). Fifteen new shunt-valves were divided into five groups of three identical valves each, and then exposed to a series of six simulated MRI scans. After each of the exposures, the valves were evaluated to determine if the valve settings had changed, and whether the valves could be reprogrammed. The study produced 18 evaluations for each line of shunt-valves.

Results: Exposure of the first generation EPS-valves to a 3T magnetic field resulted in frequent changes in the valve settings; however, all valves retained their ability to be reprogrammed. Repeated exposure of the second generation EPS-valves has no effect on shunt valve settings, and all valves retained their ability to be interrogated and reprogrammed.

Conclusions: Second generation EPS-valves with locking mechanisms can be safely exposed to repeated 3T MRI systems, without evidence that shunt settings will change. The exposure of the first generation EPS-valves to 3T MRI results in frequent changes in shunt settings that necessitate re-evaluation soon after MRI to avoid complications.

Key Words: Magnetic resonance imaging, programmable, reliability, shunt-valve, 3-Tesla, Testing

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INTRODUCTION

The last half-century has seen significant advancement in the management of hydrocephalus. In 1955, John Holter, an American engineer, invented the first cerebrospinal fluid (CSF) shunt valve for implantation into his son who had been born with hydrocephalus.[2] Initially, all shunt valves had fixed opening pressures. While these valves were a major step forward, they required that the surgeon make an educated guess at the best pressure for a particular patient. Significant overdrainage or underdrainage of CSF required surgical revision of the valve with its associated risks. Percutaneously adjustable shunt-valves were the next milestone in the treatment of these patients, with the first adjustable valves approved for use in the United States in 1998. These externally programmable EPS-valves allow the surgeon to noninvasively optimize the opening pressure of a valve before and after implantation. Because all available EPS-valves utilize a magnetic drive system to control valve settings, exposure to strong magnetic fields and radiofrequency (RF) energy during magnetic resonance imaging (MRI) may lead to unexpected changes in shunt settings, or potentially damage the shunt magnets impairing the ability to reprogram the valves.

The first generation of EPS-valves (Codman Medos®, Medtronic Strata® and Sophysa Sophy® valves) have no locking mechanism to prevent changes in the shunt settings by external magnets other than the manufacturers' programmer. As a result, these valves are at risk of being reprogrammed during MR imaging, and must be reevaluated after any MRI study to assure that the valve setting has not changed. This can create significant issues for patient safety when a scan is performed on an emergency basis at a center unfamiliar with the shunt valve, or when the appropriate tools for reprogramming the valve are not readily available. At the very least, it is an inconvenience for the patient and physician. In addition, repeated exposure to MRI at 3T field strength may affect the ability to reprogram these first generation EPS-valves.

The second generation of EPS-valves includes a locking mechanism designed to help minimize the risk of unintentional changes in valve settings. The Codman Certas® and Sophysa Polaris® valves utilize a dual-magnet design, while the Miethke proGAV® valve uses a mechanical locking mechanism to prevent changes to valves settings by strong magnetic fields other than the programming tools.

Presently, there are an estimated 11,000 diagnostic MRI units in the United States, an increasing number of which are high-field strength 3T units. These units offer an improved signal to noise ratio, which in turn leads to improved image quality and reduced scan times; however, 3T MRI may increase the risks for problems in patients with EPS-valves. While multiple groups have published reports describing the results of MRI testing with EPS-valves, the availability of manuscripts evaluating the interaction of these valves with 3T MRI systems is limited. A search of the Medline data base identified only five peer-reviewed publications, examining the effects of 3T MRI on the second generation EPS-valves: three describe the results of testing the Polaris® valve,[3,4,6] two the proGAV® valve,[4,9] and one the Certas® valve.[7] To our knowledge, none of these reports directly compare all second-generation valves under similar conditions, or include testing with valves in the three most common positions used clinically for shunt placement. The goal of this study was to directly compare the effects of multiple 3T MRI exposures (a worst-case scenario) on the first- and second-generation EPS-valves under identical simulated clinical conditions.

MATERIALS AND METHODS

This study was conducted using a total of 15 new EPS-valves, 3 identical valves from each available product line [Table 1]. Studies were performed using a Signa HDx 450 3T MRI unit, Software 14M5a (General Electric Healthcare, Waukesha, Wisconsin). This study consisted of three parts: Part 1 of this study evaluated the effects of repeated exposure to a 3T MRI field typical for a standard MRI scan. Three matching shunt-valves were filled with sterile water and fixed to one side of a water-filled phantom head. The valves were placed in the three most common positions encountered clinically; midfrontal convexity, retroauricular, and occipital [Figure 1]. The phantom was then positioned on the MRI table with care to simulate the normal location of a patient's head for brain imaging [Figure 2]. The table was advanced into the magnet to the position normally used for performing a standard MRI of the brain. The phantom was left in position for 30 min (the average time for a typical non-contrast MRI scan with diffusion imaging); the MRI table was then withdrawn. The phantom head was removed from the table, and the shunt-valves were checked with both X-ray imaging and the manufacturers' shunt tools

Table 1: List of externally programmable shunt-valves

Valve	Locking mechanism (Y/N)	Manufacturer's information
Codman Medos®	N	Codman & Shurtleff, Inc., 325 Paramount Drive, Raynham, MA, USA
Medtronic Strata® NSC	N	Medtronic, Inc., 710 Medtronic Parkway, NE Minneapolis, MN, USA
Codman Certas®	Y	Codman & Shurtleff, Inc., 325 Paramount Drive, Raynham, MA, USA
Sophysa Polaris®	Y	Sophysa USA Inc., 760 West 16th St., bldg. N, Costa Mesa, CA, USA
Miethke proGAV®	Y	Aesculap AG, Am Aesculap-Platz, 78532 Tuttlingen, Germany

Figure 1: Photograph of fluid filled phantom demonstrating the locations of the left-side of the phantom used for placement of the shunt valves. These same positions were used on the right-side of the phantom [Used with permission from Barrow Neurological Institute]

Figure 2: Photograph demonstrating the imaging position used for the phantom whether the head coil was active or not [Used with permission from Barrow Neurological Institute]

to document the valve setting. After documenting the settings, the shunts were adjusted up or down one level, and the new settings were confirmed with both the manufacturers' shunt tools and X-ray imaging. The phantom head was returned to the MRI table and the entire process was repeated four times – two times with the valves on the left side, and two on the right.

Part II of the study evaluated the combined effects of the 3T magnetic field and the microwave radiation produced by the RF imaging coils on the shunt function. Two complete MRI scans were performed using the head coil and normal imaging sequences [Table 2], simulating a standard MRI of the brain without and with contrast. Three identical shunt-valves from each of the product lines were initially fixed to the left side of the phantom head [Figure 1]. The phantom head was positioned on the MRI table [Figure 2], and the table was advanced into the magnet to the position normally used for a standard MRI of the brain. After completing the normal precontrast imaging sequences [Table 2], the MRI table with the phantom head was completely withdrawn from the scanner to simulate the normal clinical routine for the administration of contrast. The phantom was then advanced back into the scanner for the final (post-contrast) T1-weighted coronal and axial scans. The phantom was withdrawn from the scanner, and the valves were evaluated with both X-ray imaging and the manufacturers' shunt tools to document the shunt settings. The shunt valves were adjusted up or down one level, and the new settings were confirmed by both X-ray imaging and the manufacturers' shunt tools. The valves were repositioned on the right side of the phantom, and the scanning and evaluation process were repeated.

In Part III of the study, one valve from each shunt line was used to evaluate the extent of MRI artifact it produced. Testing was carried out by performing MRI with the valves placed inside of a gadolinium-doped, saline-filled plastic phantom (measuring 14 cm diameter × 16 cm depth) following aspects of the American Society for Testing Materials (ASTM) International Designation. The shunt-valves were secured to a nylon mesh frame to facilitate positioning and imaging within this phantom [Figure 3]. MR imaging was performed using the same 3T Signa HDx system as documented above, using the following two pulse sequences:

T1-weighted, spin echo pulse sequence; repetition time = 500 ms; echo time = 20 ms; matrix size, 256 × 256; section thickness, 10 mm; field of view 24 cm; number of excitations, 1.

Gradient-recalled echo (GRE) pulse sequence; repetition time = 100 ms; echo time = 15 ms; flip angle = 30°; matrix size, 256 × 256; section thickness, 10 mm; field of view 24 cm; number of excitations, 1.

These are two commonly used pulse sequences in MR imaging with the T1-weighted sequence producing the least, and the GRE sequence producing the greatest metallic induced artifact. The valves were placed with their long axis in the vertical plane, and axial and coronal images were obtained. Final image locations were selected from multiple "scout" MR images to represent the largest, or worst-case, artifacts for each valve. The planimetry software provided with the MR system was used to measure the cross-sectional areas for the artifacts [Figure 4]. The accuracy of these measurements is ±10%. All artifact measurements were made by an observer blinded to the valve types.

RESULTS

The results for Part I (four 30 min exposures to 3T

Table 2: Details of the imaging parameters used in Part II of the protocol

Sequence no	Imaging parameters	Scan timing	Scanning range	Acquisition timing
1	3-PLocalizer Coil = 8HRBRAIN Seq = Gradient Echo Plane = 3-PLANE Mode = 2D Ph-FOV = 1.00 Img-Opt = Seq, Fast		FOV = 24.0 Sl-Th = 5.0 Space = 1.5	Freq = 256 Phase = 128 NEX = 1.00 Ph-FOV = 1.00 F-Dir = Unswap Cont = No Ph-Corr = No
2	ASSET cal Coil = 8HRBRAIN Seq = Gradient Echo Plan = AXIAL Mode = 2D IMG-Opt = Fast, Calib		FOV = 30.0 Sl-Th = 6.0 Space = 0.0 Slices = 20	F-Dir = R/L Cont = No Ph-Corr = No
3	DWI ASSET Coil = 8HRBRAIN Seq = Spin Echo Plan = AXIAL Mode = 2D IMG-Opt = EPI, DIFF, Asset	TE = Minimum TR = 10000.0 Shots = 1	FOV = 24.0 Sl-Th = 5.0 Space = 0.0 Slices = 30	Freq = 128 Phase = 128 NEX = 1.00 Ph-FOV = 1.00 F-Dir = R/L Cont = No Ph-Corr = Yes
4	Sagittal T2 FSE Coil = 8HRBRAIN Seq = FSE-XL Plan = SAGITTAL Mode = 2D IMG-Opt = TRF, Fast	TE1 = 80.0 TR = 4117.0 ETL = 32 RBW = 62.5	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 17	Freq = 416 Phase = 288 NEX = 2.00 Ph-FOV = 1.00 F-Dir = S/I Cont = No Ph-Corr = Yes
5	Axial T2 Propeller Coil = 8HRBRAIN Seq = FSE-XL Plan = AXIAL Mode = 2D IMG-Opt = Fast	TE = 111.7 TR = 5000 ETL = 30 RBW = 30	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 20	Freq = 448 NEX = 1.50 Ph-FOV = 1.00 F-Dir = A/P Cont = No Ph-Corr = No
6	Axial T2 FLAIR Coil = 8HRBRAIN Seq = T2 flair Plan = OBLIQUE Mode = 2D IMG-Opt = TRF, Fast	TE1 = 150.0 TR = 9500.0 TI = 2250 RBW = 31.25	FOV = 24.0 Sl-Th = 5.0 Space = 0.0 Slices = 28	Freq = 352 Phase = 224 NEX = 1.00 F-Dir = A/P Cont = No Ph-Corr = No
7	Axial T1 SE Coil = 8HRBRAIN Seq = Spin Echo Plan = OBLIQUE Mode = 2D IMG-Opt = None	TE = Min Full TR = 550.0 RBW = 15.63	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 20	Freq = 352 Phase = 256 NEX = 1.00 Ph-FOV = 0.75 F-Dir = A/P Cont = No Ph-Corr = No
8	Coronal 2D T2*GRE Coil = 8HRBRAIN Seq = Gradient Echo Plan = OBLIQUE Mode = 2D IMG-Opt = FC	TE1 = 10.0 TE2 = 22.0 TR = 725.0 Flip = 25 RBW1 = 31.25 RBW2 = 31.25	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 24	Freq = 512 Phase = 192 NEX = 1.00 Ph-FOV = 0.75 F-Dir = S/I Cont = No Ph-Corr = No

Contd...

Table 2: Contd...

Sequence no	Imaging parameters	Scan timing	Scanning range	Acquisition timing
9	+C Sagittal T2 SE Coil = 8HRBRAIN Seq = Spin Echo Plan = SAGITTAL Mode = 2D IMG-Opt = EDR	TE1 = Min Full TR = 467.0 RBW = 15.63	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 17	Freq = 352 Phase = 256 NEX = 1.00 Ph-FOV = 0.75 F-Dir = S/I Cont = Yes Ph-Corr = No
10	+C Axial T1 SE Coil = 8HRBRAIN Seq = Spin Echo Plan = OBLIQUE Mode = 2D IMG-Opt = EDR	TE = Min Full TR = 550.0 RBW = 15.63	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 20	Freq = 352 Phase = 256 NEX = 1.00 Ph-FOV = 0.75 F-Dir = A/P Cont = Yes Ph-Corr = No
11	+C Coronal T1 SE Coil = 8HRBRAIN Seq = Spin Echo Plan = OBLIQUE Mode = 2D IMG-Opt = EDR	TE = Min Full TR = 650.0 RBW = 15.63	FOV = 24.0 Sl-Th = 5.0 Space = 2.5 Slices = 24	Freq = 352 Phase = 192 NEX = 1.00 Ph-FOV = 0.75 F-Dir = S/I Cont = Yes Ph-Corr = No

This is the imaging sequence used at the primary author's institution for standard MRI without and with contrast

Figure 3: Photograph demonstrating the artifact testing phantom with a shunt valve suspended in the center of the chamber for evaluation. During testing, the phantom is filled with gadolinium-doped saline [Used with permission from Barrow Neurological Institute]

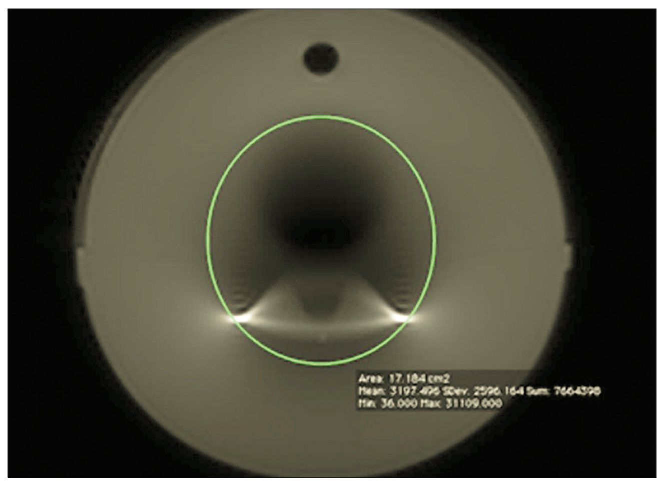

Figure 4: Sample image captured during evaluation for artifact testing; coronal T1-weighted, spin echo pulse sequence. Image locations for measurement were selected to represent the largest, or worse-case, artifacts for each valve [Used with permission from Barrow Neurological Institute]

magnetic field) and Part II (two complete MRI scans with full RF load) are presented in Tables 3–12. Repeated exposure of the first-generation EPS-valves to a 3T magnetic field without and with RF radiation resulted in frequent changes in the valve settings; however, all valves retained their ability to be reprogrammed [Tables 3, 4, 8 and 9]. Valve settings changed during 72% of the exposures of the Codman Medos® shunt-valves and during 83% of the exposures for the Medtronic Strata® valves. In contrast, the same exposures had no effect on the second-generation EPS-valves [Tables 5–7 and 10–12]. The Codman Certas®, Miethke proGAV®, and Sophysa Polaris® shunt valve settings remained unchanged, and the valves retained their ability to be interrogated and reprogrammed with the manufacturer's tools.

Artifact testing results are presented in Table 13. The shunt-valves all produced similar degrees of artifact with the exceptions that the Medtronic Strata® valve produced the greatest degree of artifact on the T1-weighted scans,

Table 3: Results of exposure of Codman Medos® valves to 3T magnetic field simulating four consecutive magnetic resonance imaging scans

3-Tesla exposure	Codman Medos® Valve ID	CM-A	CM-B	CM-C
1	Valve location	1L	2L	3L
	Initial valve setting	40	60	90
30 min[a]	Setting change? Y/N (PVS[†])	Y (50)	Y(50)	Y (70)
	Valve tool reads setting Correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1L	2L	3L
	New valve setting	30	70	110
30 min[a]	Setting change? Y/N (PVS[b])	Y (60)	N (70)	Y (100)
	Valve tool reads setting Correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y
3	Valve location	1R	2R	3R
	New valve setting	120	150	170
30 min[a]	Setting change? Y/N (PVS[b])	Y (130)	Y (170)	N (170)
	Valve tool reads setting Correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y
4	Valve location	1R	2R	3R
	New valve setting	110	170	190
30 min[a]	Setting change? Y/N (PVS[b])	Y (140)	N (170)	Y (180)
	Valve tool reads setting Correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y
	New setting	30	120	200

[a]Minutes, [b]Postexposure valve setting

Table 4: Results of exposure of Medtronic Strata® valves to 3-Tesla magnetic field simulating four consecutive magnetic resonance imaging scans

3-Tesla exposure	Medtronic Strata® Valve ID	MS-A	MS-B	MS-C
1	Valve location	1L	2L	3L
	Initial valve setting	0.5	1.5	2.5
30 min[a]	Setting change? Y/N (PVS[b])	Y (1.5)	N (1.5)	Y (2.0)
	Valve tool reads setting Correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1L	2L	3L
	New valve setting	0.5	1.0	2.0
30 min[a]	Setting change? Y/N (PVS[b])	Y (1.5)	N (1.0)	Y (2.5)
	Valve tool reads setting Correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
3	Valve location	1R	2R	3R
	New valve setting	0.5	1.5	2.0
30 min[a]	Setting change? Y/N (PVS[b])	Y (2.0)	Y (2.0)	N (2.0)
	Valve tool reads setting Correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
4	Valve location	1R	2R	3R
	New valve setting	0.5	1.5	2.5
30 min[a]	Setting change? Y/N (PVS[b])	Y (2.0)	Y (2.0)	Y (2.0)
	Valve tool reads setting Correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New setting	0.5	1.5	2.5

[a]Minutes, [b]Postexposure valve setting

and the Sophysa Polaris® valve produced the greatest artifact with the GRE pulse sequence.

DISCUSSION

While MR imaging has become the gold standard for the evaluation of numerous acute and chronic neurological conditions involving the brain and spine, it may present a risk to patients with EPS-valves. The permanent magnets used in these valves are potentially susceptible to damage when exposed to the strong magnetic fields used in MRI, particularly the high-field strength, 3T systems. Permanent magnets exhibit a characteristic called "coercivity", which is the ability of a material to withstand being demagnetized by the application of a stronger magnetic field.[5] Modern permanent magnet materials such as Sm–Co (samarium–cobalt) and Ni–Fe–B (nickel–iron–boron) that are used in these valves have high coercivity; however, with a strong enough magnetic field, or prolonged exposure, it is possible to demagnetize the magnet, or to lower its overall magnetic output ("knock it down"). In addition, the microwave radiation produced by the RF coils during imaging may result in heating of the metallic components of a shunt valve and could potentially damage the shunt mechanism. Such changes may affect the ability to interrogate or reprogram the shunt valve.

In this study, exposure of the first generation EPS-valves to a 3T magnet resulted in changes in pressure settings during 70–80% of simulated scans. Similar results have been reported by other investigators, and emphasize the importance of evaluating patients as soon as possible after an MRI scan to avoid problems from over- or underdrainage of CSF.[1,3,9] When MR imaging is being performed on an emergency basis in a patient with a CSF shunt (e.g. presentation with acute stroke symptoms), it is highly recommended that pre- and postimaging X-rays of the shunt-valve be obtained. This not only documents the type of shunt (fixed pressure or EP shunt-valve) and the preimaging setting, but helps ensure that the proper programming tools are available to interrogate and reprogram the valve if necessary.

In general, 3T MRI is not recommended in patients with

Table 5: Results of exposure of Codman Certas® valves to 3-Tesla magnetic field simulating four consecutive magnetic resonance imaging scans

3 Tesla exposure	Codman Certas® Valve ID	CC-A	CC-B	CC-C
1	Valve location	1L	2L	3L
	Initial valve setting	1	4	7
30 min[a]	setting change? Y/N (PVS[b])	N (1)	N (4)	N (7)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1L	2L	3L
	New valve etting	2	5	6
30 min[a]	Setting change? Y/N (PVS[b])	N (2)	N (5)	N (6)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
3	Valve location	1R	2R	3R
	New valve setting	1	4	7
30 min[a]	Setting change? Y/N (PVS[b])	N (1)	N (4)	N (7)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
4	Valve location	1R	2R	3R
	New valve setting	2	5	6
30 min[a]	Setting change? Y/N (PVS[b])	N (2)	N (5)	N (6)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New setting	1	4	7

[a]Minutes, [b]Postexposure valve setting

Table 6: Results of exposure of Meithke proGAV® (PG) shunt valve to 3-Tesla magnetic field of simulating four consecutive magnetic resonance imaging scans

3 Tesla exposure	Meithke proGAV® Valve ID	PG-A	PG-B	PG-C
1	Valve location	1L	2L	3L
	Initial valve setting	30	120	200
30 min[a]	Setting change? Y/N (PVS[b])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1L	2L	3L
	New valve setting	50	140	180
30 min[a]	Setting change? Y/N (PVS[b])	N (50)	N (140)	N (180)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
3	Valve location	1R	2R	3R
	New setting	30	120	200
30 min[a]	Setting change? Y/N (PVS[b])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
4	Valve location	1R	2R	3R
	New valve setting	50	140	180
30 min[a]	Setting change? Y/N (PVS[b])	N (50)	N (140)	N (180)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New setting	30	120	200

[a]Minutes, [b]Postexposure valve setting

the first generation programmable shunt-valves. There have been conflicting reports regarding the tolerance of these valves to exposure to a 3T magnetic field;[1,3,8] however, we found that even multiple exposures to a 3T magnetic field (consistent with six complete MRI scans in one day) has no detrimental effect on the programming mechanisms.

The results of this study confirm previous reports that second generation EPS-valves are compatible with high-field strength, 3T MRI systems.[1,3,4,6,7,9] In this protocol, we compared all three available second generation EPS-valves side-by-side. Repeated exposure of these valves to a 3T MRI field produced no effect on shunt settings, or the ability to reprogram the shunt valve. The shunt tools provided by the manufacturers allow these valves to be readily interrogated for the pressure setting. This feature eliminates the need for multiple X-rays pre- and post-MRI for valve assessment. Our findings confirmed the accuracy of these tools for valve assessment even after multiple exposures of the shunt-valve to a 3T MRI field. There was 100% correlation between the assessment tools and conventional X-ray imaging for valve settings.

As expected, the magnets used in EPS-valves all created significant metallic artifact during imaging.[4,10] Our testing revealed that on T1-weighted images the Miethke ProGAV valve produced the least area of artifact, while the Medtronic Strata® valve produced the greatest artifact on both axial and coronal images (mean, 32 cm) up to twice the size of the artifact produced by all other EPS-valves. On GRE pulse sequences, the Codman Medos valve produced the least artifact, while the Sophysa Polaris® valve produced the greatest artifact (mean, 73 cm^2) which was 35–70% greater than the other EPS-valves. The volume of metallic artifact may be an important issue when selecting a shunt-valve for a particular patient, particularly in those cases where intracranial pathology will require serial MRI scans for follow-up.

CONCLUSION

All second generation EPS-valves with locking

Table 7: Results of exposure of Sophysa Polaris® valves to 3-Tesla magnetic field simulating 4 consecutive magnetic resonance imaging scans

3 Tesla exposure	Sophysa Polaris® Valve ID	SP-A	SP-B	SP-C
1	Valve location	1L	2L	3L
	Initial valve setting	30	120	200
30 min[a]	Setting change? Y/N (PVS[b])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1L	2L	3L
	New valve setting	70	150	110
30 min[a]	Setting change? Y/N (PVS[b])	N (70)	N (150)	N (110)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
3	Valve location	1R	2R	3R
	New valve setting	30	120	200
30 min[a]	Setting change? Y/N (PVS[b])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
4	Valve location	1R	2R	3R
	New valve setting	70	150	110
30 min[a]	Setting change? Y/N (PVS[b])	N (70)	N (150)	N (110)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New setting	30	120	200

[a]Minutes, [b]Postexposure valve setting

Table 8: Exposure of Codman Medos® Valves to 3-Tesla magnetic field and RF coil energy simulating two consecutive magnetic resonance imaging scans (without and with contrast)

MRI	Codman Medos® Valve ID	CM-A	CM-B	CM-C
1	Valve location	1L	2L	3L
	Initial valve setting	40	60	90
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	Y (50)	Y(50)	Y (70)
	Valve tool reads setting correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1R	2R	3R
	Initial valve setting	30	120	200
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	Y (60)	N (120)	Y (170)
	Valve tool reads setting correctly? Y/N	NA	NA	NA
	Valve adjustable? Y/N	Y	Y	Y

[a]Postexposure valve setting

Table 9: Exposure of Medtronic Strata® Valves to 3-Tesla magnetic field and RF coil energy simulating two consecutive magnetic resonance imaging scans (without and with contrast)

MRI	Medtronic Strata® Valve ID	MS-A	MS-B	MS-C
1	Valve location	1L	2L	3L
	Initial valve setting	0.5	1.5	2.5
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	Y (2.0)	Y (1.0)	Y (2.0)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1R	2R	3R
	Initial valve setting	0.5	1.5	2.5
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	Y(1.5)	N(1.5)	Y (2.0)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New valve setting	0.5	2.0	1.0

[a]Postexposure valve setting

Table 10: Exposure of Codman Certas® valves to 3-Tesla magnetic field and RF coil energy simulating two consecutive magnetic resonance imaging scans (without and with contrast)

MRI	Codman Certas® Valve ID	CS-A	CS-B	CS-C
1	Valve location	1L	2L	3L
	Initial valve setting	1	4	7
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (1)	N (4)	N (7)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1R	2R	3R
	Initial valve setting	2	5	3
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (2)	N (5)	N (3)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New valve setting	1	1	1

[a]Postexposure valve setting

Table 11: Exposure of Meithke proGAV® valves to 3-Tesla magnetic field and RF coil energy simulating two consecutive magnetic resonance imaging scans (without and with contrast)

MRI	Meithke proGAV® Valve ID	PG-A	PG-B	PG-C
1	Valve location	1L	2L	3L
	Initial valve setting	30	120	200
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1R	2R	3R
	Initial valve setting	50	140	180
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (50)	N (140)	N (180)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New valve setting	30	120	200

[a]Postexposure valve setting

Table 12: Exposure of Sophysa Polaris® Valves to 3-Tesla field and RF coil energy simulating two consecutive magnetic resonance imaging scans (without and with contrast)

MRI	Sophysa Polaris® Valve ID	SP-A	SP-B	SP-C
1	Valve location	1L	2L	3L
	Initial valve setting	30	120	200
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (30)	N (120)	N (200)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
2	Valve location	1R	2R	3R
	Initial valve setting	70	150	110
	Precontrast MRI completed			
	Postcontrast MRI completed			
	Setting change? Y/N (PVS[a])	N (70)	N (150)	N (110)
	Valve tool reads setting correctly? Y/N	Y	Y	Y
	Valve adjustable? Y/N	Y	Y	Y
	New valve setting	30	120	200

[a]Postexposure valve setting

Table 13: Maximal area of metallic artifact (cm^2)

Shunt-valve	Codman Medos®	Medtronic Strata®	Codman Certas®	Miethke ProGAV®	Sophisa Polaris®
MRI[a] sequence					
AX T1 SE[b]	15.6	32.0	23.0	14.2	15.8
COR T1 SE[c]	17.1	32.0	10.3	17.3	20.0
Mean	16.3	32.0	16.7	15.8	17.9
AX T2 GRE[d]	47.7	59.0	55.0	50.0	83.0
COR T2 GRE[e]	38.5	49.0	50.0	39.6	63.0
Mean	43.1	54.0	52.5	44.8	73.0

[a]Magnetic resonance imaging, [b]Axial T1-weighted, spin echo pulse sequence, [c]Coronal T1-weighted, spin echo pulse sequence, [d]Axial gradient-recalled echo pulse sequence, [e]Coronal gradient-recalled echo pulse sequence

mechanisms safely tolerated repeated exposure to a 3T MRI field, without evidence of effect on shunt settings or programming function. Exposure of the first generation EPS-valves to 3T MRI results in frequent changes in valve settings that necessitate the re-evaluation of shunt patients soon after any MRI procedure; however, the shunt-valves maintained their ability to be readily reprogrammed.

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