J Neurosurg 96:331–334, 2002

Electromagnetic field hazards involving adjustable shunt valves in hydrocephalus

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Object. Standard therapy for hydrocephalus involves shunts and valves, which are frequently adjustable. Because of increasing "electromagnetic smog" (for example, that generated by cellular phones), these valves are often exposed to electromagnetic fields.

Methods. Various magnetic fields were tested for their effects on two different kinds of adjustable valves. The minimum magnetic flux density affecting the adjustment of the valve was determined. Results were compared with magnetic fields found in contemporary everyday life.

In homogeneous magnetic fields the adjustment of one valve (Sophysa model SM8) was changed at 5 mT, whereas the second valve (Codman Hakim model CM) was not affected. In nonhomogeneous fields the SM8 valve was affected at 25 mT and the CM valve at 15 mT. Thus, these valves may be affected by headphones and telephone receivers. Surroundings such as the Japanese magnetic suspension railway and the lead cabin of electrical railway engines, in which critical levels of magnetic flux may be present, may also affect adjustable valves. The high-frequency fields of cellular phones, however, have no effect on these valves.

Conclusions. Every surgeon who implants these valves and every patient who receives them should know the possible hazards. The valve selection should be adapted to the environment of the patient. Devices with critical levels of electromagnetic flux that are used in the homes of patients should be replaced by ones with lower magnetic fields. The future construction of these valves should be modified in such a way that their adjustment requires a higher magnetic flux density, so that the valves become less sensitive to unwanted effects from environmental magnetic fields.

KEY WORDS • **hydrocephalus** • **adjustable valve** • **cellular phone**

SINCE 1949 ventriculoperitoneal or ventriculoatrial shunt placement has become a routine procedure for the treatment of hydrocephalus,[7] in addition to alternatives such as third ventriculostomy. In these shunts a valve regulates the flow of cerebrospinal fluid. Since 1985, percutaneously adjustable valves have been used.[1,4,6,9,11] In principle, these valves are rotors that may be percutaneously adjusted using an external magnet or a special programming tool, which also works with magnetic fields. They can thus be adapted to the individual needs of the patient. An unwanted change in the valve setting could cause overdrainage or increased intracranial pressure, with serious effects.

Nowadays an increasing number of devices used in professional life as well as at home generate magnetic or electromagnetic fields. Theoretically, these may have an unwanted effect on adjustable valves. This study was initiated after we made some observations of malfunctioning shunts associated with unexplained changes in the valve adjustment. Additionally, we have been asked by patients if their valves could be affected by the use of cellular phones. We decided to examine systematically two types of adjustable valves for their susceptibility to electromagnetic fields common in everyday life. The purpose of this study was to determine the weakest magnetic field that could change the valve pressure setting.

Abbreviation used in this paper: B_{cr} = critical magnetic flux density; T = tesla.

Materials and Methods

We investigated two adjustable valves, the Codman Hakim programmable valve model CM (Johnson & Johnson, Inc., Raynham, MA) and the Sophysa model SM8 (Sophysa Co., Orsay, France). We tested the resistance of these valves in homogeneous and nonhomogeneous magnetic fields. Static, sinusoidal, and pulselike magnetic fields were investigated under homogeneous conditions. In each of the following experiments we looked for the minimum field strengths required to change the valve setting at least one pressure level.

The valves were placed in a homogeneous magnetic field within a coil with an iron core. The minimum magnetic flux density necessary to alter the pressure setting of the valve was registered. The valves were placed into the magnetic field 10 times. When no change in the valve setting was registered the flux density was increased in 1-mT steps. This procedure was repeated until a change in the valve setting was noticed in at least one instance, and the flux density was registered. For static magnetic fields the flux density was directly measured using a milliteslameter with a Hall probe. In time-dependent harmonic fields the flux density $\hat{B}$ was calculated

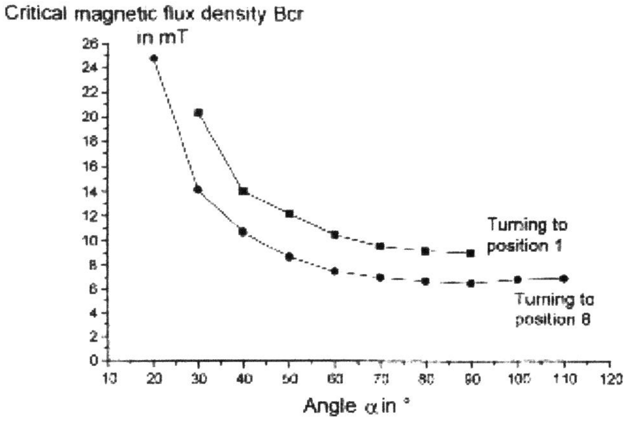

FIG. 1. Graph showing the B_{cr} in relation to angle α between valve and field direction in the SM8 valve and the dependence of B_{cr} on the direction of valve changing (position 1 = lowest pressure; position 8 = highest pressure).

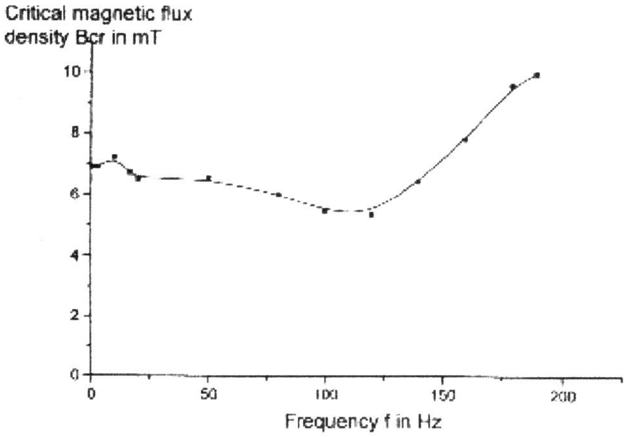

FIG. 2. Graph showing B_{cr} in relation to frequency f in the SM8 valve.

from the measured induced voltage Û in a special measurement coil (N turns), observing the cross-sectional area A of the coil and the frequency f, as shown in the following equation: $\hat{B} = \hat{U}/(2\pi fNA)$. The frequencies varied between 0.5 Hz and 200 Hz with special attention paid to the technical frequencies of 16.67 Hz and 50 Hz. In tests in which pulselike fields were examined the pulse duration varied between 1.3 msec and 500 msec.

The studies in homogeneous fields were done with regard to angles between the valve and magnetic flux directions and with regard to the change in the valve position compared with its former position. In nonhomogeneous fields the valve was positioned close to the pole of a strong permanent magnet and was then moved closer to the magnet in 1-mm steps, beginning at a distance of 20 mm. The measurement at each distance was repeated 10 times when the valve setting was unchanged. The distance at which the first change in the valve setting was noticed was registered, and for this distance a corresponding flux density was determined by a calibration curve.

After we determined the B_{cr}, these results were compared with known values in the literature about technical magnetic fields. Additionally, we determined the magnetic fields generated by devices present in a typical contemporary residence. Devices with magnetic fields of critical strength were tested by moving and shaking the valves while they were being exposed to the magnetic fields.

Furthermore, the magnetic fields of two cellular phones operating in the 900-MHz range (D-net) and the 1.8-GHz range (E-net) were tested for their ability to change the valve setting. The field strengths of these phones were measured by an electromagnetic field probe (EMR 300; Wandel & Goltermann Co., Eningen, Germany). After that, the phones were placed next to the valves, which were checked for a change in their pressure settings. This experiment was performed when the phone was set on low power (good receiving conditions) and when it was set on maximum power (extremely bad receiving conditions). Each experiment was repeated 10 times.

Results

Laboratory Data

The susceptibility of the SM8 valve to homogeneous, static magnetic fields depends on the initial pressure setting of the device. A change from pressure position 6 (positions ranged from 1, lowest pressure, to 8, highest pressure level) requires the lowest magnetic flux density. The B_{cr} also depends on the direction of the rotation of the mechanism within the valve; the lower flux density was required for rotations towards position 8. The most effective angle α between the magnetic field direction and the valve is an angle of 90°. The absolutely lowest flux density (critical magnetic flux density, worst case) required to cause a change in the valve pressure setting was found to be 6.5 mT. If the valve was shaken while it was exposed to the magnetic field, the B_{cr} could be lowered to 5 mT (Fig. 1).

The B_{cr} in sinusoidal magnetic fields was found to be related to frequency. The lowest critical effective field strength was 5.4 mT at a frequency of 120 Hz. The results of frequency dependence are shown in Fig. 2.

The B_{cr} significantly increased at frequencies higher than 200 Hz (see also results of effects of cellular phones). It should be mentioned that at frequencies higher than 10 Hz a loud noise or strong vibrations of the valve could be noticed as signs of a possible change in adjustment. This happened at field strengths just below B_{cr}.

The CM valve was not affected by the homogeneous, static magnetic field. Because it consists of 10 magnetic dipoles, the sum of the homogeneous field forces is zero. In 10 measurements at each valve position with magnetic flux densities up to 100 mT, we found that these levels did not cause a change in the valve setting.

In a nonhomogeneous, static magnetic field, which was detected in close vicinity to the poles of magnetic dipoles, the CM valve could be affected at a maximum distance of 10 mm, which means a minimum flux density of 15 mT is capable of changing the valve setting. The same minimum flux density was required when an electromagnet was used and the frequency dependence was tested. The frequency had no bearing on the B_{cr}. The minimum flux density was the same, no matter in which direction the valve setting was changed.

In this nonhomogeneous, static magnetic field, the SM8 valve was affected from within 6 mm of the magnet, which is equal to a minimum flux density of more than 35 mT.

Comparison With Common Environmental Magnetic Fields

The static magnetic fields of some household appliances were measured and the results are presented in Table 1. For all these items the main magnetic field source is a permanent magnet, for example, that found in a loudspeaker or in an earpiece. All appliances that can reach the B_{cr} are designated in Table 1, which shows that all of them could change

TABLE 1

*Examples of household appliances with static magnetic fields**

Device	Measured Flux Density (mT)	Effect on Valve Setting	
		SM8	CM
commercially available radio	2.3		
loudspeaker boxes (type PS22; Onkyo)	2.2		
loudspeaker kit	3.0		
Sony speakers	2.0		
TV set (type 25PT4403/00; Philips)	0.7		
TV set (type 37DT-25S; Sharp)	1.6		
headphone (type MDR 013, Sony)	14.0	unchanged	changed
Walkman earphone (WM-EX352, Sony)	23.0	unchanged	changed
earphone (unknown type)	7.0		
cellular telephone (S10D; Siemens)	17.5	unchanged	changed
attached-cord telephone (type profiset 20; Siemens)	0.0		
attached-cord telephone (type 551T25HD; Siemens)			
1st specimen			
at earpiece	1.8		
at mouthpiece	6.3		
2nd specimen			
at earpiece	4.7		
at mouthpiece	8.2		
comfort telephone (Sinus 43AB; Siemens)			
attached-cord receiver	8.5		
cordless hand apparatus	34.0	changed	changed

* The behavior of the valves in these magnetic fields was tested if the measured flux density was in the range of B_{cr}. Abbreviation: TV = television.

TABLE 2

Maximum values of low-frequency, sinusoidal magnetic fields in home, workplace, and public environments

Device/System/Vehicle	Frequency	Magnetic Flux Density (maximum)
electrical shaver, electrical cooker, table lamp	50 Hz	1 mT
TV, fan heater (30-cm distance)	50 Hz	0.4 mT
hair dryer (30-cm distance)	50 Hz	2.5 mT
other electrical appliances: washing machine, dryer, vacuum cleaner, storage space heater (30-cm distance)	50 Hz	100 μT
power distribution/transformer stations	50 Hz	0.5 mT
spot welding machines	50 Hz	2 mT (up to 130 mT)
induction heating systems	50 Hz to <10 kHz	4.5 mT (up to 130 mT)
soldering iron (30-cm distance)	50 Hz	2 mT
operational area of machine tools	50 Hz	0.1 mT
cab of electrical railway engines	16.67 Hz	up to 50 mT
beneath overhead power lines	50 Hz	200 μT
low voltage power transformer (30-cm distance)	50 Hz	4 to 40 μT
railway, 50 m distance from track	16.67 Hz	up to 0.6 μT
train compartment in local train	16.67 Hz	up to 13 μT
Washington, D.C., Metro	5–40 Hz	up to 60 μT

the adjustment of the CM valve, whereas the hand apparatus of a cordless phone was powerful enough to reset both valves.

The direction of the change in the valve pressure setting could not be predicted. It probably depends on the direction of the magnetic field lines, which is normally unknown in everyday life.

The magnetic flux densities of low-frequency sinusoidal fields in residential, workplace, and public life reported in the literature[2,5,8,10] are presented in Table 2. There are some appliances that create flux densities beyond the B_{cr}.

The cellular phones tested (two D-net devices) produced a maximum flux density of 0.36 μT. In the context of safety requirements for users, the German standard (DIN VDE 0848-2)[3] allows peak values of 9.4 μT (for f = 900 MHz, corresponding to D-net) and 13.4 μT (for f = 1.8 GHz, corresponding to E-net). These values represent no danger for patients with an implanted valve (Fig. 2). Accordingly, no change in the valves' adjustment could be achieved in our investigation by cellular phones of the C-, D-, or E-net types.

Discussion

The study reported here is confined to laboratory findings in ex vivo valves. The effect of magnetic fields on implanted valves has not yet been investigated.

The purpose of this study was to identify the weakest magnetic field capable of changing the valve pressure setting. This weakest magnetic field was considered a threshold; patients with these valves should only be exposed to magnetic fields of lower strength. Of course, our results were not evaluated statistically. Our tests do not permit us to predict which magnetic field would have a 50% likelihood of affecting the valve setting.

Because only one valve from each manufacturer was examined, variability in the susceptibility of different specimens of the same type of valves to magnetic fields cannot be ruled out. Our experiments do not quantify which magnetic fields may change the valve pressure setting by more than one level, because repeated exposures to the weakest effective magnetic field may still lead to marked changes in valve pressure settings.

Patients frequently ask whether a cellular phone could have an effect on the pressure setting of the valve. This can be definitively denied based on the results of our study. Only the permanent magnet in the loudspeaker of a telephone can influence the valve in individual cases. This could also happen with either conventional, attached-cord, or cordless telephones. Similar effects could be expected from permanent magnets in headphones or earphones. For the safety of patients with implanted adjustable valves, only the use of devices containing a piezoelectrical loudspeaker, which has no significant magnetic field, can be recommended.

Any permanent magnet in the household and in the workplace (for example, magnets for whiteboards) may represent a potential hazard for patients with adjustable valves and should not be used in the vicinity of people with these valves.

In the household the possibility of affecting the valve exists when a hair dryer is used within 30 cm of the shunt. No difficulties are to be expected near television sets, computer monitors, or stereo loudspeakers.

There are no critical magnetic fields associated with public transportation vehicles except for the Japanese magnetic suspension railway, for which the magnetic flux densities in the cabin are significantly higher than the critical value.

Just as in patients with pacemakers, conveyance by these vehicles should not be permitted for patients with an adjustable valve. On the other hand the German magnetic suspension railway "Transrapid" is not dangerous for these patients, because it has a much lower magnetic field strength.

Workplace exposure of patients with adjustable valves should also be avoided in specific areas with a strong static magnetic field. In particular, this would involve electrolytic systems, superconducting magnets, and energy storage units, and of course, magnetic resonance examination rooms. In terms of low-frequency magnetic fields, welding devices and induction heating systems should be regarded as potential hazards. Interestingly, the critical value of flux density for patients with an adjustable valve could be found in the cockpit of an electrical railway engine.

If the professional situation of a patient were to be considered before shunt implantation, the valve model can be selected according to the needs of the individual. The CM valve is not affected by homogeneous magnetic fields. In nonhomogeneous magnetic fields the SM8 valve (critical flux density 35 mT) is more stable than the CM valve (B_c 15 mT).

In future designs for such valves, higher magnetic flux densities should be considered for their adjustment. This would minimize the risk of an unwanted change in the pressure level by exposure to low magnetic fields in everyday life.

Conclusions

The pressure level of adjustable valves can be changed inadvertently by electromagnetic fields present in everyday life. Recipients of these valves and their physicians should be aware of these hazards. Critical devices in the patients' households should be replaced by less magnetic ones. The use of cellular phones has no effect on the adjustment of the valve. The two kinds of valves tested show different susceptibilities to different magnetic fields. The choice of a valve should be adapted to the workplace environment of the patient. As a safeguard, future valve designs should be constructed in such a way that they require higher magnetic flux densities for their readjustment.

Disclosure

The authors have no financial interest in any company or dealer engaged in the production or distribution of shunting devices.

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Manuscript received November 27, 2000.
Accepted in final form October 2, 2001.
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