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Possible effects of dielectrophoretic fields in the brains of MRI operators and MS patients: a radiologically isolated syndrome evaluation

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Abstract: Frequent use of magnetic resonance imaging (MRI) devices, which are major contributors in understanding health problems in the human body, is a subject that needs to be taken into consideration both for patients and for operators who are constantly in the vicinity of devices. In this context, electromagnetic impact assessment of an MRI device was performed at the point where the patient entered the device. Dielectrophoretic fields induced by radio frequency (RF) coils of an MRI scanner on male and female operator brain models were computed by using dispersive electrical medium parameters. The main cause of induced secondary dielectrophoretic fields by the RF coils of the MRI scanner is the veins modelled as monopole antennas on the lateral ventricle. The results explain that the dielectrophoretic fields near the veins on the ependymal surfaces are the main cause of Dawson fingers that may develop in the brains of multiple sclerosis (MS) patients and people at risk of the disease. Due to the use of the phantom results and the dispersive values of the electrical medium parameters, the results can be said to be close to the actual values and reliable. Therefore, the study will contribute to the confirmation of the hypotheses, developed by the author from a different perspective, related to the etiology of MS and will provide an accurate understanding of the concept of radiologically isolated syndrome. Everyone, including MRI designers, neurologists, radiologists, operators, and MS patients, can find any of the original information about MS that they need.

Key words: Multiple sclerosis, dielectrophoretic force, Dawson fingers, MRI, radiologically isolated syndrome, MRI operators, etiology

1. Introduction

Increasing use of MRI devices, which play a significant role in the diagnosis of MS and other diseases, has brought concerns as well as the new conveniences for patients and device operators. Although the subjects of concern may bring disadvantages to MS patients and MRI technicians, the MRI scanners have made positive contributions to the understanding of multiple sclerosis (MS) [1]. The Dawson fingers (DFs), which were first observed by neuropathologist James Walker Dawson, were assessed by many neurologists and researchers interested in MS. Thus far, DF formations have been thought to occur as a result of pressure differences in the Virchow–Robin spaces and inflammation or mechanical damage around the blood vessels caused by gaps. Although the lesion–vein relationship has been known for many years as a result of postmortem studies, this connection has not been demonstrated with in vivo experiments [2]. An exact approach for real specific tests for MS has not been given either. The author's hypotheses put forth scientific evidence about the etiology of MS, and their accuracy has been assessed within the 12 different approaches [3, 4]. Taking into account the

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author's hypotheses, this study explains the main cause of DFs and also shows that MRI equipment can lead to occupational health problems for MRI operators. In this way, recommendations for the conscious use of MRI instruments will be provided. In one study, it was shown that radiologically isolated syndrome (RIS) and MS may be formed by dielectrophoretic force effects in the brain and spinal cord [1]. The study showed that the RIS is an accelerated form of MS, that is, RIS is an event of displacement of myelin basic proteins (MBPs) and nerves with contribution from the intensive dielectrophoretic force of some MRI scanners. In fact, it has been shown that the identification of such a syndrome is not correct [1]. Some locations in a human brain are more suitable for plaque formations in MS than others. However, the collection of MBPs occurs so slowly that it takes a significant amount of time to observe symptoms in daily life. No one can expect to observe the long-term formation mechanism of MS. However, if the brain of a patient or an MRI operator is frequently located inside or near an MRI scanner, an acceleration of the collection and movement of the aforementioned plaques, and a temporary displacement of neurons is possible. Similar syndromes can be created in any person with or without MS. This syndrome is an artificial one that is created by the MRI scanner. For this reason, it is meaningless to call this event RIS and to present it as a complicated phenomenon. When the author's hypotheses on the etiology of MS are examined [1, 3, 4], it may be possible to evaluate this study objectively.

2. Statement of the problem

Let us consider the electromagnetic waves coming into a human brain from an electromagnetic field (EMF) source. Figure 1 shows a human brain under the influence of the electromagnetic field generated by any external EMF source. These EMF sources can be either natural EMF sources, such as lightning, or artificial EMF sources such as, MRI scanners, mobile phones, and base stations.

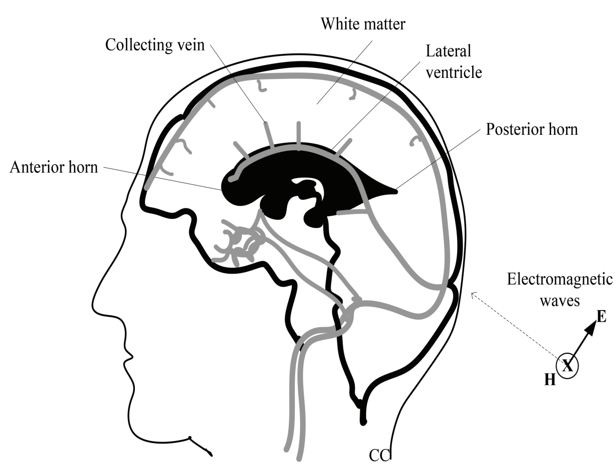

Figure 1. Schematic representation of the veins over the lateral ventricle.

The sagittal, axial flair MRI images of the typical high-signal fingers extending perpendicular to the ependymal surface can be seen in most studies [5].

The aim here is to determine the properties of dielectrophoretic force occurring around the large periventricular collecting veins as a result of the secondary EMF source. The bilateral ventricles are full of cerebrospinal fluid (CSF), and the periventricular veins are settled perpendicular to the bilateral ventricles without touching the CSF. The veins have a special form in white matter; they may be considered as short vertical monopole

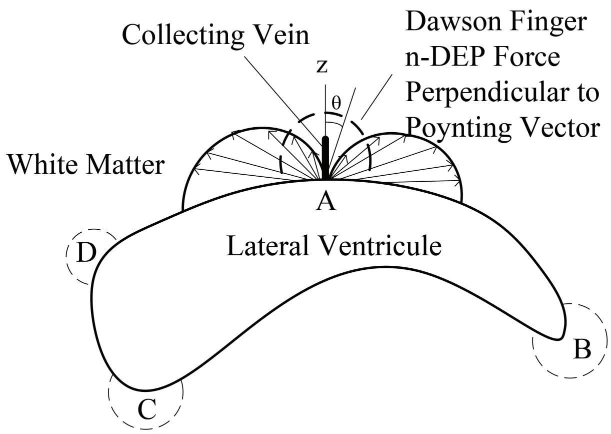

Figure 2. Schematic representation of the possible locations of Dawson finger-like formations.

antennas on the lateral ventricles, as shown in Figure 2. For simplicity, the lateral ventricles are assumed to be on a half-space plane including CSF (taking into account the volume of CSF). The problem is transformed to the short monopole antenna, located over the CSF half-space within white matter. The EMF of the ideal dipole operating as the receiver antenna system in white matter can be modelled by using the image theory and subsequently solved. Taking into account Equations 1 and 2 and the dispersive constitutive relations (Equations 3 and 4), the EMF of this dipole antenna can be computed. In the calculation on an electromagnetic model of a physical event, if the dispersive electrical medium parameters are taken into account in accordance with the dispersion rules, the calculation results will be very close to the results of the experiment. In this case, the computed results comply with the experimental results. It is evident that the total electric field at any point in white matter is equal to the sum of the primary electric field (E_p) and the secondary electric field (E_s). Here E_p is formed by the external EMF source in the white matter, and E_s is formed by the induced current on the veins in the white matter by the external EMF source.

MRI scanners create RF pulses up to 300 MHz, such as 1T: 42.6 MHz, 1.5T: 63.9 MHz, 3T: 126.8 MHz, 4T: 170.4 MHz, and 7T: 298.2 MHz, which are required for the hydrogen nuclei to resonate. In the literature, MRI applications at higher frequencies, which provide high-quality images, have been studied [6]. According to the author's findings, the dielectric constants of white matter, gray matter, and CSF are equal to each other at a frequency of 126 MHz [1]; therefore, a 3T MRI scanner should be selected to diagnose MS in the brain. This information is important for neurologists, radiologists, and MRI operators. Otherwise, incorrect assessments can be made. During MRI scans of the brain, some researchers have experienced that 3T MRI scanners give better results compared to MRI scanners that operate at other frequencies [7]. The range of frequencies of the excitation pulse and the magnitude of the gradient field determine the width of the image slice. The pulse generator of an MRI scanner produces an output signal with a relatively narrow ± 1 kHz bandwidth. In general, an excitation pulse can be assumed to be an asymmetric signal. Asymmetric EMFs are problematic both in terms of their negative contribution to plaque formations and difficulties in their calculation. Sinusoidal EMFs are used as stimulants in MRI applications and are advantageous in standard exposure evaluations. In the computations, the RF signals are assumed to be sinusoidal signals. If a sinusoidal excitation on the RF windings in MRI scanners may cause problems in terms of the formation of MS, in case of taking the pulses stimulation (producing asymmetric EMFs), it is clear that more problems could occur. In this context, the computational results are generated in the case of working as an operator near an MRI scanner. However, RF coils induce more EMF for patients who are inside MRI scanners. When patients inside MRI scanners are considered, the dielectrophoretic force is more effective. The induced EMFs in (or on) the anatomically equivalent models of the whole bodies of male (NORMAN) and female (NAOMI) MRI workers have been calculated using the average values of induced current density by the method of finite difference time domain [8, 9]. As a result of the analytical derivations from the Maxwell and Helmholtz equations, the secondary complete magnetic and electric field intensity vectors of any electromagnetic field source in a lossy and dispersive medium can be determined (Equations 1 and 2). Let us consider the lateral ventricle and the veins, which are located in an upright position to the lateral ventricle. This system is located in the white matter. The conductivities of the blood within the veins and the CSF within the lateral ventricle, at the operating frequencies of the MRI scanner are found from the Cole–Cole dispersion equation (3). This system behaves like a monopole antenna placed on the more conductive CSF medium and can be assumed to be a dipole, along with image of the vein. In other words, the problem is transformed into the finding of EMF of dipole working in white matter due to electric field intensity (determined by the phantom study [8]). Equation (2) was calculated by using the Cole–Cole dispersion formula (3) by the Mathcad program.

$$\mathbf{H}_s = \frac{\widetilde{I}\,\Delta z}{4\,\pi}\left(\frac{\gamma}{R} + \frac{1}{R^2}\right) e^{-\gamma R}\, sin\theta\, \widehat{a_\phi}\ (A/m), \tag{1}$$

$$\mathbf{E}_s = \frac{\widetilde{I}\,\Delta z}{4\,\pi}\, j\,\omega\,\mu_0\left(1 + \frac{1}{\gamma\,R} + \frac{1}{(\gamma\,R)^2}\right)\frac{e^{-\gamma R}}{R}\sin\theta\,\widehat{a_\theta} + \frac{\widetilde{I}\,\Delta z}{2\,\pi}\, j\,\omega\,\mu_0\left(\frac{1}{\gamma\,R} + \frac{1}{(\gamma\,R)^2}\right)\frac{e^{-\gamma R}}{R}\cos\theta\,\widehat{a_R}\ (V/m), \tag{2}$$

where σ is the conductivity of the medium at low frequencies, ω is the angular frequency, ϵ is the dispersive dielectric permittivity and can be expanded as $\epsilon = \epsilon' - j\,\epsilon''$, ϵ' is the real part of the dielectric permittivity of the medium and ϵ'' is the imaginary part of the dielectric permittivity of the medium, μ_0 is the permeability of the free space, $\gamma = j\,\beta N$ is the propagation coefficient of the medium, $\widetilde{I} = I_0\, e^{j\omega t}$ is the time-harmonic current, R is the distance between the source and field points, and N is the refractive index of the medium and can be written in terms of the dispersive medium parameters, θ is the angle between z direction and position vector of observation point, Δz is the antenna length, j is the unit complex number, β is the phase constant, ϵ_∞ is the relative dielectric permittivity at high frequencies, τ is the time constant, α is the exponent parameter, which takes a value between 0 and 1.

$$N(f) = \sqrt{\epsilon_r' - j\,\epsilon_r'' - j\frac{\sigma}{\omega\,\epsilon_0}}, \tag{3}$$

$$\epsilon_r(f)_{disp.} = \epsilon_\infty + \sum_{n=1}^{4}\frac{\Delta\,\epsilon_n}{1 + (j\,\omega_n\,\tau_n)^{\alpha_n}}. \tag{4}$$

The total induced currents on the collecting veins in the brains of NORMAN and NAOMI, sourced by the gradient coils and three types of magnet, have been determined respectively, as shown in Tables 1 and 2.

As shown in Table 3, by use of Equation 2, the secondary induced electric field intensities at a point P (R = 5 mm, $\theta = 90^0$) near the vein on the ephendymal surface was calculated for NORMAN and NAOMI's brains. In the computation of the secondary induced electric field intensities, the dispersive values of the electrical

Table 1. Induced currents on the collecting veins in the brain of NORMAN (A) where r = 0.3 m and z = 0 m for 1.5T, 4T, 7T MRI scanners.

Secondary induced currents in the male brain (A) r = 0.3 m, z = 0 m NORMAN Gradients + Magnet			
	1.5T	4T	7T
Collecting veins $I_{avg}(\mu A)$	9.72614	10.114725	10.241
$E_p(mV/m)$ in brain [8]	542.83	614.62	674.88
$J_{avg}(mA/m^2)$	49.56	51.54	53.2
$\sigma(WM),(S/m)(NORMAN, NAOMI)$	0.225	0.292	0.340
$\sigma(GM)(NORMAN, NAOMI)$	0.188	0.203	0.217
$\sigma(CSF)(NORMAN, NAOMI)$	2.065	2.171	2.216

Table 2. Induced currents on the collecting veins in the brain of NAOMI (A) where r = 0.3 m and z = 0 m for 1.5T, 4T, 7T MRI scanners.

Induced currents in the female brain (A), r = 0.3 m, z = 0 m NAOMI Gradients + Magnet			
	1.5T	4T	7T
Collecting veins $I_{avg}(\mu A)$	0.81149375	0.845641	0.87292
$E_p(mV/m)$ in brain [8]	442.10	505.43	547.65
$J_{avg}(mA/m^2)$	41.35	43.09	44.48

Table 3. Secondary induced electric field intensity (mV/m) in the brains of NORMAN and NAOMI computed by equation Equation 2.

Secondary induced electric field intensity (mV/m) in the brains of NORMAN and NAOMI (R=5 mm, $\theta = 90^0$)			
	1.5T	4T	7T
$E_s(mV/m)(NORMAN)$	158.1	100.6	69.7
$E_s(mV/m)(NAOMI))$	131.9	84.1	59.5

parameters of white matter was considered. When the θ angle approaches zero, the amplitude of secondary induced electric field gradually converges to zero. Therefore, a suitable dielectrophoretic force field occurs; this field is effective on the myelin groups around the vein and will also displace them. At the same time, these kinds of dielectrophoretic force fields may occur around the wedge-shaped points B, C, and D on lateral ventricles. These assessments are also valid for the similar situations in the brain and spinal cord. Nerve cells resembling rosary made from myelin sheath containing 80% fat are found branched in different directions in the brain. If a human brain is stimulated by an EMF, the nerve cells move locally to the places where the gradient of the square of the electric field is minimal. These cases were encountered after the MRI applications, especially in MS patients and people vulnerable to the disease. The movement of nerve cells is similar to the movement of the starlings cluster (MOSC). In order to understand the motion directions of nerve cells, it is necessary to investigate the change of CM factor with respect to frequency. These outcomes supporting the author's hypotheses [1, 3, 4] are in agreement with the change of CM factor with respect to frequency in the case of the MBP particles located within two different media, such as white matter and grey matter [4]. Briefly, MBP or nerve cells will move towards the places where electric field intensity decreases. Moreover, these events are independent of the origin of the EMF source. The origin of the EMF source can be both natural and artificial. Here, the important thing is the electric field intensity of the EMF source. Even in the absence of any artificial EMF source, under suitable conditions, susceptibility to the MS disease or MS itself can be seen [1, 3, 4]. As shown in the experimental results of the studies [10], the fetal nerve cells accepted as dielectric particles were collected within the electric fields with gradients in a short time. In one study, it can be seen that cytokine-like formations were obtained experimentally under the influence of a dielectrophoretic force [11]. Similarly, groups of nerve cells sequenced side by side in the white matter tend to move towards the appropriate locations depending on the properties of the dielectrophoretic force distribution in the white matter. That is why DFs seem oval in appearance around the veins.

3. Conclusion

When an electromagnetic field is applied to a human brain, the neurons take position according to the negative dielectrophoretic force conditions (as seen in MOSC and neurofibrillary tangle) depending on the electrical parameters of the human brain. The mechanism of formation of dielectrophoretic force fields and its relevance to MS disease have been given for the first time in science world in the author's study [3]. To date, there has been no experimental study showing that the main cause of Dawson's fingers directly is DEP. However, the results of the experimental study by the author and his colleagues showing that cytokine-like formations were formed by DEP forces may be sufficient to explain this relationship. In this experiment, DEP force generated by the electric Hertz dipole in the T cell models resulted in matter accumulations. The results can be seen clearly in the study [11]. The relationship between live tissues and MS is tried to be understood by numerous experiments using mice. Although numerous experiments were conducted on this issue, the relationship between living organisms and MS was not understood. In one of the author's studies [12], the author wrote that "If the researchers could look at the etiology of MS disease from the perspective of my theory, they could explain the etiology of MS". The activity of nerve cells and the spatial change of this activity can be changed by the DEP force at a very small amount. The current flowing through the synapse in the nerve cells is $I_{synapse} = 1\ nA$, whereas the current induced by MRI in the brain is around $I_{ind.} = 10\ \mu A$. The neurons with mass loss, as compared to healthy neurons, ensure easy compliance with negative dielectrophoretic force fields. In patients with MS and people who are vulnerable to the disease, the amount of myelin loss or mass loss is also higher. The formations in the form of MOSC and neurofibrillary tangle identified as DFs in MRI scans may be seen, especially in MS patients and people who are vulnerable to the disease. In light of the author's hypothesis, the choice of the operating frequency of MRI scanners for MS diagnosis is very important. It can be deduced from the author's hypotheses that these formations can be easily detected by 3T MRI scanners. For healthcare professionals and technicians who are constantly working near MRI devices, keeping these facts in mind is very important for their health and performance. Due to developments in MRI scanner technology, and the author's hypotheses, the etiology of DFs become more comprehensible. Briefly, DFs point out the author's hypotheses about the etiology of MS. The existence of DF formations in the brains of some people is known. However, the occurrence mechanism of DFs has been misinterpreted in the literature. During and after brain MRI scans, these finger-shaped formations can occur in regions which have higher conductivities compared to those around them, such as ependymal surfaces, wedge-shaped discontinuities, areas near the blood vessels, and posterior and anterior horns. Unlike true DFs, these DF-like formations in the human brain cannot be explained by mechanical damage. The Canbay hypotheses can be used to identify possible places where the accumulation of plaque formations might begin. Furthermore, the main cause of DFs can be explained by contributions from the Canbay hypotheses.

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