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Review

Magnetic resonance imaging by using nano-magnetic particles

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ABSTRACT

Magnetism and magnetic materials play a major role in various biological applications, such as magnetic bioseparation, magnetic resonance imaging (MRI), hyperthermia treatment of cancer and drug delivery. Among these techniques, MRI is a powerful method not only for diagnostic radiology but also for therapeutic medicine that utilizes a magnetic field and radio waves. Recently, this technique has contributed greatly to the promotion of the human quality life. Thus, this paper presents a short review of the physical principles and recent advances of MRI, as well as providing a summary of the synthesis methods and properties of contrast agents, like different core materials and surfactants.

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1. Introduction

Among different biomedicine areas, magnetic resonance imaging (MRI) is regarded to be one of the most powerful diagnostic tools in medical science [1–6] due to the following advantages: the extreme imaging flexibility, the high patient acceptance, the capability to evaluate anatomic and physiologic parameters, as well as the acquisition of unique clinical information.

With the development of MRI, numerous researchers have attempted to design complementary imaging probes or contrast agents to improve the sensitivity and detectability of the tools [7–11]. Without the contrast agent, biological and functional information-rich images cannot be obtainable. Among different forms of probes, inorganic nanometer-sized colloidal particles have extensively been utilized in many imaging systems due to of their numerous useful electronic, optical, and magnetic properties. The nano-particle-based MRI contrast agents consist of three parts: (i) the core nano-particles, which generate the signal enhancement [12–14], (ii) the water-dispersible shells, which endow compatibility in the biological environment, and (iii) the bioactive materials for targeting purpose [15].

From the perspective of historical studies, the clinical MRI studies first appeared in 1979. The first commercial MRI scanner was produced in 1980. As early as 1985 magnets with a field strength of 1.5 T were available even for commercial clinical MR imaging systems. Between 1985 and 1995, much effort was made to develop faster gradient systems, and new sequence types became feasible using those gradient systems [16,17]. Unfortunately, the biological effects of nerve stimulation prevent a further increase in gradient slow rates for the whole-body examinations. The past few years were dominated by the development of multiple receiver coil systems, allowing for recording MRI data simultaneously from large body regions with high sensitivity. Recently, researchers have attempted to develop the parallel imaging to increase the speed and to decrease the imaging time which leads to lower patient throughput and further movement artifacts [16]. In recent years, the magnetic development has influenced the MRI system [17].

Considering the importance of the MRI technique in medical science and the investigations previously conducted in the field, this paper has provided a brief description of the history, physics of the MRI system and synthesis methods of nano-particles.

2. Principles of magnetic resonance imaging

MRI uses the differentiation between healthy and pathological tissues. It takes advantage of the magnetic properties of hydrogen atoms present in the body tissues, for example in water, membrane lipids and proteins [15–17]. It makes use of the magnetic properties of hydrogen and its interaction with both a large strong external magnetic field and radio waves to produce the highly detailed images of the human body. Hydrogen has a significant magnetic moment and has an abundance of about one hundred of percent in the human body. For the mentioned reasons, it simply uses the hydrogen proton in the routine clinical imaging. The type of magnets used for MR imaging usually belongs to one of the three types: permanent, resistive, and superconductive.

When the nuclei of protons are exposed to a strong magnetic field, their spins align in a parallel or antiparallel manner with the

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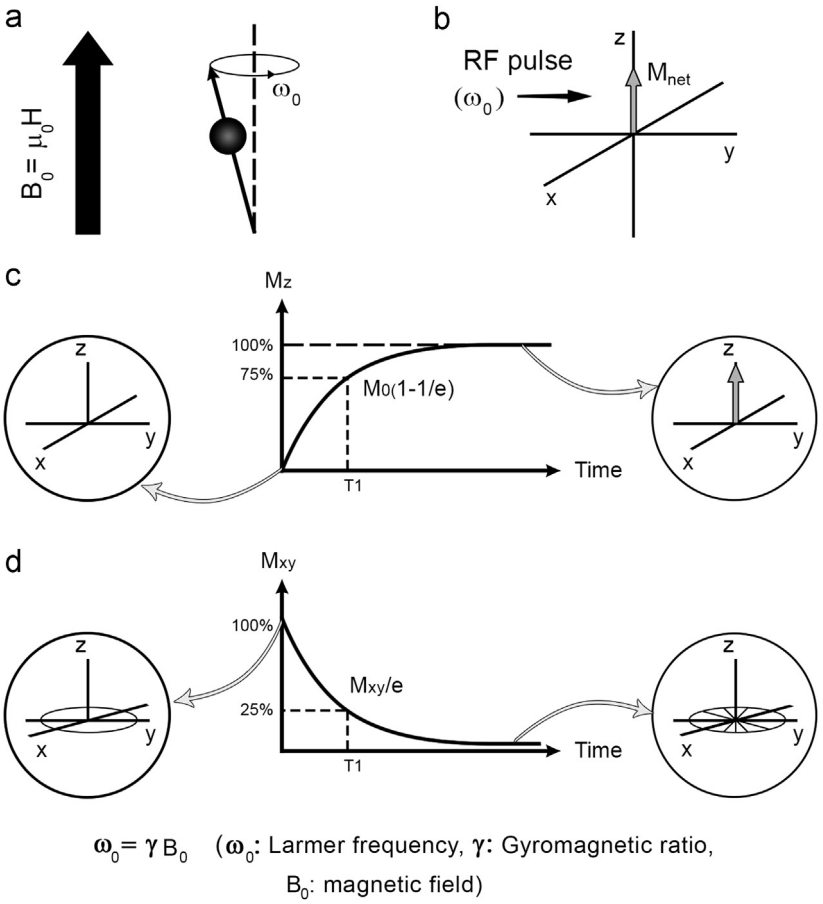

Fig. 1. Magnetic resonance imaging (a) spins align to the magnetic field and precess under Larmor frequency and (b) after induction of RF pulse, magnetization of spins changes. Spins take relaxation process of (c) T_1 relaxation and (d) T_2 relaxation (from Ref. [15]).

magnetic field. During their alignment, the spins precess under a specified frequency, which is known as the Larmor frequency (ω_0, Fig. 1a) [15]. When a resonance frequency in the radio-frequency range (RF = 15–60 MHz) is introduced to the nuclei by the radio frequency coil near the specimen (the static magnetic field), the protons absorb energy from the oscillating magnetic field and are excited to the higher energy state. When the alternating field is switched off, the nuclei return or relax to the equilibrium state, thereby emitting energy at the same frequency as previously absorbed (Fig. 1b) [15]. There are two different relaxation pathways. The first one, which is known as longitudinal or T_1 relaxation, involves the decreased net magnetization (M_z) recovering to the initial state (Fig. 1c) [15]. The second, transverse or T_2 relaxation, involves the induced magnetization on the perpendicular plane (M_{xy}) disappearing by the de-phasing of the spins (Fig. 1d) [15].

For high fields, the applied RF for the excitation of nuclear magnetization must be adapted, and the MR signal exhibits a higher frequency as well. The wavelength becomes shorter in the higher magnetic field. Table 1 depicts the field-dependent wavelengths in air and in water for H_1 and some other biologically important nuclei [18].

The Larmor frequency difference between nuclei with different chemical bonds increases linearly with the applied field. For example, the chemical shift difference between water signals and methylene signals (the dominating signals from fatty acids and triglycerides) amounts to roughly 220 Hz at 1.5 T, but is increased to 440 Hz at 3 T. The varying molecular structures and the amount of hydrogen in various tissues affect the way the protons behave in the external field. There are a large number of protons available (6.6×10^{19} in every mm^3 of water) in which the effective signal (2×10^{14} proton moments per mm^3) is observable [19–22].

Table 1
Radio frequency wavelength in air and in water for several biologically important nuclei at 1.5, 3 and 7 T (reproduced with permission from Ref. [18]).

Field strength (T)	Nucleus	Wavelength in air (cm)	Wavelength in water (cm)
1.5	^{1}H	470	52
	^{13}C	1870	210
	^{23}Na	1780	200
	^{31}P	1160	129
3.0	^{1}H	235	26
	^{13}C	940	105
	^{23}Na	890	100
	^{31}P	580	64
7.0	^{1}H	100	11
	^{13}C	400	45
	^{23}Na	380	42
	^{31}P	250	28

2.1. Static magnetic field

The static or main magnetic field is used to align the nuclei in the patient body even when the MRI scanner is not imaging. Several structures within humans including the retina, pineal gland, and some cells in the paranasal sinuses are affected by the static magnetic fields. The strengths of the static magnetic

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