Magnetic resonance imaging: Basic concepts and applications

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Magnetic resonance imaging (MRI) is a state-of-the-art imaging modality that has gained considerable attention in clinical medicine, particularly diagnostic radiology, because of its noninvasive nature and its sensitivity to the state of biological tissue. As an exquisite representation of the spatial distribution of mobile protons in the body, MRI presents the soft-tissue anatomical picture in any desired plane. This article reviews the historical development, the conceptual basics, and the diagnostic applications of various MRI techniques.

ABOUT half a century ago, two independent groups of American scientists led by Edward Purcell[1] (Harvard University) and Felix Bloch[2,3] (Stanford University, USA) discovered hydrogen (proton) nuclear magnetic resonance (NMR) in solids and liquids, respectively. These discoveries led to the joint award of the Nobel prize to Bloch and Purcell in 1952.

NMR was initially used for spectroscopy and chemical structure elucidation, and towards the late 1960s, its use was demonstrated to produce signals from a live animal[4]. Several other research teams, including those of Cooke[5], Hansen[6], and Hazlewood[7], began to publish further detailed studies on muscle in 1971. In the same year, observations on tissue specimens from animal tumours reported by Damadian[8] generated considerable interest in view of their medical diagnostic potential, and attempts by others to confirm and extend that work soon got underway, resulting in reports on rat hepatomas by Hollis and Saryan[9] and on a tumour in a living mouse by Weisman *et al.*[10] the following year.

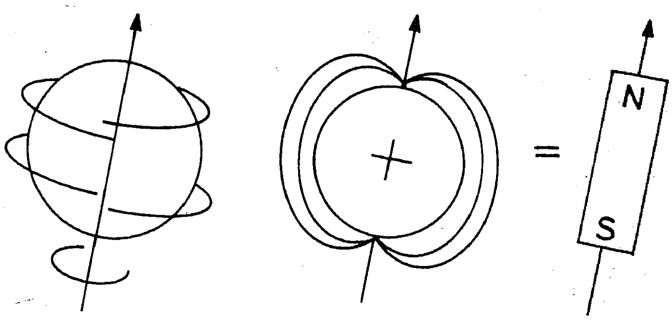
The concept of magnetic resonance (MR) image formation evolved in the early 1970s, when Lauterbur produced two-dimensional proton images of a water sample[11]. This work soon led to imaging of other objects such as oranges, lemons and red pepper, then live animals and ultimately humans[12,13]. MRI thus came into being as a safe, noninvasive diagnostic technique in biomedical research[14] and clinical practice[15].

The purpose of this article is to acquaint the practitioner of chemical and biological sciences with the fundamentals of this magnetic resonance method. Although a knowledge of quantum mechanics of spin particles, electromagnetic theory and radiofrequency electronics, and computational techniques is necessary for a deep and thorough understanding of MRI, in this article such topics have been deliberately circumvented in the interests of a clearer overview.

Basic phenomenon – magnetization

How does one manipulate tiny magnetic nuclei to obtain a three-dimensional image of the human organ? The first step is to magnetize the tissue.

The nucleus of hydrogen is not only positively charged but also has the inherent property of a 'spin' (Figure 1 *a*), and a spinning electric charge generates a magnetic field (Figure 1 *b*, *c*). The proton is therefore conceptualized as a spinning 'nuclear magnetic dipole' and depicted as a vector parallel to the axis of spin. In a neutral environment the billions of protons in bulk matter such as tissues, for example, have their magnetic moment vectors randomly oriented, averaging the nett bulk magnetization to zero. In the presence of an applied static magnetic field (B_0), however, these dipoles 'precess', or execute a wobbling motion delineating the surface of a cone, analogous to the familiar example of a spinning top wobbling in the earth's gravitational field.



a *b* *c*

Figure 1. *a*, The concept of nuclear 'spin'; *b* and *c*, The spinning nucleus viewed as a tiny magnet.

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