MAGNETIC RESONANCE IMAGING IN ORTHOPAEDIC DIAGNOSIS

Essay submitted to the Faculty of Medicine,
Ain-Shams University
In partial fulfilment of the requirements of

MASTER OF ORTHOPAEDICS

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1992

بسم الله الرحمن الرحيم

ACKNOWLEDGMENT

Praise to be done to ALLAH, most merciful and most compassionate, without his help nothing could be reached.

Words cannot adequately express the feelings of gratitude I have for all those who helped me to complete this work.

I would like to express my deepest gratitude and appreciation to Prof. Dr. Hussein El-Khateeb, Professor of Orthopaedics, Faculty of Medicine, Ain-Shams University for his fatherly encouragement, support and guidance throughout this work.

I am also greatly indebted and grateful to Dr. Hany Mamdouh Hefny Lecturer of Orthopaedics, Faculty of Medicine, Ain-Shams University, for his kind supervision, precious advice and alert enthusiasm in the fulfillment of this work.

بسم الله الرحمن الرحيم

INTRODUCTION

In reviewing the history of medical imaging, many investigators cite two major milestones, the first was the discovery By Roentgen of the X-ray at the end of the nineteenth century; the second was the elucidation of the phenomenon of magnetic resonance in 1946. Soon after the clinical introduction of magnetic resonance imaging in early 1980s, it rapidly gained widespread acceptance as an excellent imaging modality for the musculoskeletal system. Despite its lack of ability to directly visualize cortical bone and calcification, many factors combine to make magnetic resonance imaging (MRI) useful in the study of the musculoskeletal system; foremost, its reliance on the principles of magnetism rather than the use of ionizing radiation; the superior soft tissue resolution of MRI allows non-invasive visualization of many disease processes involving the bone marrow, joints and soft tissue structures, which in the past could not be imaged; the flexibility of imaging in multiple planes aids in determining the extent of given pathology.

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CHAPTER 1

BASIC PRINCIPLES

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SIGNAL INTENSITY OF MUSCULOSKELETAL TISSUES
MRI EQUIPMENT
POTENTIAL HAZARADS AND ARTIFACTS

PHYSICS

Magnetic Resonance Imaging (MRI) is a diagnostic technique based on the fact that certain nuclei, placed in a magnetic field and acted upon by a suitable radio-frequency pulse, undergo changes in their energy states which results in a measurable radio-signal. The first successful nuclear magnetic resonance (NMR) experiments were described by Black and Purcell independently in 1946.

Damadian and Lauterbur indicated the potential of NMR to obtain images of the intact human body in the early 1970s.

The nuclear part of NMR refers to the fact that atomic nuclei with an odd number of protons possess an intrinsic angular momentum or "spin" and generate a small magnetic field as it spin. Because of its natural abundance in the human body and its favorable magnetic properties, the hydrogen nucleus is currently used in MR imaging. Under normal circumstances, protons in the human body have a random orientation and their small magnetic fields cancel, leaving no net magnetization.

When such nuclei are placed in an external magnetic field they attempt to align with it. More nuclei align in the parallel (low energy state) than the anti-parallel (high energy state) orientation (Fig. 1). Therefore net magnetization is in the same direction of the external field. (Paushter DM et al, 1984)

It is important to understand that the magnetic moments do not align perfectly with the external field direction but they rotate about its axis, a phenomenon termed precession. These two motions of the proton are analogous to the movement of a child's spinning top which when spun on its own axis also wobbles around the earth's gravitational field. (Fig. 2)

This precessional frequency is the product of the strength of the external field "BO" and a constant "y" which is unique for each nuclear species, and it is called the Larmor frequency "WO"

$$WO = y\ BO$$

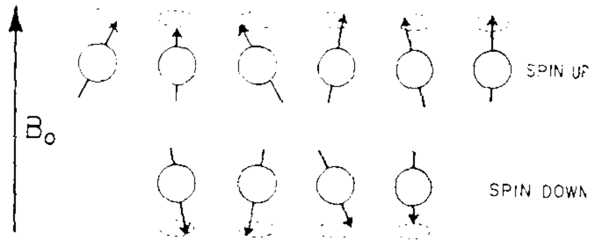

Fig. (1)

Net magnetization and precession

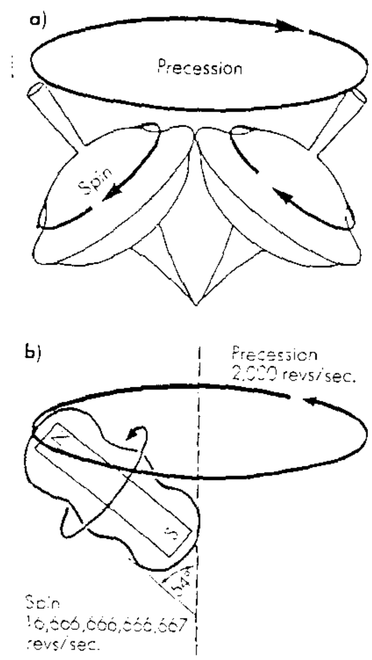

Fig. (2)

The concept of precession - in a spinning top (a) and in a proton (b)

The axes of a magnetic field classically are defined in a three dimensional coordinate system. The Z axis correspond to the axis of the applied external field. The Y and X axes are perpendicular to one another and define a plane perpendicular to the Z axis.

Once a material being tested has reached equilibrium within the applied field, the net magnetization vector of the protons is parallel to the Z axis. (Fig. 3)

A voltage change or signal can be created by tipping Z axis (longitudinal) magnetization into the XY (transverse) plane.

Transverse magnetization is induced by adding energy to the system in the form of radio-frequency (RF) pulse. This RF pulse is generated at the resonant frequency for the proton, as defined by the Larmor equation, and applied perpendicular to the Z axis. The amount to which the longitudinal magnetization is tipped out of the Z axis and into the transverse plane depends on the strength and duration of the applied RF pulse.

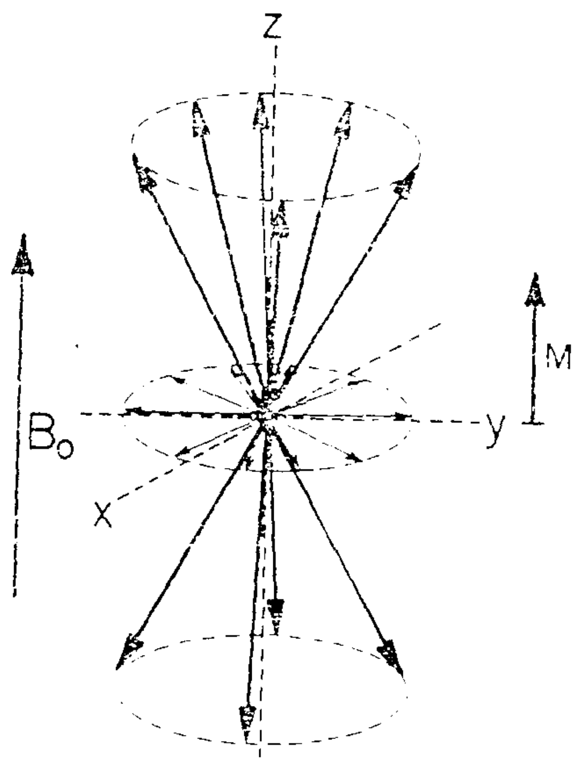

Fig. (3)

Three perpendicular axes (X, Y, and Z) define the coordinates of the external magnetic field. At equilibrium, there is a net longitudinal magnetization (M) oriented parallel to the direction of the external field (BO)

A 90 degree pulse is of sufficient strength and duration to rotate the longitudinal magnetization vector into the transverse plane. A 180 degree pulse rotates the magnetization vector into the opposite Z direction (Fig 4).

When the RF pulse is stopped, the system returns to equilibrium again with the magnetization vector precessing about the main field again by a complex motion. During return to equilibrium the magnetization vector precesses in the XY plane and describes a continuous spiral as the XY vector becomes a smaller (decay), and the Z vector gets larger. Resonance here refers to change in the energy states caused by absorption of specific radio-frequency. The resultant oscillation in the XY plane is detected as voltage changes in a receiver positioned in the XY plane (Paushter DM, et al, 1984).

The phenomenon of return to equilibrium is termed relaxation and is characterized by two simultaneous but independent time constants, T1 and T2.

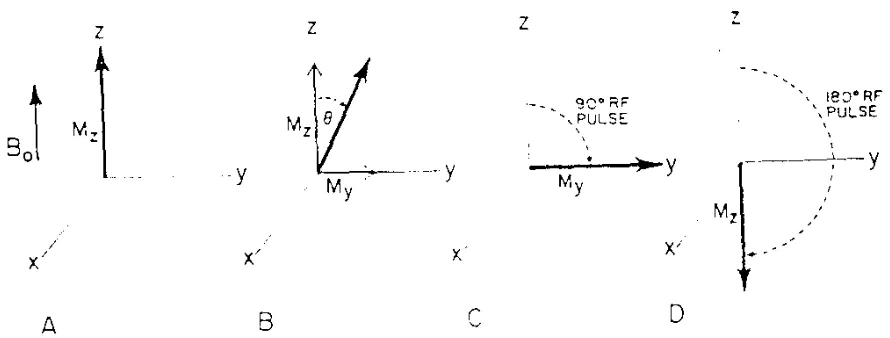

Fig. (4)

Transverse magnetization, 90 and 180 degree radio-frequency (RF) pulses.

A. At equilibrium in an external field (BO) there is net longitudinal magnetization (M_Z).

B. An RF pulse at the resonant frequency will tip the M_Z magnetization toward the transverse plane by a certain amount (O)

C. An RF pulse that tips longitudinal magnetization 90 degrees into the transverse plane is termed a 90 degree pulse.

D. A 180 degree pulse

T1 Relaxation :

(Longitudinal relaxation or spin-Lattic relaxation):

It is the time constant which describes how the magnetization returns to its original state of equilibrium. During return, the displaced nuclei lose the extra-energy they gained from the RF pulse to their local environment.

T2 Relaxation :

(Transverse relaxation or spin-spin relaxation) :

It is the time constant which describes how the spinning nuclei become out of phase with one another i.e. measure of the time required for spins that have been induced to rotate together in phase by the RF pulse to lose that coherent rotation. Therefore T2 reflects loss of transverse magnetization owing to interactions with adjacent nuclei and inhomogeneities in the applied field.

The way in which a specific nucleus is selected for study is related to the resonant frequency of the RF field being unique for that nucleus at a specified magnetic field strength. In the case of hydrogen the resonant frequency is 42.6 megahertz at 1.0 Tesla field strength.

[field strength is measured in tesla unit : T)