European Journal of Radiology 89 (2017) 7–13

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Safety issues and updates under MR environments

Soo Jung Kim, Kyung Ah Kim*

Department of Radiology, St. Vincent's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 22 September 2016
Received in revised form 11 January 2017
Accepted 13 January 2017

Keywords:
Magnetic resonance (MR)
Safety
Magnetic field
Biologic effects

ABSTRACT

Magnetic resonance (MR) imaging is a useful imaging tool with superior soft tissue contrast for diagnostic evaluation. The MR environments poses unique risks to patients and employees differently from ionizing radiation exposure originated from computed tomography and plain x-ray films. The technology associated with MR system has evolved continuously since its introduction in the late 1970s. MR systems have advanced with static magnetic fields, faster and stronger gradient magnetic fields and more powerful radiofrequency transmission coils. Higher field strengths of MR offers greater signal to noise capability and better spatial resolution, resulting in better visualization of anatomic detail, with a reduction in scan time. With the rapid evolution of technology associated with MR, we encounter new MR-related circumstances and unexpected dangerous conditions. A comprehensive update of our knowledge about MR safety is necessary to prevent MR-related accidents and to ensure safety for patients and staff associated with MR. This review presents an overview about MR-related safety issues and updates.

1. Introduction

Magnetic resonance (MR) imaging is a medical imaging tool used to provide anatomic and detailed diagnostic information with superior soft tissue contrast and no radiation hazard. Almost 36,000 MR scanners have been installed worldwide [1]. Strong static magnet and changing magnetic fields associated with gradients and radiofrequency (RF) pulses are needed for MR images production (Fig. 1). These magnetic powers may affect directly to substances under magnetic field provoking physical movement and mis-regulation of active devices. The power can also turn into different forms such as heat energy, neurostimulation, and acoustic noise etc. Continuous evolution of technology has achieved a stronger magnetic field and faster and stronger gradient fields and RF transmissions in the MR system. The rapid evolution of MR technology makes previous knowledge outdated and requires new precautions. Therefore, all individuals associated with MR examinations should have adequate, basic and updated knowledge of MR safety. This review presents an overview of conventional MR safety issues and updates.

2. Magnetic fields in the MR environment

2.1. Static magnetic fields (B0)

A coil of alloy wire around a magnet bore is immersed in liquid helium to create a superconducting system, which cools down to a temperature close to absolute zero and conducts much larger electric currents than ordinary wire without impedance, achieving a strong magnetic field [2]. Once the magnetic field is established, persistent currents will flow within the superconducting loop for years, preserving the magnetic field as long as the coil is maintained in a superconducting state with liquid helium [2]. The static field strength used clinically is between 0.2 and 3.0 T, although the magnetic strength for research can reach 17.5 T [1,3,4]. The installation of a 7 T system for clinical applications beyond 3 T systems has increased gradually [4–6]. The U.S. Food and Drug Administration (FDA) considers a magnetic field safe up to 8 T for adults, children, and infants aged more than 1 month, and 4 T is considered safe for neonates. There is no measured effect on the human body in a lower magnetic field, but unexpected biological effects can occur within stronger magnetic fields. Any significant biological effects tend to occur above 4 T [7]. The velocity of capillary red blood cells can decrease under static magnetic fields, as shown in an animal study [8]. Systolic blood pressure was reported to increase an average 3.6 mmHg at 8 T [9]. The human body has naturally paramagnetic tissue components, such as iron, but the iron is distributed with-

* Corresponding author at: Department of Radiology, St. Vincent's Hospital, Jidong, Paldal-gu, Suwon-si, Gyeonggi-do 16247, Republic of Korea.
E-mail addresses: bellenina@daum.net, bellenina@catholic.ac.kr (K.A. Kim).

http://dx.doi.org/10.1016/j.ejrad.2017.01.010
0720-048X/

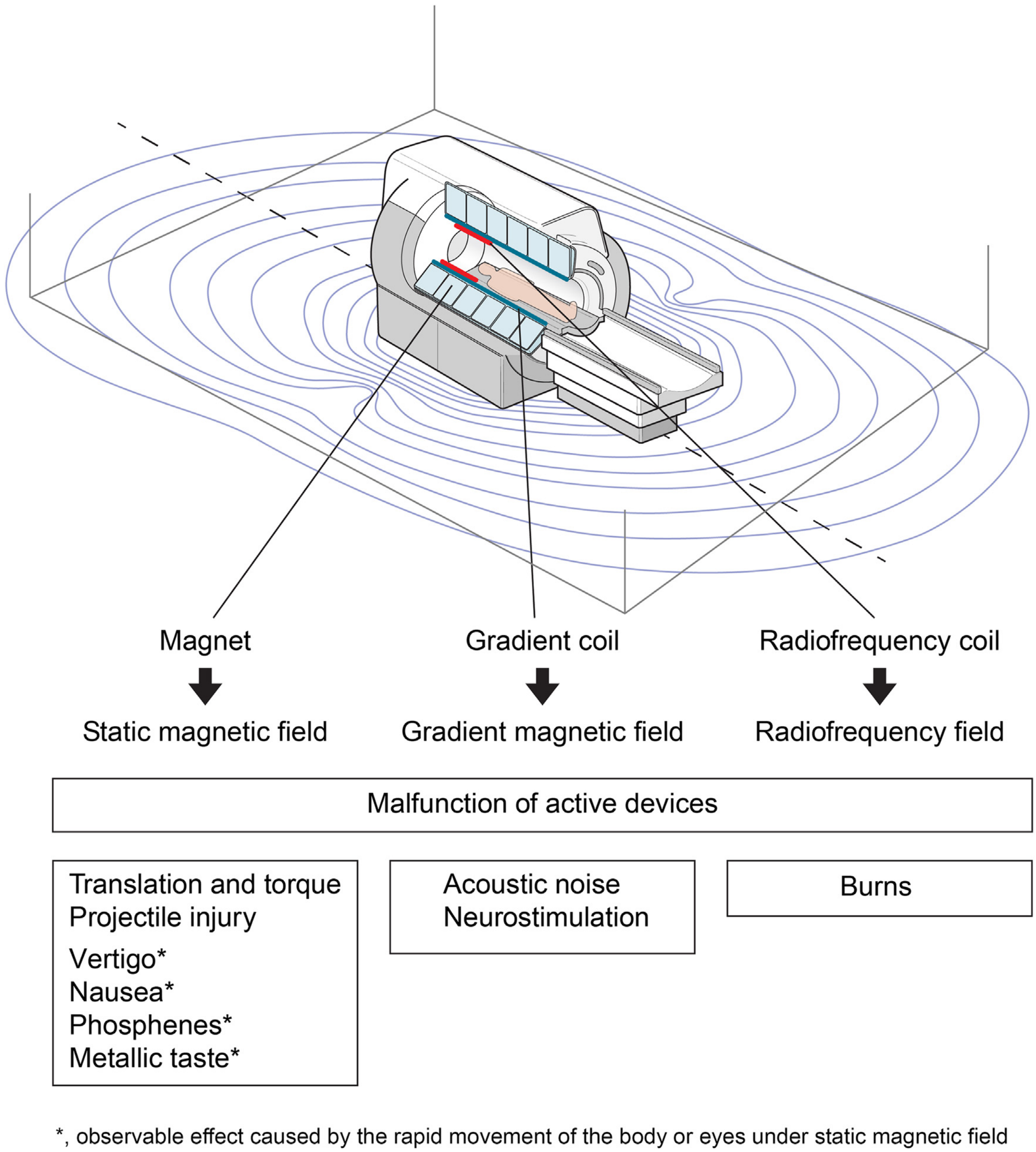

Fig. 1. The components of MRI system and adverse effects associated with each magnetic field.

out a bulk ferromagnetic form and does not interact strongly with applied fields [10]. The ability of a static magnetic field to cause cancer or other biological effects is still in debate [11,12]. Static magnetic fields primarily exert attractive forces on nearby metallic objects within the magnetic field and produce translational force, torque, and projectile movement.

2.2. *Gradient magnetic fields*

Gradient coils are installed within the magnet bore and generate magnetic field variations for the three Cartesian coordinates [13]. Gradient coils with rapidly changing currents encode the MR imaging signal with spatial information and create image slices of a specific body part [2]. A clinical MR scanner usually generates a gradient field of 0–50 mT/m [14]. There are rapid fluctuations in the current that result in microscopic coil movements, and this is the source of the noise generated by a MR imaging scanner. Time-varying magnetic fields induce electrical currents in tissues that are sufficient to stimulate nerve cells and muscle fibers [15]. Assuming equal dB/dt for the various gradient axes, gradient-induced electrical fields are highest for the largest normal body cross section [13]. The anatomical sites of stimulation vary with the gradient [13]. At extremely high levels, cardiac stimulation or ventricular fibrillation can occur, and the mean threshold level for the heart is 3600 T/s [1]. These outcomes require exceedingly large gradient fields, greater than those used by commercially available MR systems [13].

2.3. *Radiofrequency fields*

An MR imaging system requires RF transmission coils to excite nuclear magnetization inside the human body and RF receiver coils to acquire the nuclear MR signal. Each RF coil has a different size and