Contrasts in MRI

MRI pulse sequences are used to produce the contrast in an MRI image. In a spin echo sequence, there are generally two parameters that influence the contrast of a tissue with the spin density p: the repetition time (TR) and the echo time (TE):

$$s = \rho\left(1 - e^{\frac{-TR}{T_1}}\right)e^{\frac{-TR}{T_2}}$$

The repetition time TR is the time between two excitation pulses. The echo time (TE) is the time between an excitation pulse and MR signal sampling when the echo maximum occurs (Fig. 4). In a gradient echo sequence, there are in general three parameters that influence the contrast: the flip angle of the excitation pulse a, TE, and TR (Fig. 5).

T_1 Contrast

T_1 is the longitudinal or spin-lattice relaxation time. Not all energy that was put into the system with an RF pulse during the excitation returns to the RF coil. Some of the energy is lost and heats up the surrounding tissue, referred to as the lattice. The time course that describes the system's return to thermal equilibrium is mathematically described by an exponential curve. T_1-weighted pulse sequences use short TR and short TE. Different body tissues have different T_1 relaxation times. After an excitation pulse, the longitudinal magnetization vector of fat realigns relatively quickly with the static magnetic field B0 again, and it therefore appears bright on a T_1 weighted image. Water shows much slower longitudinal magnetization realignment after a radiofrequency pulse and appears relatively dark on T_1 weighted images (Fig. 6).

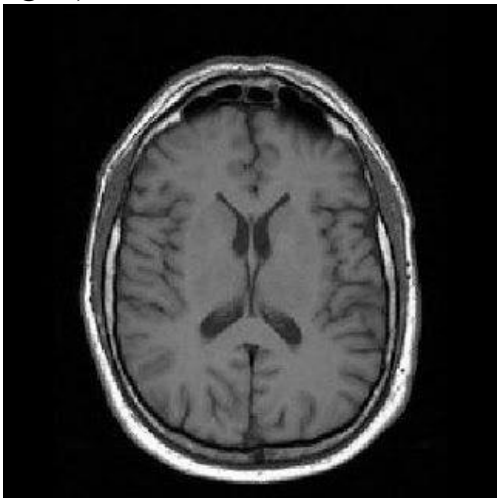

Fig. 6 Axial T1-weighted MR image of the human brain

T_2 Contrast

T2 is the transverse or spin-lattice relaxation time. Random fluctuations of the local magnetic field lead to random variations in the precession frequency of the nuclear spins in the human body. After an excitation pulse, the initial phase coherence of the nuclear spins will be lost when they get out of phase which is described by an exponential decay with the time constant T2. T2 relaxation occurs more rapidly than T_1 relaxation. T2-weighted pulse sequences use long TR and long TE. Fluid (e.g., in the cerebrospinal fluid (CSF) spaces of the brain) appears bright on T2-weighted images (Fig. 7).

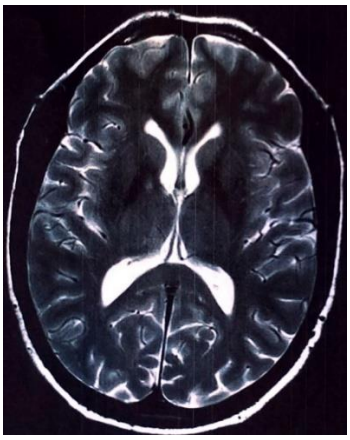

Fig. 7 Axial T2-weighted MR image of the human brain

Proton Density Contrast

Proton density-weighted images are produced by controlling the selection of scan parameters to minimize the effects of T1 and T2 resulting in an image dependent primarily on the density of protons in the imaging volume. Proton density-weighted sequences use a long TR and a short TE (Fig. 8).

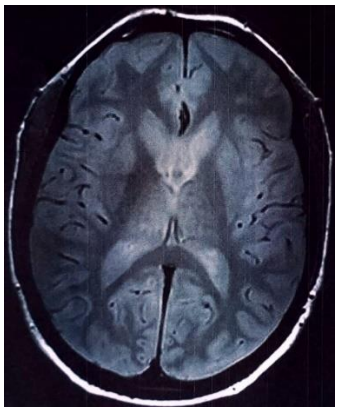

Fig. 8 Axial proton density-weighted MR image of the human brain

T_2^* Contrast

T_2^* relaxation is caused by a combination of spin-spin relaxation and magnetic field inhomogeneities. T_2^* relaxation occurs with gradient echo imaging sequences. T_2^*relaxation is faster than T_2^*relaxation. In spin echo sequences, the transverse relaxation caused by magnetic field inhomogeneities is eliminated by the 180° refocusing pulse; in gradient echo sequences, the relaxation due to magnetic field inhomogeneities cannot be eliminated. A T_2^* weighting can be achieved with a low flip angle, long echo time, and long repetition time.

Physiological and Functional MR Imaging

The strength of MRI is not only its great soft tissue contrast in high-resolution images but also its sensitivity to measure physiological and functional parameters in the human body. There are numerous MRI techniques and pulse sequences with different excitation pulse schemes and gradient schemes that were specifically developed to acquire anatomical physiological images from different parts of the human body.

Cardiac MRI

Cardiac MRI assesses noninvasively the function and structure of the cardiovascular system. Gradient echo pulse sequences are important for cardiac imaging because of their speed and versatility. These gradient echo sequences are used to assess ventricular function, blood velocities, flow, valvular function, and myocardial perfusion.

Cardiac Gating

There are two different gating techniques that are used in cardiac MRI: prospective gating and retrospective gating. In prospective gating the MR data acquisition begins only after a desired physiologic signal (e.g., the R wave of the electrocardiogram (ECG)). A trigger is used to obtain MR images only at a particular time in the cardiac cycle. In retrospective gating, the MRI data are acquired continuously, and an ECG is recorded simultaneously. The MR data can then be reordered, grouped, or correlated with phase of the cardiac cycle. Retrospective gating is typically used for cine MRI cardiac motion studies.

Cine MRI

Cine MRI produces short movies to display heart motion throughout the cardiac cycle. Cine MR images are obtained with electrocardiography (ECG) triggered segmented imaging. The segmented acquisition divides the cardiac cycle into multiple segments (frames) to produce a series of images that can be displayed as a movie (cine).