CHAPTER II

MRI brain anatomy

Image formation

A correct understanding of magnetic resonance (MR) images requires knowledge of the parameters which contribute to their formation.

First of all, unlike other imaging techniques, the MRI signal intensity is a function of multiple tissue-specific parameters, the most important being spin-lattice relaxation time ($T_1$), spin-spin relaxation time ($T_2$), proton density and flow. The wide variability of these parameters in both normal and pathologic tissues, in particular of $T_1$ and $T_2$, explains the high image contrast which is typical of this technique.

Furthermore, the operator can select the technical parameters for the sequences, such as type of RF (radiofrequency) pulses ($90^\circ$, $180^\circ$, $>90^\circ$) and their succession, values of repetition time (TR), echo time (TE) and inversion time (TI). Consequently, he can critically affect the contribution of the different parameters to the formation of the signal, often enhancing tissue contrast.

By adjusting the technical parameters for the programming of sequences, we can obtain images whose contrast will be predominantly affected by $T_1$, $T_2$, proton density or, finally, by blood flow characteristics. In clinical practice, the possibility of identifying and characterizing a wider range of normal or pathologic tissues relies on the comparative analysis of the images obtained with different weightings.

At present, the sequence which best responds to these diagnostic requirements is the spin-echo (SE) sequence. Over short time intervals (15–20'), this sequence provides $T_1$-, $T_2$- and proton density-weighted images.

The images acquired with short TR and TE settings (TR 550 msec; TE 15 msec) highlight the variations in the $T_1$ relaxation times of the different tissues. In effect, high signal density foci reflect short $T_1$ structures; low signal density foci, instead, reflect long $T_1$ structures.

On the images obtained with this sequence, the intraorbital and subcutaneous fat, as well as the fat in the cancellous bone of the diploe and of the skull base, appear as hyperintense, whereas the signal of the cerebrospinal fluid (CSF), meningeal sheaths and of compact bone is clearly hypointense. The brain tissue has an intermediate signal density, in which the darker gray matter can be discriminated from the white matter thanks to its higher water content and lower lipid component. Finally, the intrasinusal air and the high-flow vessels appear as very dark areas owing to signal loss.

The $T_1$-weighted images require short acquisition times. Therefore, they are scarcely affected by background noise and provide excellent anatomical detail. They are particularly suitable for the study of regions with high natural contrast between CSF and nervous tissue.

Long-TR (2500 msec) and short-TE (15–20 msec) images are mainly dependent on proton density. However, for very short TEs, they are affected by $T_1$, too, albeit to a lesser extent.

In proton density, the contrast ratio between gray matter and white matter reverses. The white matter has a much lower signal intensity and can be better distinguished not only from the cortex but above all from the basal ganglia. On these images, the CSF signal has not yet reached the $T_2$ curve inversion point (see Chap. I, p. 19). Therefore, it still appears as hypointense with the brain tissue, but to a much lesser extent than on short-TR sequences. Air, compact bone, dura and vessels also maintain a low signal on these images, whereas fat tissue has an initial reduction in brightness.
Long-TR and -TE (TR 2500 msec, TE 90 msec) images are called T$_2$-weighted, since they depend on the spin-spin relaxation time. On them, higher signal density districts correspond to long-T$_2$ elements. Owing to the above-mentioned contrast inversion phenomenon, the CSF signal shifts to highly hyperintense (cisternographic and myelographic effect) with respect to nervous tissue. In effect, since the signal of this tissue is highly degraded, it creates contrast in CSF spaces which demonstrates the normal vascular and nervous structures contained therein.

On T$_2$-weighted images and especially at high magnetic fields (1.5 T), the basal ganglia (globus pallidus and putamen), the nuclei of the midbrain (red nucleus, substantia nigra) and the cerebellar dentate nucleus appear as markedly hypointense areas. This reduction in signal intensity was correlated with iron content in such structures.

Long echo times induce a progressive decline in the fat tissue signal, whereas compact bone, air-filled structures and vessels remain markedly hypointense due to a nearly complete signal loss.

Even if these long-TR and long echo time sequences are degraded by background noise and motion artifacts, they are the sequences mostly used for diagnostic purposes. In effect, they are the most responsive to pathologic alterations of secondary tissues and to variations in water and protein content, to alterations of myelin or to paramagnetic contrast agents.

Their use is thus a “must” for a correct diagnostic interpretation of CNS diseases, whether neoplastic, degenerative or inflammatory. They allow alterations of the T$_2$-weighted image signal to be correlated with the corresponding proton density images.

The uniqueness of MRI lies in the fact that its semiology is based on the integrated evaluation of multiple images, acquired with adequate sequences: this generates complexity but also greater diagnostic potential.

Anatomy

Given the complexity of MRI, the chapters on pathologies will be preceded by illustrations of the normal MRI brain anatomy correlated with anatomical sections. Identification of the various structures will be facilitated by explanatory schematic drawings.

We have tried to reproduce the anatomical sections which are mostly used in practice, giving priority to the axial and coronal scans, since they are more complex and provide a wider array of anatomical relationships.

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