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K-Space

Today, medicine is no longer imaginable without diagnostic imaging. With the discovery of x-rays in 1895, an important milestone in medicine was already set but the more significant invention of the last century was magnetic resonance imaging (MRI), enabling non-invasive 3-dimensional anatomical data of the human body to be generated without ionising radiation1.

Looking back in time, the basis of MRI was nuclear magnetic resonance (NMR) in chemistry and X-rays. In 1970 the first pictures of the brain were taken. In 1973, Paul Lauterbur presented a two-dimensional NMR image of a water-filled object. In 1977, a thorax image was taken on MRI for the first time. With the findings of the projection reconstruction techniques from the computer tomography at that time, Lauterbur was able to reconstruct the two-dimensional images from the one-dimensional NMR measurement. NMR and X-rays have together led to rapid development and technological advances in medicine.

The scientific basis for MRI imaging was described in about 1800 by Jean Baptiste Fourier (1768-1830). Without this transformation, the calculation of MRI images would not be possible today. The unit for the magnetic field strength was named after the inventor Nikola Tesla (1856-1943). Nikola Tesla described the formation and effect of magnetic fields. Erwin L. Hahn discovered in 1950 the "spin echoes", which is one of the most basic methods of signal generation in magnetic resonance imaging.

The first clinical MR systems were installed in 1983. The field strengths were 0.2 - 0.5T, this was followed by 1T and 1.5T systems, which have been critical to medical imaging for the last 25 years. About ten years ago, 3T systems were introduced. The intention was to increase the field strength further to invest the obtained signal-to-noise ratio in better spatial resolution or shorter examination time. There are now more than 10 Tesla for research purposes. The technical development is so rapid that, compared to earlier, the MRI is primarily adapted to patient needs2.

MRI produces images of the human body. During scanning or sampling, the patient is placed under the effect of a constant magnetic field with controllable field gradients at all coordinates; these fields allow spatial coding and the selection of a “slice”, which is the two-dimensional element on which you want to obtain the image. The excitation is carried out with the application of a radio frequency (RF) signal, which produces the phenomenon of resonance on the selected spins, achieving the accumulation of energy, which is delivered as an NMR signal.

It is called k-space because the signals received from the NMR process are in frequency and phase. Therefore, all of these NMR data correspond to the Fourier transform of the image of the section along the path; in this way, and the reconstruction of the image is done with the application of the Fourier Inverse Transform, IFFT, on these data. To reduce the acquisition time, various alternatives have been proposed, and within these, the sampling of the k-space on trajectories that do not allow acquisition on a Cartesian grid, however, as a consequence, the complexity of the reconstruction is increased. The methods most used in the reconstruction of images acquired on non-Cartesian trajectories in k-space are the Gridding algorithms and the direct Fourier transform (DFT).

The signal recorded during an MRI sequence is stored in the space K. The space K corresponds exactly to a Fourier plane. It is therefore sufficient to apply an inverse 2D Fourier transform on the k-space to obtain an image of the section of the human body. It is the spatial coding, which makes it possible to acquire the data of the image in frequential form, adapted to the K-space3. When the system retrieves the signal, it fills a mathematical space which is called quarter space or K-space. This space K will contain all the information necessary for the formation of the image. We go from the k-space to the image by a double Fourier transform, and from the image to the Fourier space thanks to a double inverse Fourier transform. The filling of this space Fourier is an invisible step for us users, but it is essential for any formation of the image.

Reference list

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