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Clinical Perspective

Magnetic Resonance Spectroscopy and its Clinical Applications: A Review

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ABSTRACT

In vivo NMR spectroscopy is known as magnetic resonance spectroscopy (MRS). MRS has been applied as both a research and a clinical tool in order to detect visible or nonvisible abnormalities. The adaptability of MRS allows a technique that can probe a wide variety of metabolic uses across different tissues. Although MRS is mostly applied for brain tissue, it can be used for detection, localization, staging, tumour aggressiveness evaluation, and tumour response assessment of breast, prostate, hepatic, and other cancers. In this study, the medical applications of MRS in the brain, including tumours, neural and psychiatric disorder studies, breast, prostate, hepatic, gastrointestinal, and genitourinary investigations have been reviewed.

RÉSUMÉ

En 1946, Purcell, Pound et Torrey de l'Université Harvard avec et leurs collègues Bloch, Hansen et Packard de l'Université Stanford ont inventé la résonance magnétique nucléaire (RMN). Par la suite, les études en RMN ont mené à six prix Nobel dans ce domaine. La spectroscopie RMN in vivo est appelée spectroscopie par résonance magnétique (SRM) en clinique. La SRM a été utilisée autant comme outil de recherche que comme outil clinique pour la détection des anomalies visibles ou non. L'adaptabilité de la SRM en fait une technique qui peut examiner une grande variété d'utilisations métaboliques dans différents tissus. Bien que la SRM soit principalement utilisée pour les tissus cérébraux, elle peut être utilisée pour la détection, la localisation, la détermination du stade, l'évaluation du caractère agressif d'une tumeur et l'évaluation de la réponse tumorale dans le cancer du sein, de la prostate, du foie et d'autres organes. Cette étude, après un bref examen des fondements de la SRM, passe en revue les applications médicales de la SRM dans le cerveau, incluant les tumeurs, les applications médicales de la SRM, incluant les cancers et l'étude des troubles neurologiques et psychiatriques, ainsi que les examens du sein, de la prostate, du foie et des systèmes gastro-intestinal et génito-urinaire.

Keywords: Magnetic resonance spectroscopy; Medical applications; Review

Introduction

In 1946, Purcell, Pound, and Torrey from Harvard University, with their colleagues Bloch, Hansen, and Packard from Stanford University, invented nuclear magnetic resonance (NMR). This idea was sparked in 1921 when researchers found that magnetic nuclei, such as 1H and 31P in a magnetic field with specific power, obtains the ability to absorb radio frequency energy. Immediately after absorption, the nuclei begin to resonate; in this process, different atoms that exist in a molecule resonate at different frequencies. Having the opportunity to observe this event, researchers started to analyse the molecule structures precisely. Since then, NMR has been used for all kinds of materials such as solids, liquids, and gases for kinetic and structural studies. It is worth noting that NMR investigations led to six Nobel prizes in this field [1–9].

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NMR spectroscopy is an instrument that recognizes molecules and is able to specify biophysical features. The principal use of NMR in health centres is to obtain anatomic images of the body using magnetic resonance imaging (MRI). MRI in conjunction with NMR spectroscopy has numerous applications in the clinic and in biomedicine. NMR spectroscopy in the clinic is known as magnetic resonance spectroscopy (MRS). Like its application in chemistry, spectroscopy permits the discovery of tiny molecules in intracellular and extracellular spaces. The achieved spectra provide detailed evidence about metabolic track and its alterations; as a result, MRS can be used to supervise metabolic variations due to disorders and also to assess effectiveness of treatment [10–13].

Initially, MRS was not a routine clinical option for medical imaging, principally because it was not sensitive enough. But, with the arrival of high strength magnetic field scanners, for instance 3 Tesla (T) clinical magnetic resonance (MR) scanners, evolved coils, and enhanced radio frequency pulse designs, sensitivity has been greatly improved. Therefore, in vivo MRS has become a technique that is increasingly applied in the clinic [14].

MR spectra can be procured from several nuclei in the body, such as 1-Hydrogen, 31-Phosphorus, 19-Fluorine, etc. These nuclei can provide precious metabolic and physiologic data. Typically, 1H-MRS is the matter of choice because of the high sensitivity to this nucleus, proper accessibility, and the plentiful existence of hydrogen in a large number of metabolites. The routine clinical magnetic field strengths of MR systems are between the range of 0.2 and 3 T [15, 16].

Unlike MRI, MRS does not commonly produce powerful signals of water and fat, which are ordinarily of interest. In MRS applications, smaller signals stemming from metabolites are more important. Since the signal is too weak, accordingly, a magnetic field with adequate strength is needed. Hence, numerous MRS measurements are accomplished by 1.5 or 3 T MR systems. The field strength of 3 T has some clinical advantages, such as signal-to-noise ratio (SNR) increase and an increase in the ability to provide the spectra from smaller voxels [17, 18]. In this article, we present a review of MRS clinical applications following a brief description of MRS terminology.

MRS Terminology

Considering MRS has its own terminology, which readers should be familiar with before starting the review, some of the special terms have been described below. Several terms may not have been used in the text, but these words may be encountered in the literature.

Absorption Spectrum

This is the positive-definite or real part of the complex spectrum [19, 20].

Apodization

Multiplying the obtained free induction decay (FID) in a slightly varying function, such as exponentially decaying function or Gaussian. Apodization can help to diminish the noisier end of the FID. This procedure may cause peak broadening [19, 20].

Dispersion Spectrum

This is the imaginary part of the complex spectrum [19, 20].

Eddy Currents

Field gradient pulses can produce currents in the magnetic structure, which can create extra magnetic fields that add to the static field B0. Zero-order eddy currents can produce phase shifts that are frequency dependent, while first-order eddy currents can cause spin dephasing leading to SNR reduction. Just like magnetic inhomogeneities, these currents may cause peak shape distortion and make the interpretation of spectral quantities more difficult [21, 22].

J-Coupling

The magnetic field of one nucleus can affect the external magnetic field that is sensed by the adjacent nucleus. This fact stems from binding electrons that are shared between the two coupled nuclei. This causes the spectrum containing the resonance of the coupled nucleus to split into two lines; in the same manner, a doublet of two peaks can be seen (eg, the lactate [Lac] doublet). The coupling constant explains the difference in frequency between the two peaks [23, 24].

Phasing

Whenever the initial phase of FID is not zero, the real and imaginary parts of the complex spectrum contain mixtures of absorption and dispersion mode spectra [25, 26]. Phasing is the process by which the spectrum is sorted into the real and imaginary spectra, such that:

$$\text{Absorption}\ (\omega) = \text{Real}\ (\omega)\cos(\theta) + \text{Imaginary}\ (\omega)\sin(\theta)$$
$$\text{Dispersion}\ (\omega) = \text{Imaginary}\ (\omega)\cos(\theta) + \text{Real}\ (\omega)\sin(\theta)$$

Shimming

Shimming is regulating the resolution of the signal by improving the magnetic field homogeneity. The peaks in MRS spectra are very narrow in the way that the full width at half maximum can be just 1 Hz or even less. In order to obtain spectrums with this resolution, the magnetic field should be very homogeneous. Users have to surround the object with a set of shim coils. These coils produce a small magnetic field with a specific spatial profile that can be applied to cancel out the inhomogeneities in the main magnetic field [27, 28].

MRS Basics

Routinely, an MRS procedure begins with the acquisition of MR images in order to use them as a guide to indicate the region of tissue where the user needs to assess the spectrum. In single voxel spectroscopy (SVS), a single voxel (volume of tissue) is located in the tumour or in a certain area where the metabolism may be damaged as a result of patient disease. Another technique of MR spectroscopy is magnetic resonance spectroscopic imaging (MRSI), also known as chemical shift imaging [29]. In this