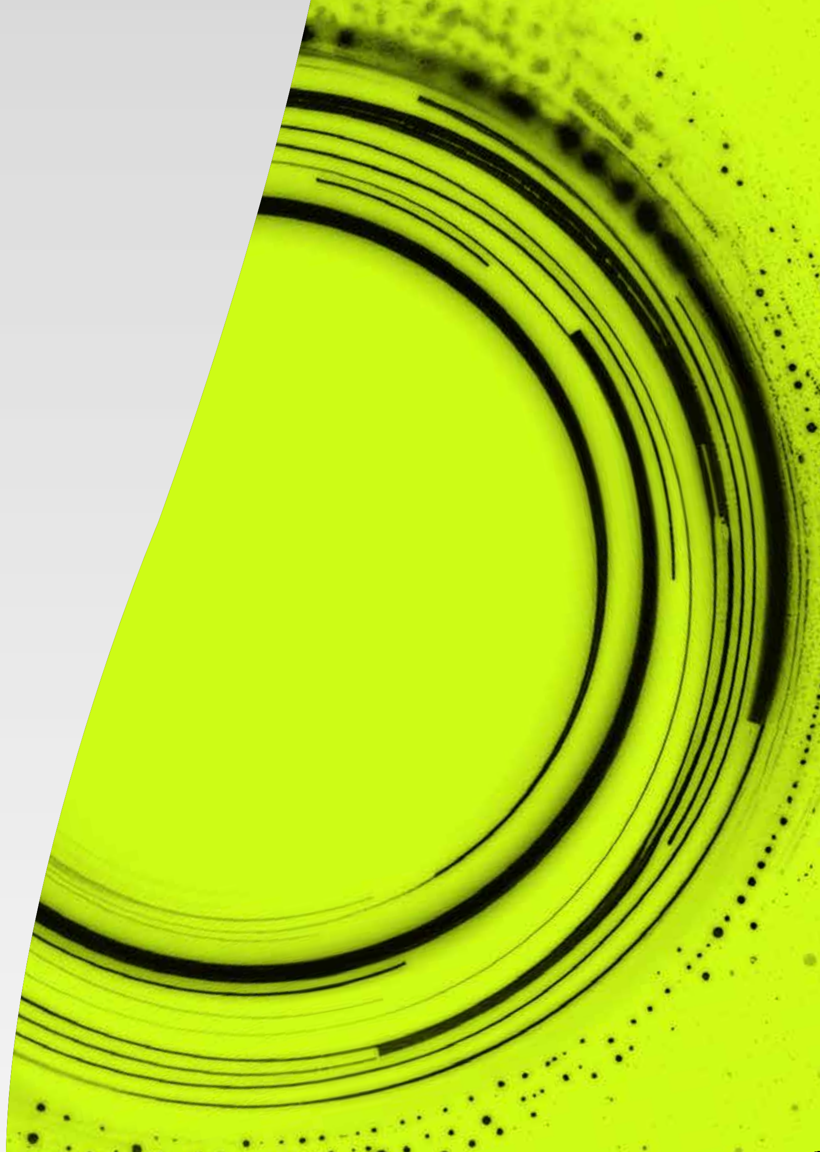
MODERN RADIOLOGY
eBook

Magnetic Resonance Imaging

磁共振成像



ESR EUROPEAN SOCIETY OF RADIOLOGY

/ Preface

Modern Radiology is a free educational resource for radiology published online by the European Society of Radiology (ESR). The title of this second, rebranded version reflects the novel didactic concept of the *ESR eBook* with its unique blend of text, images, and schematics in the form of succinct pages, supplemented by clinical imaging cases, Q&A sections and hyperlinks allowing to switch quickly between the different sections of organ-based and more technical chapters, summaries and references.

Its chapters are based on the contributions of over 100 recognised European experts, referring to both general technical and organ-based clinical imaging topics. The new graphical look showing Asklepios with fashionable glasses, symbolises the combination of classical medical teaching with contemporary style education.

Although the initial version of the *ESR eBook* was created to provide basic knowledge for medical students and teachers of undergraduate courses, it has gradually expanded its scope to include more advanced knowledge for readers who wish to 'dig deeper'. As a result, *Modern Radiology* covers also topics of the postgraduate levels of the *European Training Curriculum for Radiology*, thus addressing postgraduate educational needs of residents. In addition, it reflects feedback from medical professionals worldwide who wish to update their knowledge in specific areas of medical imaging and who have already appreciated the depth and clarity of the *ESR eBook* across the basic and more advanced educational levels.

I would like to express my heartfelt thanks to all authors who contributed their time and expertise to this voluntary, non-profit endeavour as well as Carlo Catalano, Andrea Laghi and András Palkó, who had the initial idea to create an *ESR eBook*, and - finally - to the ESR Office for their technical and administrative support.

Modern Radiology embodies a collaborative spirit and unwavering commitment to this fascinating medical discipline which is indispensable for modern patient care. I hope that this *educational* tool may encourage curiosity and critical thinking, contributing to the appreciation of the art and science of radiology across Europe and beyond.

Minerva Becker, Editor
Professor of Radiology, University of Geneva, Switzerland

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章节大纲：

/ 前言

*《现代放射学》*是由欧洲放射学协会 (European Society of Radiology, ESR) 在线发布的免费放射学教育资源。第二版（更名版）标题反映了 *ESR 电子书*新颖的教学概念，它以简洁页面的形式巧妙地融合文本、图像和示意图，并辅以临床影像学案例、问答部分和内容超链接，使读者能够在各基于器官的部分、更具技术性的章节、摘要以及参考文献之间快速切换浏览。

其章节以 100 多名公认欧洲专家的优秀稿件为根基，涉及各类一般技术和基于器官的临床影像学主题。同时采用了全新的图形外观，展示了佩戴时尚眼镜的 Asklepios，象征着传统医学教学与现代风格教育的结合。

虽然初版 *ESR 电子书*旨在为医学生和本科生教师提供医学基础知识，但现已逐渐扩充其知识领域，为希望“深入挖掘”的读者提供了更多高阶技术知识。因此，*《现代放射学》*还涵盖了*欧洲放射学培训课程*研究生水平的各类主题，旨在解决住院医师的研究生教育需求。此外，书中还囊括了全球医疗专业人士的反馈，他们希望更新自己在医学影像特定领域的知识，并对 *ESR 电子书*在基础和高等教育水平上的深度和清晰度表示高度赞赏。

我要衷心感谢所有为这项非营利活动自愿贡献时间和专业知识的作者，以及最初提出创作 *ESR 电子书*的 Carlo Catalano、Andrea Laghi 和 András Palkó，最后还要感谢 ESR 办公室所提供的技术和行政支持。

*《现代放射学》*充分体现了医者的协作精神和对这门热门医学学科坚定不移的承诺，这是现代患者护理必须具备的优秀精神品质。我希望这款*教育*工具能够激励各位始终保持好奇心和批判性思维，从而促进整个欧洲乃至欧洲以外地区对放射学艺术和科学的认识。

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/ MR Imaging

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This is a translation of the Chapter of the **Modern Radiology eBook.**

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Magnetic Resonance Imaging

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NOTE FROM THE COORDINATORS:
Thank you to Chinese radiology experts for bridging languages and open the world-class English resource by ESR to every Mandarin-speaking student, fueling global radiology talent with a single click

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章节大纲：

/ 翻译致谢

本章节为《现代放射学电子书》的部分译文。

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磁共振成像

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译者寄语：
感谢中国放射学专家们的倾力奉献！你们跨越了语言的鸿沟，将欧洲放射学会 (ESR) 的世界级学术宝库呈献给广大中文学子。如今，前沿智慧一键即达，为全球放射学人才的蓬勃发展注入了强劲动力。

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/ Signage

<■> **CORE KNOWLEDGE**

>■< **FURTHER KNOWLEDGE**

<!> **ATTENTION**

>|< **COMPARE**

<?> **QUESTIONS**

<↑> **HYPERLINKS**

<∞> **REFERENCES**

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/ 导示

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>■< **进阶知识**

<!> **注意**

>|< **比较**

<?> **问题**

<↑> **超链接**

<∞> **参考文献**

MODERN RADIOLOGY eBook

Based on the ESR Curriculum for Radiological Education

Magnetic Resonance Imaging

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MR Imaging

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MR 成像

章节大纲：

基于 ESR 课程的放射学教育

磁共振成像

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- The Basics
- Safety and Access Restriction
- Components of the MRI System

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- Relaxation
- Signal Reception
- Spatial Encoding – Z Direction
- Spatial Encoding – X and Y Directions
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- Gradients and MRI Noise

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- What is an Echo?
- Importance of TE & TR for Contrast?
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- 弛豫
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- 空间编码 - Z 方向
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- 信号与图像的关系
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- 反转恢复 (IR)
- 扩散加权成像 (DWI)
- 扩散张量成像 (DTI)
- 飞行时间 (ToF)
- 功能性 MRI (fMRI)
- 波谱分析

MRI 对比剂

- 灌注成像 (PI)

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章节大纲：

/ MRI 系统

/ The Basics

MRI is a non-invasive sophisticated technique that uses powerful magnetic fields to image the human body.

An MRI scanner is composed of 3 main parts:

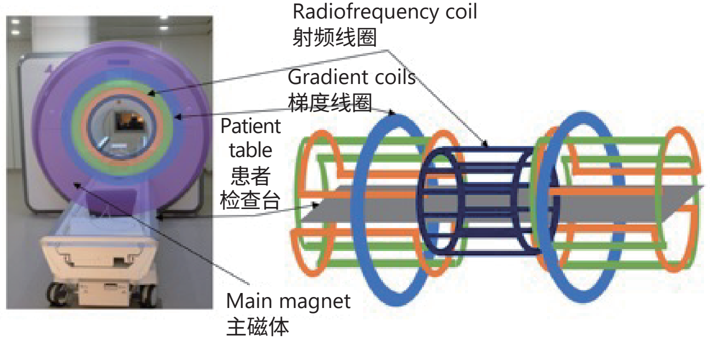
/ **Main magnet**: to produce the main static magnetic field (B_0).

/ **Gradient coils**: to produce deliberate variations in B_0.

/ **Radiofrequency (RF) coils**: which act like the antennas of the MRI system: they transmit the RF field, and they receive the resulting signal.

Main magnet

The superconductive magnet (superconductive = no resistance to electricity) produces a high intensity magnetic field called "B_0". The magnet is cooled with liquid Helium (and liquid Nitrogen). It is used to generate a net magnetisation of tissue inside the bore. The bore size is 60-70 cm in diameter.



Order of magnitude for magnetic field strengths:

/ Earth magnetic field at latitude 0°: 31 μT

/ Fridge magnet : 5 mT

/ Junkyard/scrap magnet : 1T

/ Medical MRI : most often 1.5T and 3.0T, rarely 7.0T

>■< FURTHER KNOWLEDGE

Constant electric current in a wire generates a static magnetic field (Biot-Savart law). The magnetic field strengths is proportional to the electric current.

<!> ATTENTION

Contraindications or restrictions for MRI :

/ Claustrophobia

/ Ferromagnetic metal in the body

/ Some pacemakers, electronic implants, ...

/ MR Imaging

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章节大纲：

/ 基础知识

MRI 是一种无创的精密技术，其原理是利用强磁场对人体进行成像。

MRI 扫描仪主要由 3 部分组成：

/ **主磁体**：用于产生主静态磁场 (B_0)。

/ **梯度线圈**：用于使 B_0 生成刻意变化。

/ **射频 (RF) 线圈**：其作用类似于 MRI 系统的天线：既负责传输 RF 场，也负责接收产生的信号。

主磁体

超导磁体（超导 = 无电阻）可产生高强度磁场，称为 "B_0"。磁体需使用液氦（及液氮）冷却，其作用是激发孔腔内组织产生净磁化强度。孔径直径为 60-70 cm。

磁场强度数量级参考：

/ 纬度 0° 处的地磁场：31 μT

/ 冰箱磁贴：5 mT

/ 垃圾场/废磁铁：1T

/ 医用 MRI：最常用 1.5T 和 3.0T，少数情况下使用 7.0T

>■< 进阶知识

电线中的恒定电流可产生静态磁场（Biot-Savart 定律）。磁场强度与电流大小成正比。

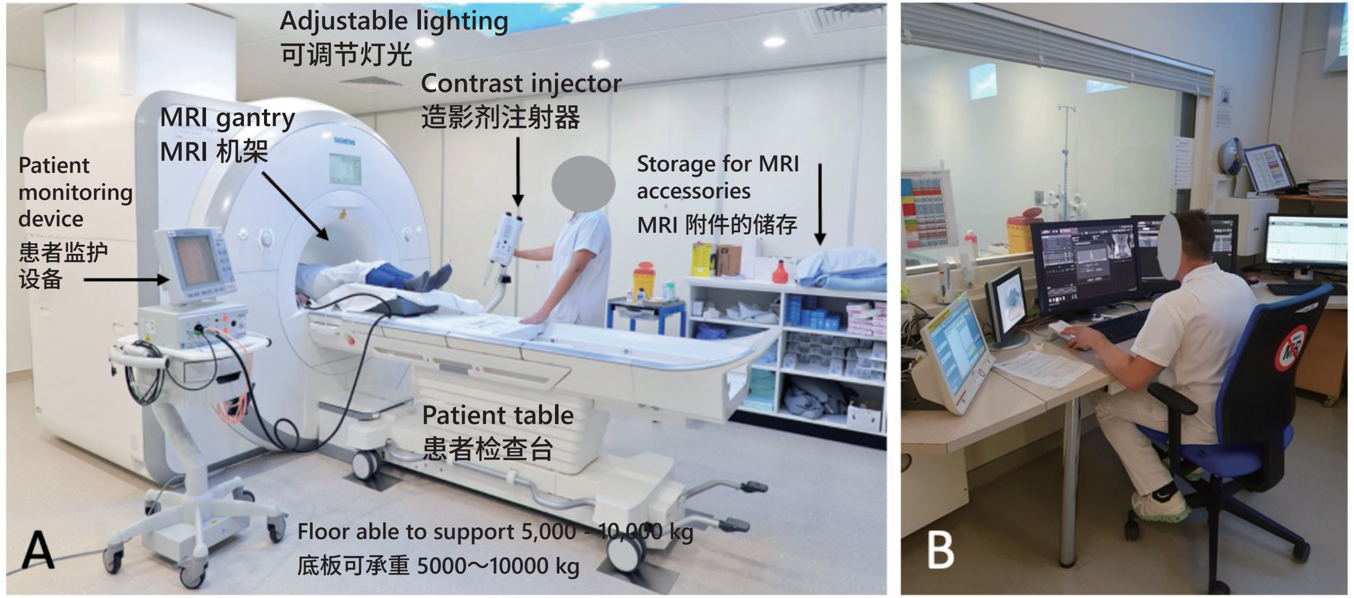
<!> 注意

MRI 的禁忌证或限制：

/ 幽闭恐惧症

/ 体内存在铁磁性金属

/ 一些起搏器、电子植入物、...



The walls of the MRI magnet room (A) have layers which perform different functions: magnetic shielding to confine the stationary magnetic field, RF shielding to hinder electromagnetic noise to enter or exit the magnet room and acoustic shielding to restrict noise transmission beyond the magnet room. The control room (B) is located immediately outside the magnet room. It contains the operator console, computer equipment, communication devices, monitors (ECG and O_2).

MR Imaging

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章节大纲：

MRI 磁体室 (A) 的墙体采用多层结构，各层具备不同功能：磁屏蔽层用于约束固定磁场；RF 屏蔽层用于阻隔电磁噪声进出磁体室；声学屏蔽层则用于限制噪声向磁体室外传播。控制室 (B) 紧邻磁体室外侧设置，内部配备操作控制台、计算机设备、通信装置、监护仪（ECG 和 O_2）。

/ Safety and Access Restriction

/ The magnet is always ON!

/ The main magnetic field B_0 is always active. Never approach the field with a **ferromagnetic*** object.

/ The attraction force associated with the torque will pull the object through the main magnet with **uncontrollable** force: projectile effect or missile effect.

/ **Past incidents unfortunately killed people!**

/ This explains why safety rules around MRI are very strict!

/ Patients undergoing MRI examinations must remove all metallic objects. Some radiology departments use ferromagnetic detection devices.

MRI accident on a 1.5T MR system. A floor polishing machine was attracted by the magnetic field. It could only be removed by ramping down the magnetic field. Shown is the back side (head end) of the MRI. Reproduced from:

https://commons.wikimedia.org/wiki/File:MRI_accident_on_a_1.5_Tesla_MR_system.jpg

* Ferromagnetic objects contain :

/ Iron, Cobalt, Nickel
/ Alloys of these components

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章节大纲：

/ 安全与访问限制

/ 磁体始终处于开启状态！

/ 主磁体 B_0 始终处于活动状态。切勿携带任何**铁磁性***物体靠近磁场。

/ 与磁力矩相关的强大吸引力会以**不可控**的力量将物体吸入主磁体：抛射效应或导弹效应。

/ **过往事故中，此类事件可造成人员伤亡！**

/ 这也正是 MRI 相关安全规范极为严格的原因！

/ 接受 MRI 检查的患者必须取下所有金属物品。部分放射科配备铁磁探测设备。

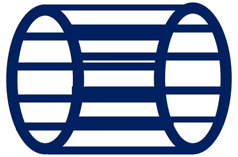
*铁磁性物体包含：

/ 铁、钴、镍
/ 上述金属的合金

1.5T MR 系统的 MRI 事故。一台地面抛光机被磁场吸入，最终只能通过逐步降低磁场强度的方式移除。图示为该 MRI 的背面（头端）。来源：

https://commons.wikimedia.org/wiki/File:MRI_accident_on_a_1.5_Tesla_MR_system.jpg

/ Components

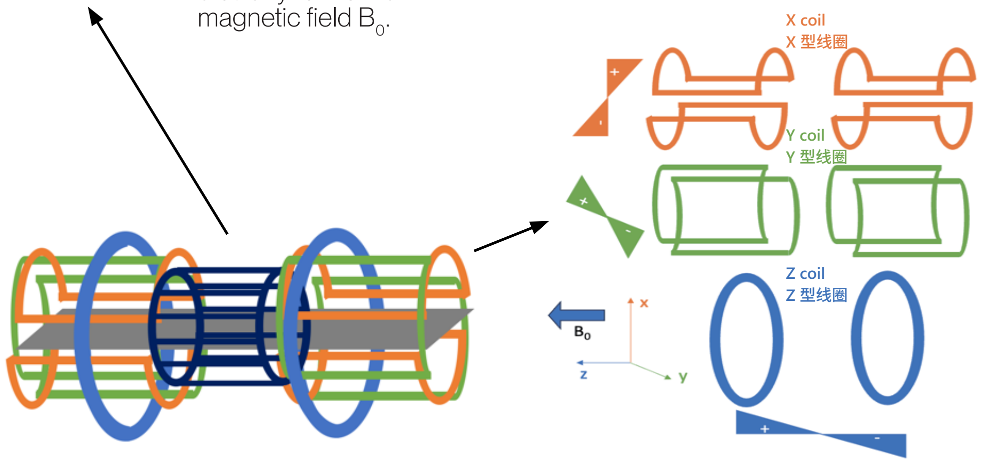


Radiofrequency coil

Produces a varying magnetic field that is used to tip the net magnetisation perpendicularly to the main magnetic field B_0.

Gradient coils

Produce varying magnetic fields in 3 spatial directions (x, y, z). Used to spatially encode the MRI signal.



We'll see on the next pages how each of these parts contributes to the production of images →

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章节大纲：

/ 组件

射频线圈

产生变化的磁场，用于使净磁化垂直于主磁场 B_0。

梯度线圈

在 3 个空间方向（x，y，z）产生变化的磁场。

用于对 MRI 信号进行空间编码。

后续页面将详细说明各组件如何协同完成图像生成 →

/ MRI Principle

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章节大纲：

/ MRI 原理

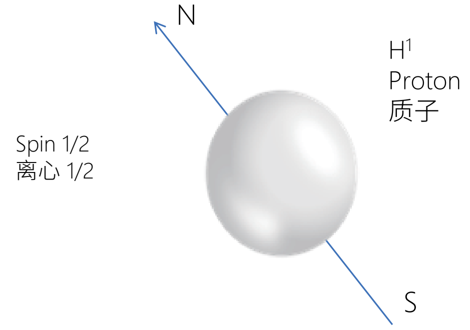
/ MRI Principle

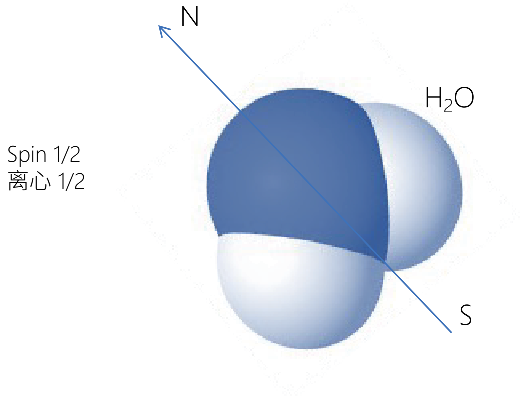
The nucleus of an atom is composed of protons (positive charge) and neutrons (no charge) which all rotate around their own axis. The electrons (negative charge) revolve around the nucleus, and they also rotate around their own axis.

The rotation of all these particles produces an angular moment of rotation, which is called **spin**. A spin is a fundamental property of atoms like mass or electrical charge. Spin comes in multiples of ½.

As the proton has a positive charge and as it rotates continuously, it creates a small magnetic field, called **magnetic moment** (i.e., it behaves like a tiny magnet with a north and south pole).

- / There is a natural abundance of H2O in biological tissues and, therefore, an abundance of H[1].
- / H[1] **mainly occurs** in water in the human body.
- / Human body composition → ~ 60% - 70% water (2 H[1]).
- / H[1] has a **large** magnetic moment.
- / The magnetic property of H[1] is used to mainly image the water distribution of tissues in the body with MRI.





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章节大纲：

/ MRI 原理

原子核由质子（带正电）和中子（不带电）组成，二者均围绕自身轴自转。电子（带负电）既绕原子核公转，也围绕自身轴自转。

所有粒子的旋转产生旋转角动量，称为**自旋**。自旋是原子的基本属性，类似质量或电荷，取值为 ½ 的倍数。

由于质子带正电且持续旋转，会产生微小磁场，称为**磁矩**（即，其行为类似于具有南北极的微型磁体）。

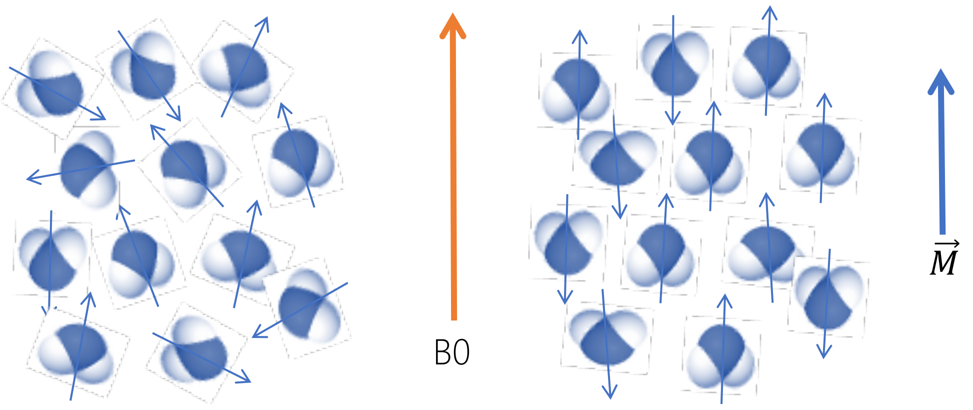
- / 生物组织中富含水 (H_2O)，因此 H[1] 含量极高。
- / H[1] **主要存在**于人体的水中。
- / 人体成分 → 约 60% - 70% 的水（每个水分子含 2 个 H[1]）。
- / H[1] 的磁矩**较大**。
- / H[1] 的磁性主要用来对体内组织的水分分布进行 MRI 成像。

/ MRI Principle

When biological tissue is placed in a strong magnetic field, a **net magnetisation vector** is created. To effectively explain this phenomenon, quantum mechanics is required, which is beyond the scope of this chapter.

This effect applies to atoms with **specific magnetic moment properties**, i.e., nucleus with spin quantum number = ½ : H^1 / C^{13} / N^{15} / O^{17} / Na^{23} / ...

Alignment **parallel ↑ or anti-parallel ↓ to the magnetic field**, corresponds to two different energy states. Most protons align parallel to B_0 as this requires less energy than the antiparallel alignment. The net magnetisation $\vec{M}$ is created by the fraction of spin in excess in one of the energy states:



Outside the magnetic field
磁场外部

Inside the magnetic field
磁场内部

EXAMPLE :
fraction in excess
@ 3T ~10 on 10^6 !

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章节大纲：

/ MRI 原理

当生物组织被置于强磁场中时，会产生**净磁化矢量**。为了有效地解释这种现象，需要采用量子力学，这超出了本章范畴。

此效应适用于具有**特定磁矩性质**的原子，即自旋量子数 = ½ 的原子核： H^1 / C^{13} / N^{15} / O^{17} / Na^{23} / …

与磁场平行 ↑ 或反平行 ↓ 排列，对应于两种不同能态。多数质子与 B_0 平行排列，因为这比反平行排列所需能量更少。净磁化 $\vec{M}$ 由其中某一能态的自旋过剩比例产生：

示例：3T 下，自旋过剩比例约为 $10/10^6$！

/ Signal Production

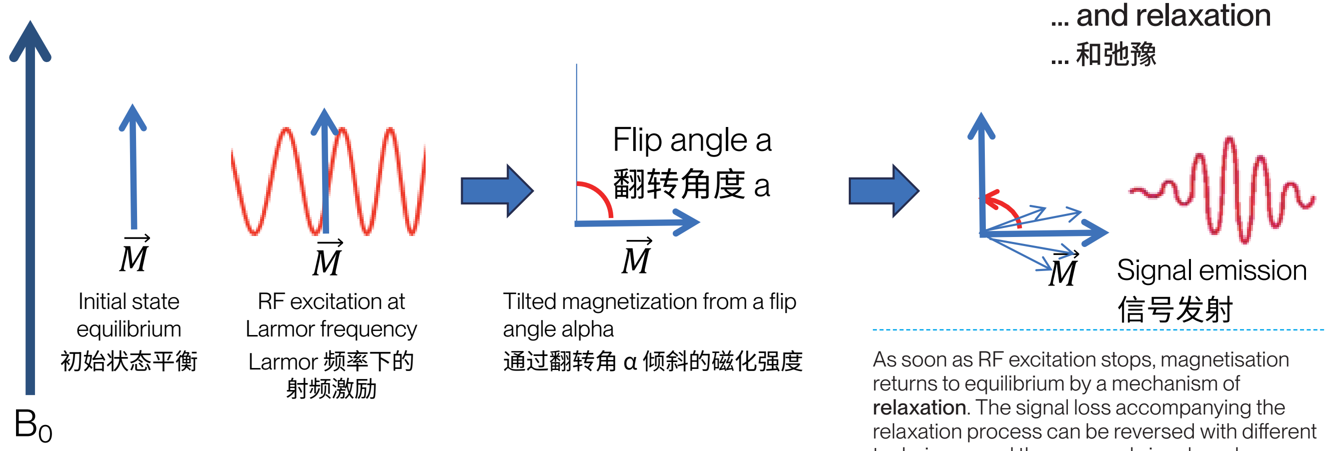
Excitation ...

/ To create a signal from the tissue, a radiofrequency (RF) wave is used. It is tuned to the resonance frequency of the spins called « Larmor frequency » f, defined by:
$f = \gamma B_0$

/ Where γ is the gyromagnetic ratio (γ = 42.58 MHz/T) and B_0 the magnetic field strength.

- / At 1.5T, f = 64 MHz
- / At 3T, f = 128 MHz

... and relaxation
... 和弛豫



As soon as RF excitation stops, magnetisation returns to equilibrium by a mechanism of **relaxation**. The signal loss accompanying the relaxation process can be reversed with different techniques and the reversed signal can be recorded!

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 信号产生

激发...

/ 要从组织中产生信号，需使用射频 (RF) 波。将其调谐为自旋的共振频率，称为“拉莫尔频率”f，定义为：
$f = \gamma B_0$

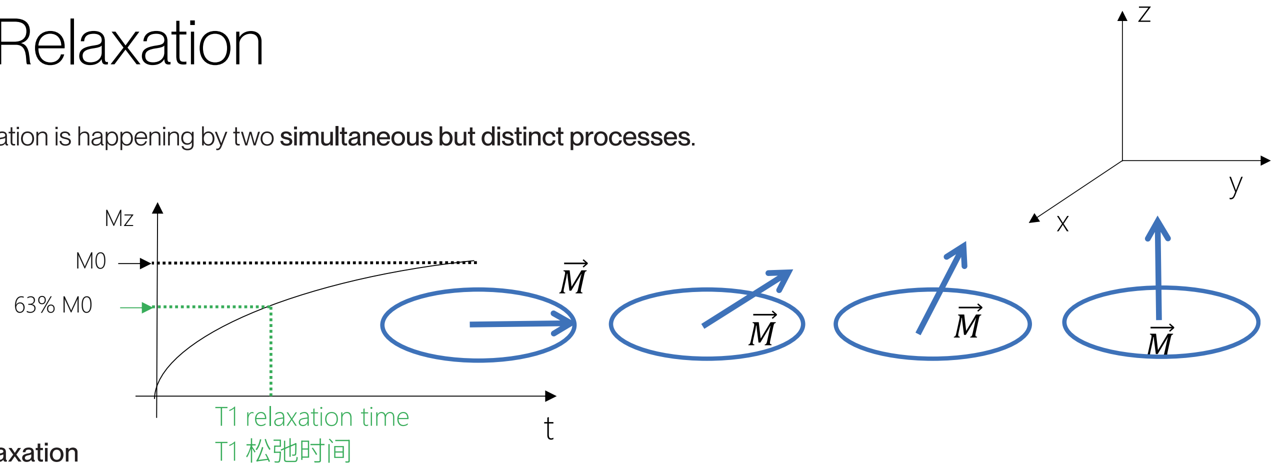
/ 其中 γ 为旋磁比 (γ = 42.58 MHz/T)，B_0 为磁场强度。

- / 1.5T 下，f = 64 MHz
- / 3T 下，f = 128 MHz

射频激发一停止，磁化就会通过弛豫机制恢复到平衡状态。弛豫过程中伴随的信号损失可通过不同技术逆转，逆转后的信号可被记录！

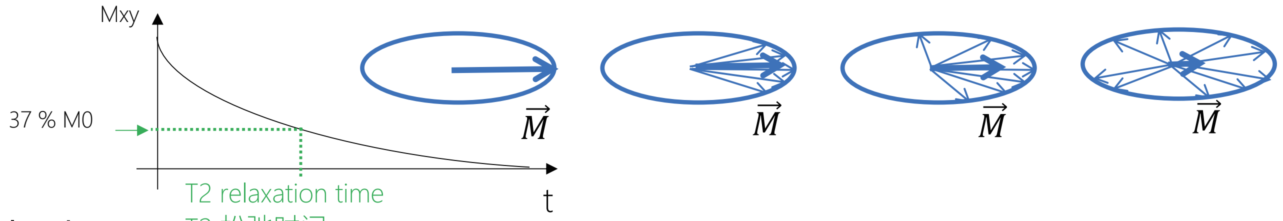
/ Relaxation

Relaxation is happening by two **simultaneous but distinct processes.**



T1 relaxation

Spin energy is dispersed into its environment (mainly nucleus and other atoms), the magnetisation is recovering its initial state along B_0 (longitudinal magnetisation). The mechanism by which M_z exponentially relaxes from a higher energy state to thermodynamic equilibrium is also called **spin-lattice relaxation**.



T2 relaxation

Magnetisation flipped in the transverse plane is reduced due to spin dephasing. Phase coherence is lost, reducing net magnetisation in the x-y plane (while net magnetisation is re-growing in the z direction through T1 relaxation!). The mechanism by which M_{xy} exponentially decays towards its equilibrium value is also called **spin-spin relaxation**.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 弛豫

弛豫由两个同时发生但本质不同的过程组成。

T1 弛豫

自旋能量向周围环境（主要为原子核及其他原子）耗散，磁化沿 B_0 方向恢复初始状态（纵向磁化）。M_z 从高能态向热力学平衡态指数性弛豫的机制也被称为**自旋-晶格弛豫**。

T2 弛豫

被翻转至横断平面的磁化强度因自旋失相位而衰减。由于相位一致性丧失，x-y 平面内的净磁化强度减弱（与此同时，通过 T1 弛豫机制，z 方向的净磁化强度正在重新增长！）。M_{xy} 向平衡值指数性衰减的机制也被称为**自旋-自旋弛豫**。

<!> ATTENTION

T1 is the time constant for regrowth of M_z (longitudinal magnetisation).

T2 is the time constant for decay/dephasing of $M_{x,y}$ (transverse magnetization).

T1 and T2 relaxation times depend on the environment, they are characteristic for different tissues!

Below some examples of T1 and T2 relaxation values at 1.5T

TISSUE TYPE	APPROXIMATE T1 VALUE IN MS	APPROXIMATE T2 VALUE IN MS
Adipose tissues	240-250	60-80
Whole blood (deoxygenated)	1350	50
Whole blood (oxygenated)	1350	200
Cerebrospinal fluid (similar to pure water)	4200 - 4500	2100-2300
Gray matter of cerebrum	920	100
White matter of cerebrum	780	90
Liver	490	40
Kidneys	650	60-75
Muscles	860-900	50

From: https://en.wikipedia.org/wiki/Relaxation_(NMR)

MR Imaging

CHAPTER OUTLINE:

MR 成像

章节大纲：

<!> 注意

T1 是 M_z 重新增长（纵向磁化）的时间常数。

T2 是 $M_{x,\ y}$ 衰减/去相位（横向磁化）的时间常数。

T1 和 T2 弛豫时间取决于环境，是不同组织的特征性参数！

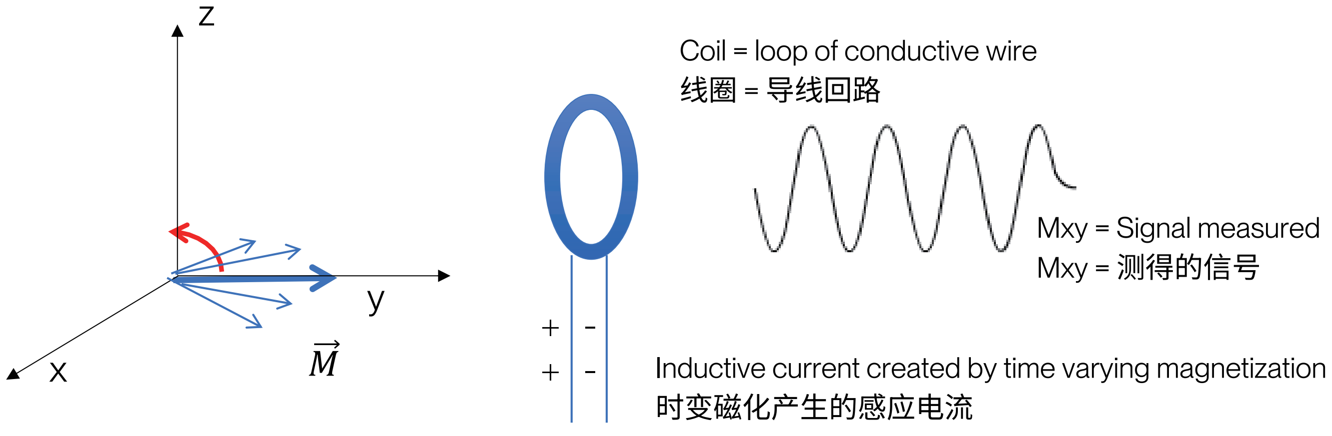
以下为 1.5T 下 T1 和 T2 弛豫值的一些示例

组织类型	近似 T1 值 (MS)	近似 T2 值 (MS)
脂肪组织	240 - 250	60 - 80
全血（脱氧）	1350	50
全血（氧合）	1350	200
脑脊液（类似纯水）	4200 - 4500	2100 - 2300
大脑灰质	920	100
大脑白质	780	90
肝脏	490	40
肾脏	650	60 - 75
肌肉	860 - 900	50

资料来源：https://en.wikipedia.org/wiki/Relaxation_(NMR)

/ Signal Reception

The periodic signal accompanying the relaxation of the excited net magnetisation can be recorded by a coil.



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

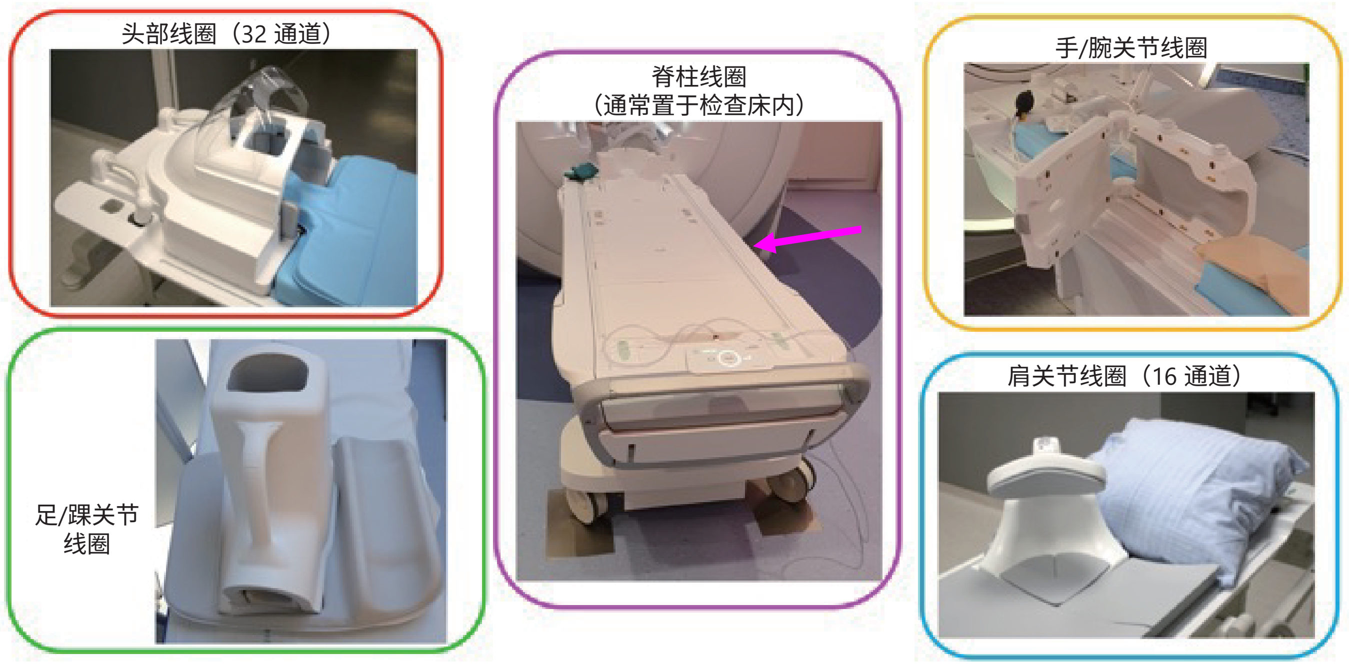
章节大纲：

/ 信号接收

伴随激发态净磁化弛豫过程的周期性信号可通过线圈记录。

Dedicated coils are used for each application:

Modern receiving coils contain several small coils (also called channels), each one receiving the emitted signal. Such configurations help to achieve high signal to noise ratio, as well as a large coverage of the anatomy to investigate.



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

针对不同应用场景，需使用专用线圈：

现代接收线圈包含多个小线圈（亦称为通道），每个通道均可接收发射的信号。这种构造不仅能有效提升信噪比，还可扩大对目标解剖结构的覆盖范围。

/ Spatial Encoding – Z Direction

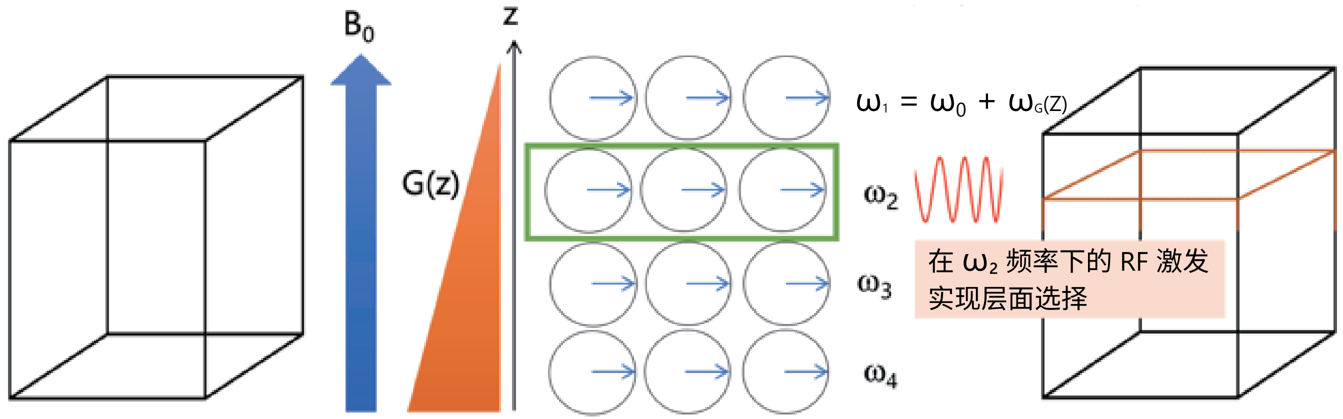
- / At this stage, signal is provided by the whole volume of tissue excited by the RF coil.
- / Remember: the system is composed of 3 gradient coils, one for each geometrical dimension (x, y, z).
- / The gradient coils are used to add some spatial encoding to the signal!
- / How does it work?

Example with slice encoding

Volume excited by the RF tuned at ω_0 (without any gradient).

Addition of magnetic field varying in z direction with the z-gradient.

To spatially select signal coming from one slice, we tune the RF to the corresponding modified frequency, here ω_2 for example.



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 空间编码 - Z 方向

- / 在此阶段，信号由 RF 线圈激发的整个组织体积提供。
- / 请谨记：该系统由 3 组梯度线圈组成，每组线圈对应一个几何维度（x、y、z）。
- / 梯度线圈的作用是为信号添加空间编码！
- / 其工作原理如何?

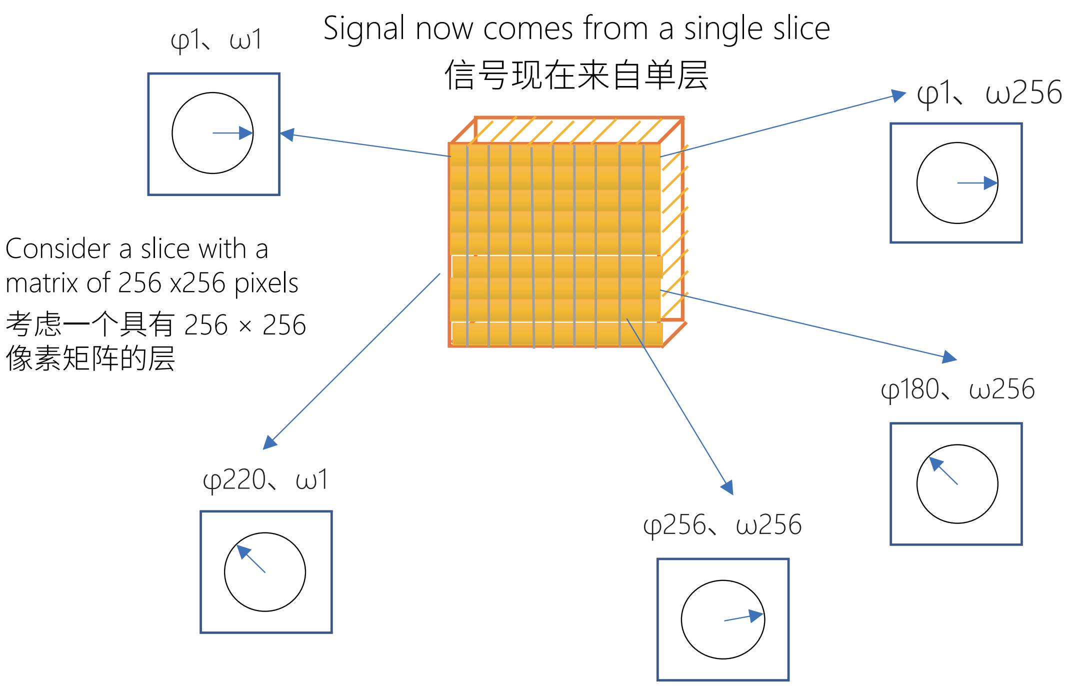
层面编码示例

RF 被调谐至 ω_0 时的射频脉冲所激发的容积（未施加任何梯度）。

通过 z 梯度施加沿 z 方向变化的磁场。

为了在空间上选择来自某一层面的信号，我们将 RF 调谐至对应的调整后频率，例如此处的 ω_2。

To add spatial information on the two other dimensions, x- and y-gradients are also used at specific timing before and during signal reception. They are used to add **spatially varying dephasing** (in the so-called **phase encoding direction**) and spatially varying frequency (in the so-called **frequency direction**).



Each voxel will contain spins with spatial information encoded within:

- / phase φ
- / frequency ω

At this step, the signal received is not yet an image but a complex combination of varying phase and frequency signals.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

为了在另外两个维度上添加空间信息，还需在信号接收前以及接收过程中的特定时间点施加 x 梯度和 y 梯度。其作用是添加**空间变化的去相位**（在所谓的**相位编码方向**上）和空间变化的频率（在所谓的**频率方向**上）。

每个体素中的自旋将携带通过以下参数编码的空间信息：

- / 相位 φ
- / 频率 ω

此时接收到的信号尚不是图像，而是不同相位与频率信号的复杂组合。

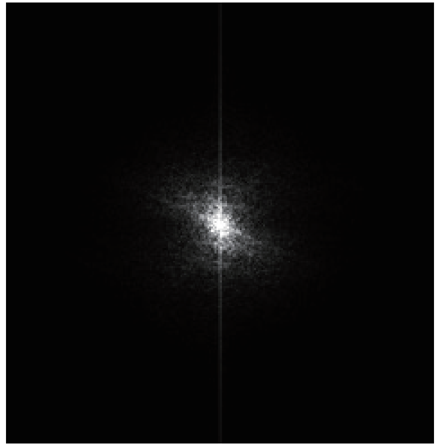
/ Relationship between Signal and Image

The measured signal is in the frequency space, the so called “k-space”. The “k” stands for a number that keeps the gradient spatial encoding information. This “k-space” can be translated into the final image using the **Fourier transform**.

<!> ATTENTION

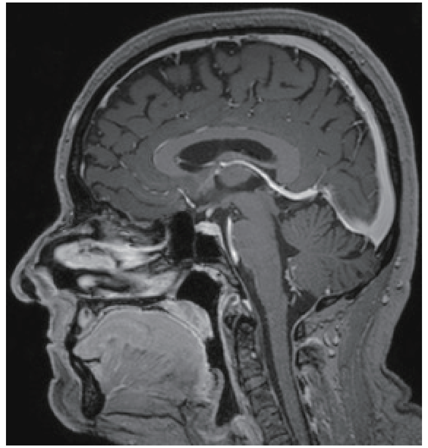
REMEMBER:
Until now we have measured magnetisation of spins with varying additional gradients, to create information contained in the frequency space (k-space). The image will be created by the Fourier transform of this k-space.

K-space
K 空间



Fourier transform
傅里叶变换

image
影像



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 信号与图像的关系

所测量的信号存在于频率空间，即所谓的“k 空间”。“k”代表存储梯度空间编码信息的数值。“k 空间”可通过傅立叶变换转换为最终图像。

<!> 注意

请谨记：
截至目前，我们通过施加变化的附加梯度来测量自旋磁化，以创建频率空间（k 空间）中包含的信息。通过对 k 空间数据进行傅里叶变换而重建出图像。

/ Gradients and MRI Noise

Gradient coils used to add spatial information to the signal produce varying magnetic fields during image acquisition. These variations make the gradient coils vibrate. This is the origin of the loud noise heard during MR image acquisition.

Illustration from: https://pixabay.com/de/photos/mann-arbeiter-presslufthammer-785548/

<!> ATTENTION

The patient must wear **hearing protection** during the exam!

140 dB	= Airplane taking off
130 dB	**= MRI**
110 dB	= Concert or nightclub
95 dB	= school cafeteria
85 dB	= lawn mower
80 dB	= car
60 dB	= conversation

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 梯度与 MRI 噪声

用于为信号添加空间信息的梯度线圈在成像过程中会产生变化的磁场，这些变化会导致梯度线圈振动，这正是 MR 图像采集过程中听到的巨大噪声的来源。

<!> 注意

检查期间，患者必须佩戴听力保护装置！

140 dB	= 飞机起飞
130 dB	**= MRI**
110 dB	= 音乐会或夜总会
95 dB	= 学校食堂
85 dB	= 割草机
80 dB	= 汽车
60 dB	= 交谈

图片来源：https://pixabay.com/de/photos/mann-arbeiter-presslufthammer-785548/

The Spin Echo Sequence

自旋回波序列

MR Imaging

MR 成像

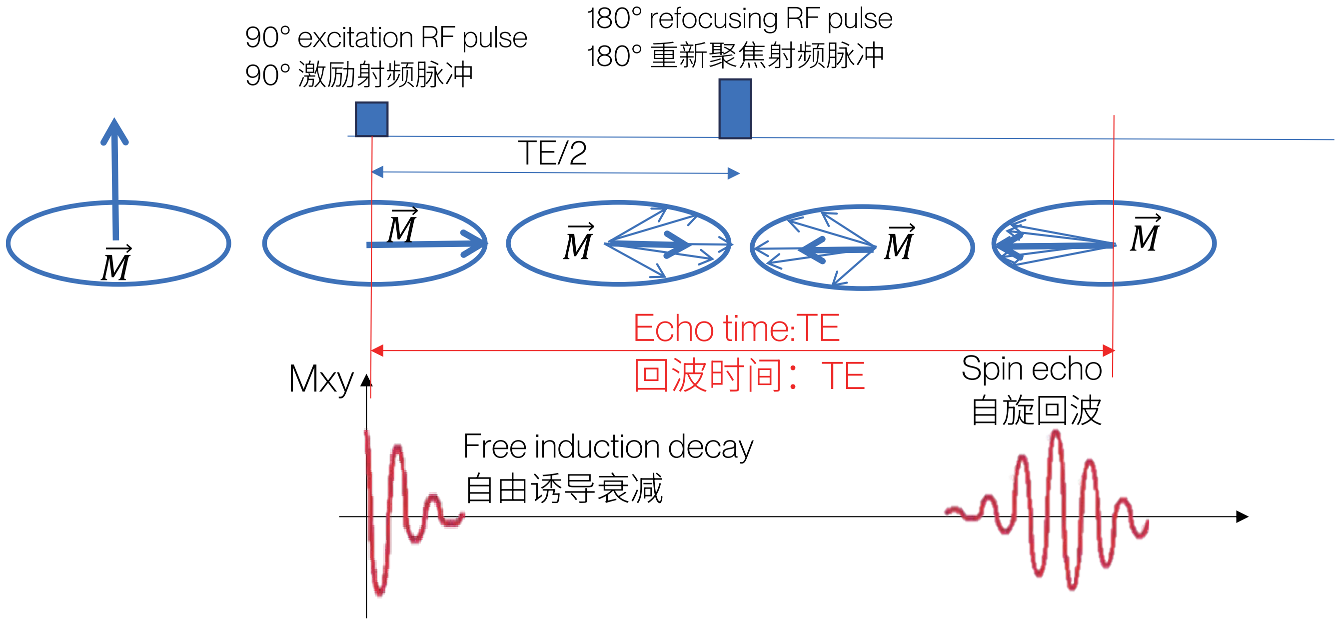
CHAPTER OUTLINE:

章节大纲：

/ What is an Echo?

When the magnetisation is coming back to equilibrium after the application of an RF pulse, the signal produced is called a "**free induction decay**".

When a second RF pulse is used, in particular a 180° pulse, or **refocusing pulse**, then an echo is created! The time between the first RF pulse and the echo is called the **echo time**.



/ MR Imaging

/ MR 成像

/ 什么是回波?

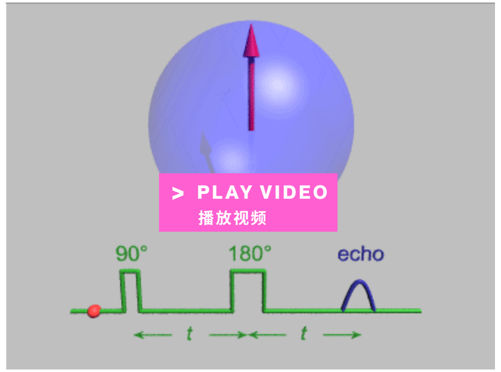
施加射频脉冲后，磁化矢量恢复至平衡状态过程中，所产生的信号被称为“**自由感应衰减**”。

当施加第二个射频脉冲时（尤其是 180° 脉冲或**重聚脉冲**），将产生回波！第一个射频脉冲与回波之间的时间称为**回波时间**。

Between the 90° and the 180° pulses spins are dephasing. Fast spinning components dephase more than slow spinning components. The 180° pulse rephases the spins by “reversing” the dephasing, so the fast-spinning components are then regaining phase to join the slow-spinning components.

Analogy > The Hare and the Tortoise
The Hare : fast spinning component
The Tortoise : slow spinning component

Illustration from: https://en.wikipedia.org/wiki/Spin_echo
Click to Play Video in Browser



Click to Play Video in Browser

MR Imaging

CHAPTER OUTLINE:

MR 成像

章节大纲：

在 90° 与 180° 脉冲之间，自旋质子群会发生相位离散现象。快速自旋成分比慢速自旋成分的相位离散更显著。180° 脉冲通过“逆转”相位离散使自旋质子群相位重聚，进而快速自旋成分与慢速自旋成分相位达到相同状态。

类比 > 野兔和乌龟
野兔：快速自旋成分
乌龟：慢速自旋成分

图片来源：https://en.wikipedia.org/wiki/Spin_echo
单击以在浏览器中播放视频

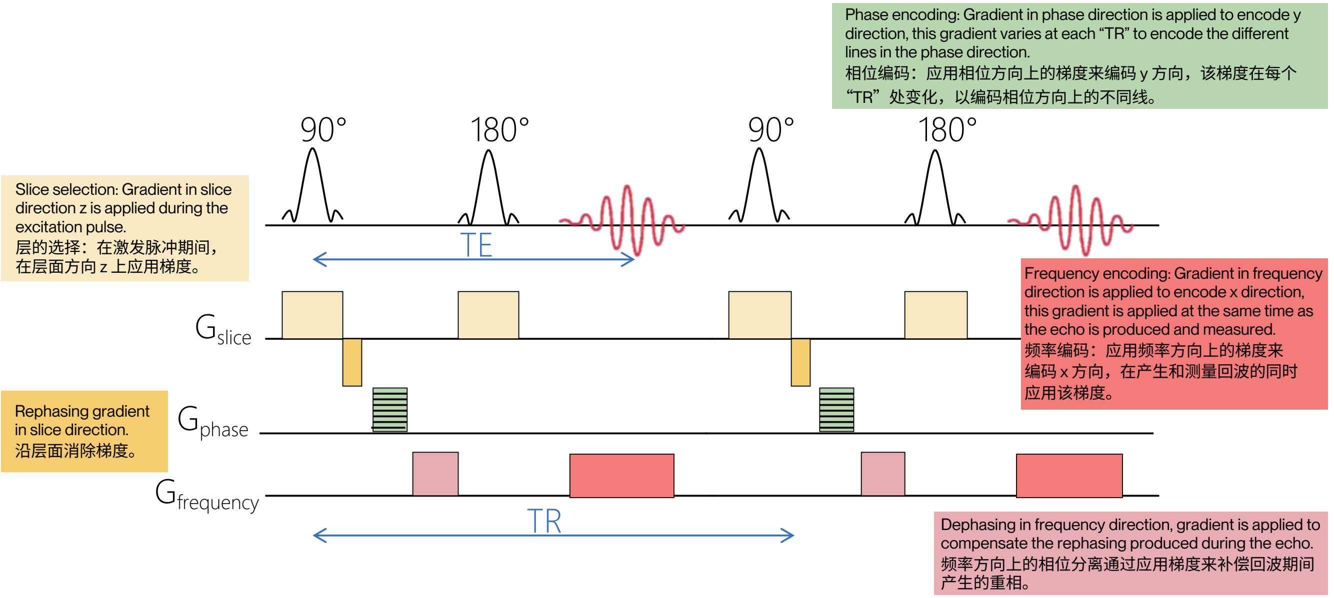
单击以在浏览器中播放视频

As explained previously, the signal coming from the echo is emitted by the whole excited volume!

Gradients are added to encode the spatial origin of the signal. The timing diagram of when and where these gradients are applied regarding the excitation RF pulses and the echo reading represents the “MR sequence”.

There are 2 important timing parameters in the sequence :

- Time between the excitation pulse and the echo: Echo time, TE.
- Time between two successive excitation pulses: Repetition time, TR.
- TE and TR are chosen by the operator!



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CHAPTER OUTLINE:

MR 成像

章节大纲：

如前所述，回波信号由整个被激励的容积发射！

通过施加梯度，可对信号进行空间编码。射频脉冲、梯度场及回波读出的时序，被称为“MR 序列”。

一个序列中有 2 个重要的时间参数：

- 射频脉冲与回波之间的时间：回波时间，TE。
- 两个连续的激励脉冲之间的时间：重复时间，TR。
- TE 和 TR 由操作员选择！

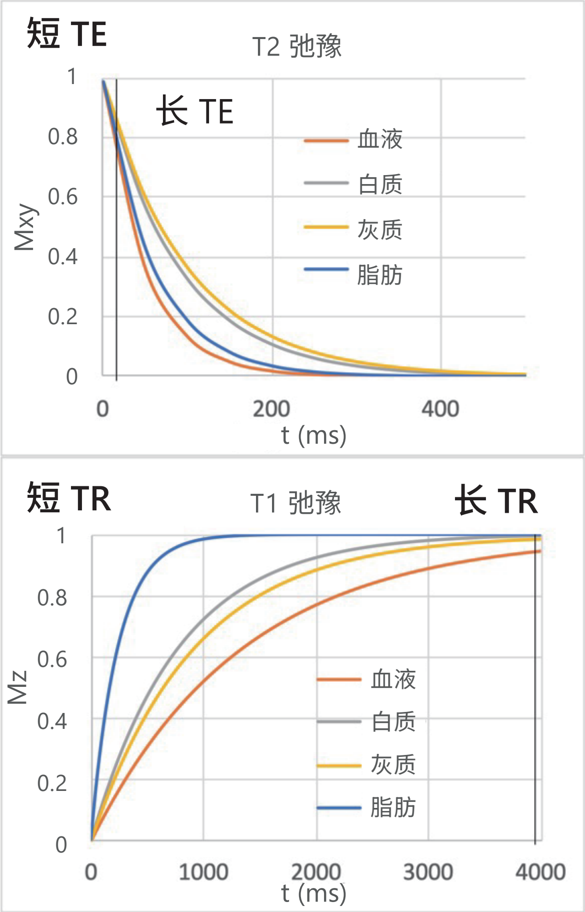
/ Importance of TE and TR for Contrast

Long TE contributes to T2 contrast.

- / Signal is less prominent for fast dephasing spins (low T2) than for slow dephasing spins (high T2).
- / Short TE does not allow spins to dephase, no contribution of T2 contrast in the signal.

Short TR contributes to T1 contrast.

- / Magnetisation regrowing is not complete, slowly growing magnetisation will give less signal (high T1) than fast growing magnetisation (low T1).
- / Long TR lets the longitudinal magnetisation regrowth to its original state, no contribution to T1 contrast.



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ TE 和 TR 对于对比度的重要性

长 TE 有助于产生 T2 对比。

- / 慢速相位离散自旋群的信号（高 T2）高于快速相位离散自旋群的信号（低 T2）。
- / TE 短，自旋群相位离散现象来不及发生，因此信号中不包含 T2 对比信息。

短 TR 有助于增产生T1 对比。

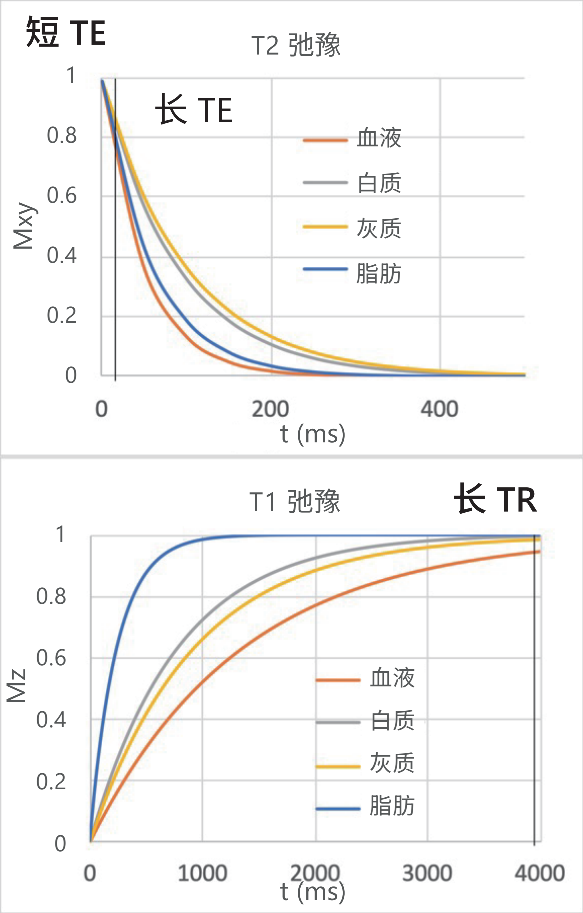
- / 纵向磁化恢复不完全，磁化恢复慢的组织产生的信号（高 T1）低于磁化恢复快的组织产生的信号（低 T1）。
- / 长 TR 可使纵向磁化重新恢复至原始状态，T1 对比消失。

To obtain an image without T1 nor T2 contrast but only sensitive to proton density, a short TE and a long TR should be used.

<-> CORE KNOWLEDGE

Summary:

- / Short TE, short TR : T1-weighted image
- / Long TE, long TR : T2-weighted image
- / Short TE, Long TR : Proton density weighted image
- / (Long TE, short TR is not used in practice)



/ MR Imaging

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/ MR 成像

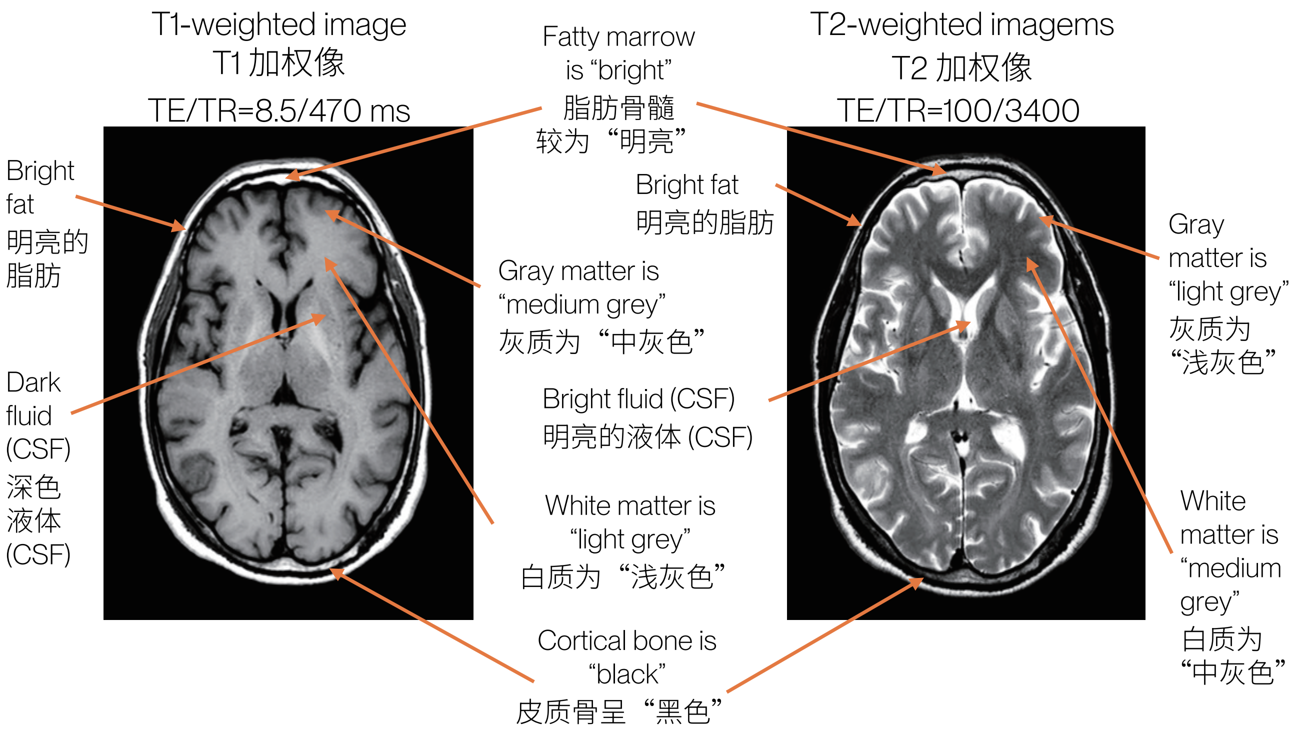
章节大纲：

若想获取无 T1 对比及 T2 对比，仅对质子密度敏感的图像，应采用短 TE 和长 TR。

<-> 核心知识

总结：

- / 短 TE、短 TR：T1 加权像
- / 长 TE、长 TR：T2 加权像
- / 短 TE、长 TR：质子密度加权像
- / （实际工作中不使用长 TE、短 TR）



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ MRI Sequences: Why are They so Long?

The **acquisition time** of an MRI sequence depends mainly on TR, on the number of phase encoding lines (matrix) and on the number of slices:

Acquisition time = TR · NPy · Nslices
- / TR = Repetition time
- / NPy = Number of phase encoding lines
- / Nslices = Number of slices

Example for a T1 sequence:
TR = 500 ms, 128 matrix size, 10 slices;
Acquisition time = 0.5 sec * 128 * 10 = 10 min 40 sec!

MRI is a slow acquisition technique!

In practice, several techniques have been developed to accelerate sequence acquisition:

- / Typical acquisition time for a 2D sequence covering the whole brain is 2 to 4 minutes.
- / Acquisition for 3D sequences is longer, typically around 4 to 6 minutes

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ MRI 序列：为何如此之长？

MRI 序列的**采集时间**主要取决于 TR、相位编码线（矩阵）的数量和层数：

采集时间 = TR · NPy · Nslices
- / TR = 重复时间
- / NPy = 相位编码线数量
- / Nslices = 层数

T1 序列示例：
TR = 500 ms，矩阵大小 128，10 层；
采集时间 = 0.5 s * 128 * 10 = 10 min 40 s！

MRI 是一种慢速采集技术！

实际应用中，为提高采集速度已开发出多种技术：

- / 覆盖全脑的 2D 序列的采集时间一般为 2 - 4 min。
- / 3D 序列的采集时间更长，通常约为 4 - 6 min

The Gradient Echo Sequence

MR Imaging

CHAPTER OUTLINE:

MR 成像

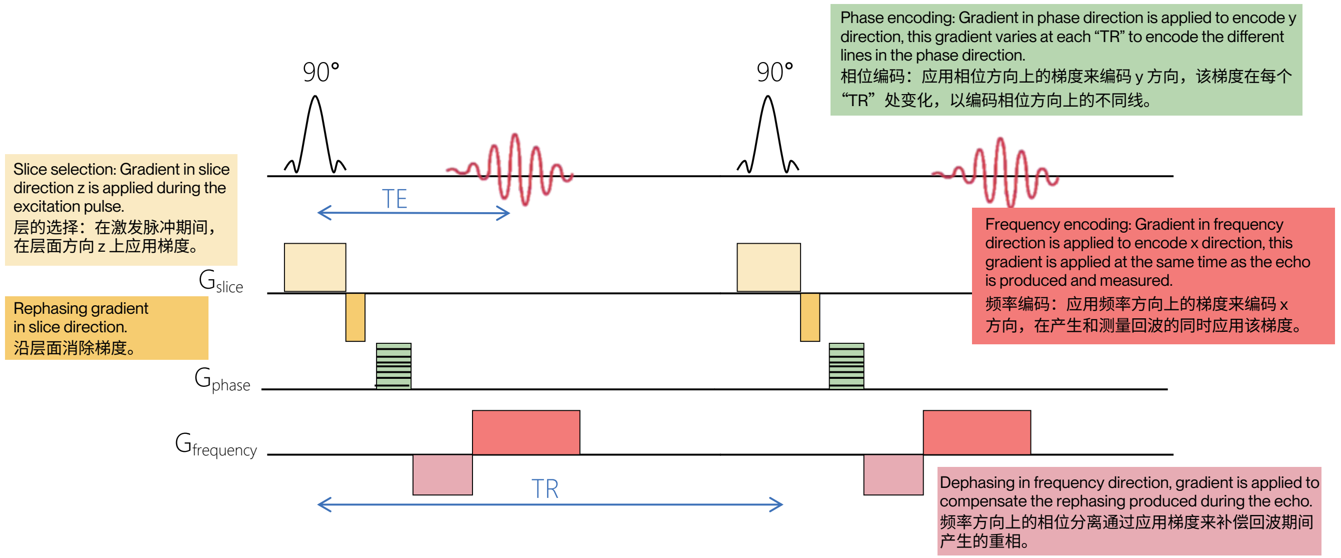
章节大纲：

梯度回波序列

The Gradient Echo (GRE) Sequence

The GRadient Echo (GRE) sequence doesn't use a 180° RF pulse to refocus the dephasing spins but uses instead a gradient to dephase and then rephase the spins, thus creating an echo.

This can shorten a lot the TE and TR and make faster images!
But... it adds dephasing errors, so it is more prone to artifacts.



MR Imaging

CHAPTER OUTLINE:

MR 成像

章节大纲：

梯度回波 (GRE) 序列

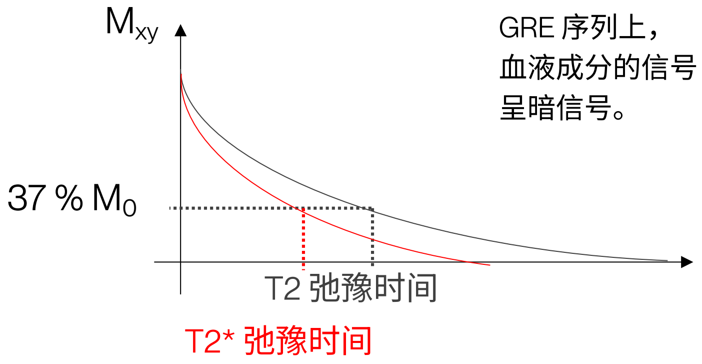
梯度回波 (GRE) 序列不使用 180° RF 脉冲重聚相位，而是通过梯度使相位离散之后再重聚，从而产生回波。

这样可大幅缩短 TE 和 TR，从而加快成像速度！
但是...它增加了相位离散误差，因此更容易产生伪影。

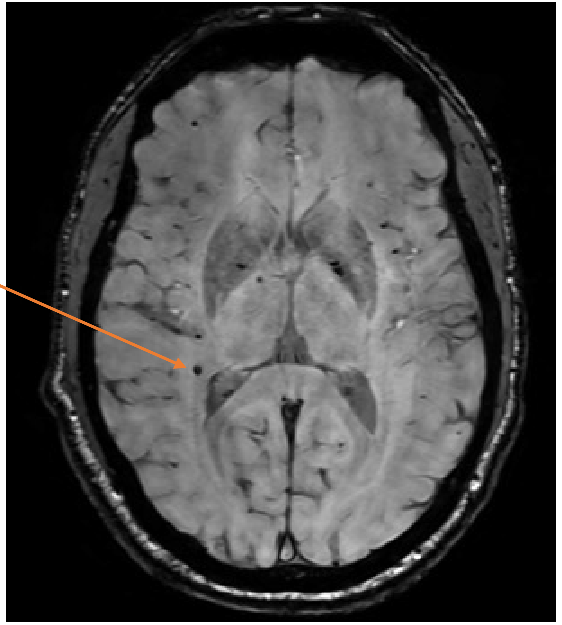
Since there is no more refocusing RF pulse, spin dephasing is now due to local magnetic field inhomogeneities in addition to the T2 effect. Therefore, the signal decreases with the T2* constant. The difference between T2 and T2* is that T2 is the ideal spin-spin relaxation caused by atomic/molecular interactions whereas T2* is the observed T2 (i.e., T2 affected by local field inhomogeneities).

<!> ATTENTION

This effect allows a **high sensitivity to local magnetic inhomogeneities** typically around blood degradation products and calcifications that are locally disturbing the magnetic field.



GRE 序列上，血液成分的信号呈暗信号。



T2* 始终 ≤ T2！

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

由于不再使用重聚相位的 RF 脉冲，因此除 T2 效应外，自旋群相位离散还受局部磁场不均匀性的影响。因此，信号衰减速率由 T2* 常数决定。T2 与 T2* 的区别在于：T2 是由原子/分子相互作用引起的理想的自旋-自旋弛豫，而 T2* 是实际观察到的 T2（即受局部磁场不均匀性影响的 T2）。

<!> 注意

这种效应使其对局部磁场不均匀性具有高度敏感性，常见于血液降解产物及钙化灶周围，容易对磁场造成局部干扰。

Other Sequences: The MRI Jungle

MR Imaging

CHAPTER OUTLINE:

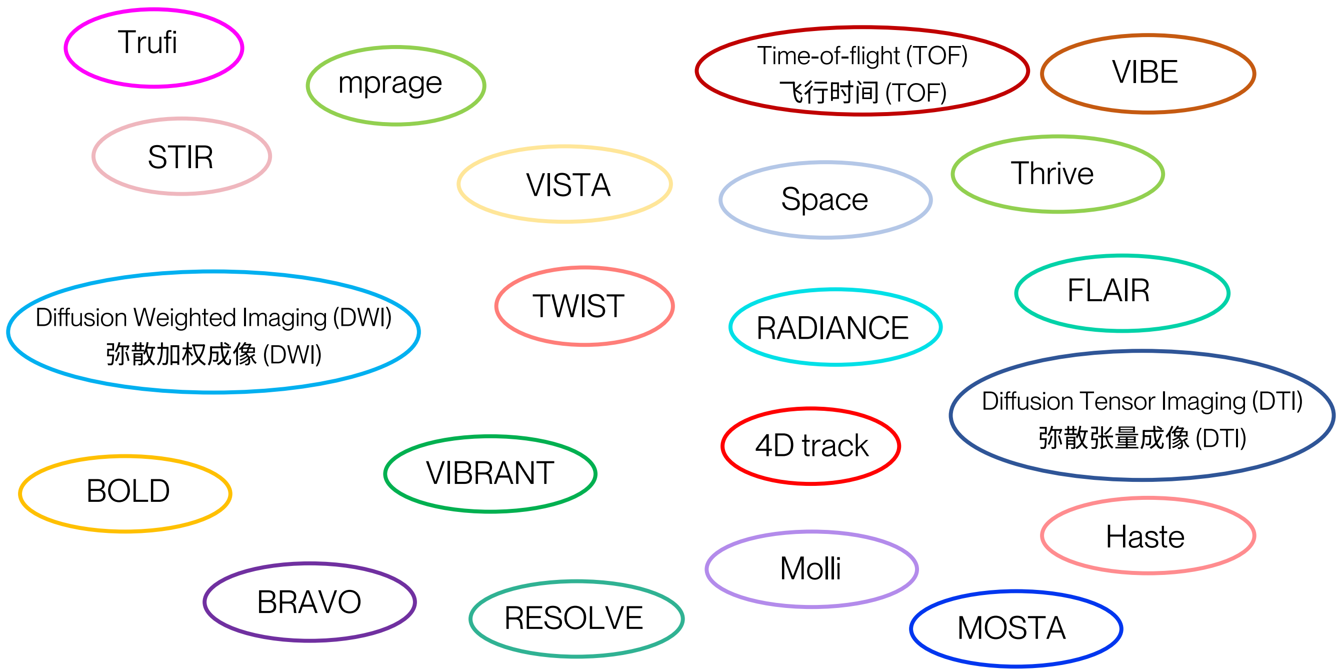
MR 成像

章节大纲：

其他序列：MRI 序列合集

/ Other Sequences : The MRI Jungle

Many different types of sequences are used for MR imaging named differently by each vendor. Nearly all are derived from SE or GRE sequences.



/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

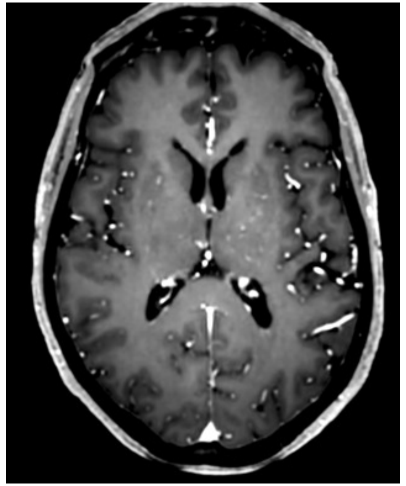
章节大纲：

/ 其他序列：MRI 序列合集

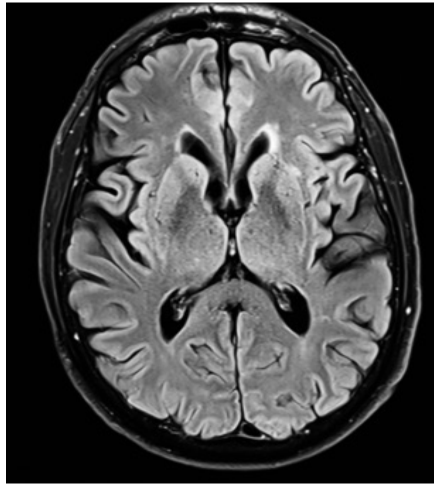
MR 成像采用多种不同类型的序列，不同厂商对其命名存在差异。但几乎所有序列均衍生自 SE 或 GRE 序列。

/ Inversion Recovery (IR)

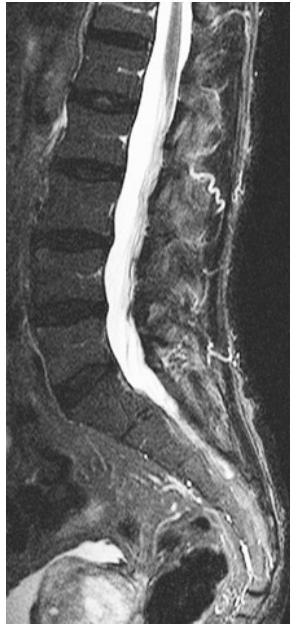
Adding a preparation pulse **before** the acquisition of the signal can increase tissue contrast or remove signal from a specific tissue. The IR-sequence uses an inversion pulse (180°) before the sequence to invert the entire magnetisation. IR techniques are widely used in neuroradiology, head and neck and cardiac Imaging applications.



IR-prepared 3D T1-weighted GRE sequence: Inversion pulse increases white matter/grey matter contrast (this image is acquired after contrast agent injection).



Fluid Attenuated IR (FLAIR): Inversion pulse is used to remove signal from cerebrospinal fluid. Hyperintense signal in white matter lesions is more visible.



STIR: Inversion pulse removes signal from fat. Hyperintense signal due to fluids or oedema is more visible.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 反转恢复 (IR)

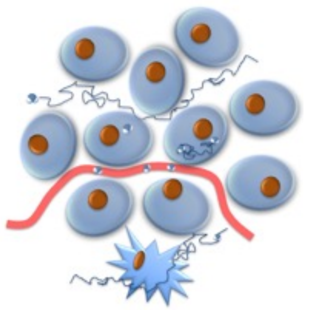
在信号采集前施加准备脉冲可增强组织对比度或消除特定组织的信号。IR 序列通过在序列前施加反转脉冲 (180°) 来反转整个磁化矢量。IR 技术广泛用于神经影像、头颈部和心脏影像。

IR 准备 3D T1 加权 GRE 序列：反转脉冲可增强白质与灰质的对比度（该图像在注射对比剂后采集）。

液体衰减反转恢复 (FLAIR)：通过反转脉冲消除脑脊液信号，使白质病变的高信号更显著。

STIR：通过反转脉冲移除脂肪信号，使液体或水肿引起的高信号更显著。

/ Diffusion Weighted Imaging (DWI)

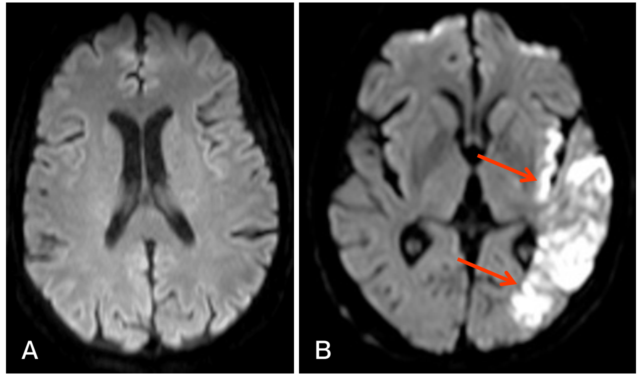


Diffusion is defined as the transport of matter resulting from the migration of atoms due to the random movements caused by differences in temperature or concentration.

> <!> ATTENTION
>
> **One of the successes of MRI is the ability to detect cellular oedema in the very early stages of a stroke, before any other type of imaging modality can show the stroke.**

MRI can be sensitive to water molecule diffusion, which depends on the environment (intracellular, extracellular, intravascular water). The MRI signal can, therefore, reflect cellular membrane integrity or cellular density.

In stroke, due to hypoperfusion, there is failure of the sodium/potassium pumps of cell membranes in the affected areas. This creates an influx of intracellular water, thus decreasing diffusion movement ("restricted diffusion"). On MRI, there is an increased signal on the DWI image.



Diffusion-weighted Images (b1000) in a normal brain (A) and in a patient with stroke in the middle cerebral artery territory (B).

> <!> ATTENTION
>
> **Hypercellular tumours also show restricted diffusion because the free movement of water molecules is hindered by the densely packed cells.**

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 扩散加权成像 (DWI)

扩散是指物质因温度或浓度差异引起的原子随机运动现象。

MRI 对水分子扩散敏感，而水分子扩散特性取决于环境（细胞内、细胞外、血管内的水）。因此，MRI 信号可反映细胞膜完整性或细胞密度。

> <!> 注意
>
> **MRI 的一项重要突破是能够在卒中的极早期（早于其他任何影像学检查手段）检测到细胞水肿。**

发生卒中时，因低灌注导致梗死区细胞膜钠钾泵功能障碍，引发细胞内水潴留，水分子扩散运动减弱（“扩散受限”），MRI 表现为 DWI 高信号。

> <!> 注意
>
> **富细胞的肿瘤因其密集排列的细胞阻碍了水分子自由运动，也表现为扩散受限。**

正常大脑 (A) 和大脑中动脉供血区卒中患者 (B) 的扩散加权图像 (b1000)。

/ Diffusion Tensor Imaging (DTI)

Biological tissues are highly **anisotropic** > i.e., the diffusion rate is NOT the same in all directions.

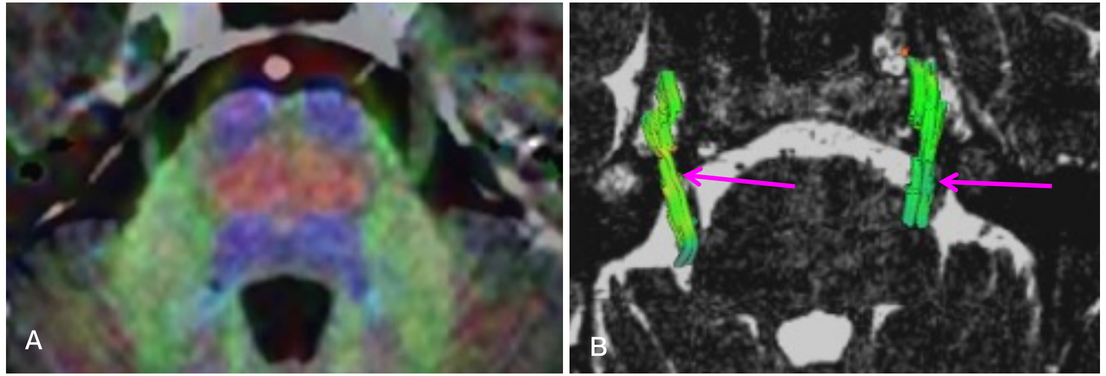
Water diffusion in the brain is **constrained by fibres**. The MRI signal is sensitive to the **preferential direction of motion** of water molecules. This can be used to “track” fibres and depict white matter tracts. The anatomical orientation of axons and fibres is coded with colours on DTI images, each colour corresponding to a specific direction of the fibres:

/ **Red** > transverse orientation

/ **Green** > anterior-posterior or posterior-anterior

/ **Blue** > craniocaudal orientation

Fibre tracts are then reconstructed depending on the clinical question using a dedicated software. Quantitative measures can be obtained, e.g., measuring the **fractional anisotropy (FA)** which is thought to reflect fibre density, myelination and axonal diameter.



Example of a DTI examination in trigeminal neuralgia. DTI images with overlaid colour-by-orientation fibres at the mid-pontine level (A). Reconstructed tracts of the trigeminal nerves onto colour-by-code orientation (B).

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 扩散张量成像 (DTI)

生物组织具有高度**各向异性**>，即扩散速率在不同方向上不一致。

脑内水分子扩散**受纤维约束**，MRI 信号对水分子**运动的优先方向**敏感，因此可用于“追踪”纤维束并显示白质通路。DTI 图像中，轴突与纤维的解剖走行以不同颜色表示，每种颜色对应纤维的特定方向：

/ **红色** > 横向

/ **绿色** > 前后或后前方向

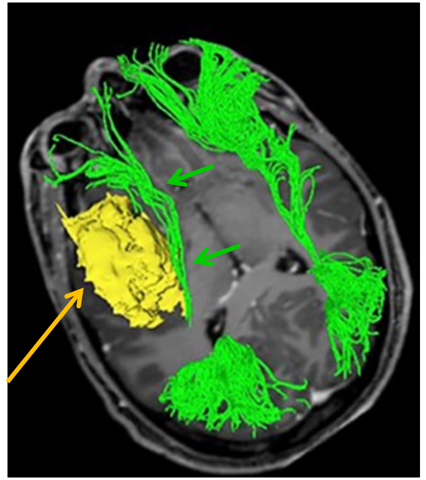
/ **蓝色** > 头尾方向

基于临床需求，可通过专用软件重建纤维束。可进行定量测量，例如测量**各向异性分数 (FA)**，其被认为反映了纤维密度、髓鞘形成及轴突直径。

三叉神经痛的 DTI 检查示例。中脑桥水平叠加纤维的 DTI 图像 (A)，彩色代表纤维走行方向。基于颜色编码重建的三叉神经纤维束 (B)。

<!> ATTENTION

In addition to showing the 3D representation of fibre tracts, DTI can detect micro-structural changes in the absence of morphologic changes. It can reveal altered white matter connectivity and allows quantitative evaluation of the integrity of different brain circuits in a variety of conditions including tumours, demyelinating diseases, trauma, Parkinson disease, pain syndromes, depression and anxiety disorders and many more.



Example of a left temporo-insular low-grade glioma (LGG) and fibre tract involvement. 3D reconstruction of the tumour (yellow), which involves the fronto-occipital longitudinal fasciculus (green).

Reproduced from: Ius T et al. Risk Assessment by Pre-surgical Tractography in Left Hemisphere Low-Grade Gliomas. Front Neurol. 2021 Feb 15;12:648432. doi: 10.3389/fneur.2021.648432.

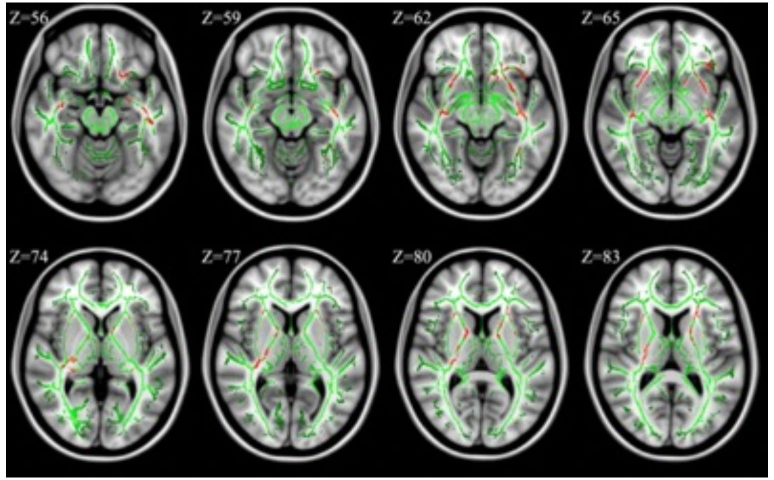


Image illustrating white matter abnormalities in adolescents with generalised anxiety disorder (GAD). Voxels are overlaid on the white matter skeleton (green). The regions of significant FA reduction in comparison to adolescents without GAD are shown in red.

Reproduced from: Liao, M. et al. White matter abnormalities in adolescents with generalized anxiety disorder: a diffusion tensor imaging study. BMC Psychiatry 14, 41 (2014). https://doi.org/10.1186/1471-244X-14-41

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

<!> 注意

除显示纤维束三维结构外，DTI 还可在形态学改变发生之前，检测到微结构改变。它可以揭示白质连接改变，并定量评估多种疾病（包括肿瘤、脱髓鞘病、创伤、帕金森病、疼痛综合征、抑郁及焦虑障碍等）不同脑环路的完整性。

左侧颞岛叶低级别胶质瘤 (LGG) 合并纤维束受累示例。肿瘤（黄色）三维重建显示其侵犯额枕纵束（绿色）。

来源： Ius T et al. Risk Assessment by Pre-surgical Tractography in Left Hemisphere Low-Grade Gliomas. Front Neurol. 2021 Feb 15;12:648432. doi: 10.3389/fneur.2021.648432.

图中显示一名广泛性焦虑障碍 (GAD) 青少年的白质异常情况。体素叠加于白质骨架（绿色）之上。与无 GAD 者相比，GAD 青少年 FA 显著减低区域用红色表示。

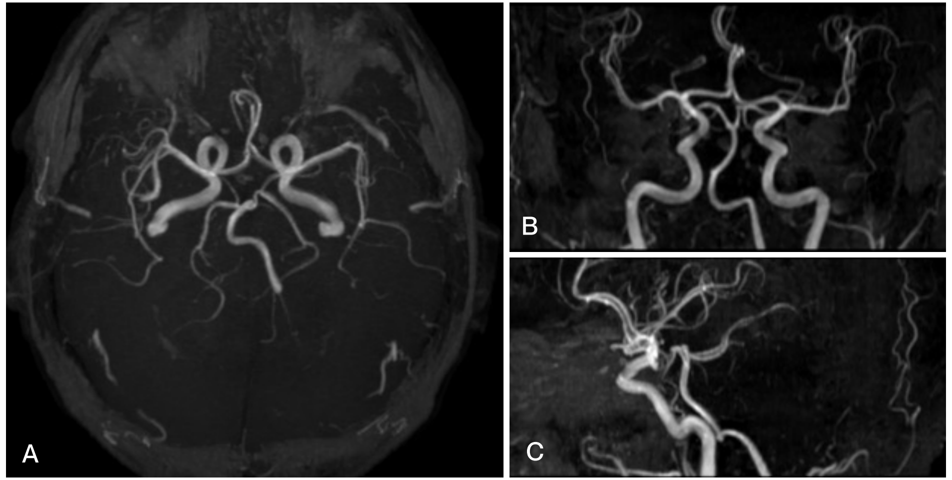
来源： Liao, M. et al. White matter abnormalities in adolescents with generalized anxiety disorder: a diffusion tensor imaging study. BMC Psychiatry 14, 41 (2014). https://doi.org/10.1186/1471-244X-14-41

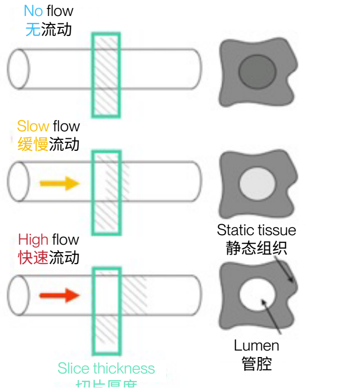
/ Time of Flight (TOF) MR Angiography (MRA)

The Time of Flight (TOF) MRA sequence allows visualisation of flowing blood in vessels thus providing angiographic images **without** the need of injecting contrast agents. The TOF sequence is based on the principle of **flow related enhancement** (i.e., fresh blood has a high initial magnetisation as opposed to stationary tissues, which are magnetically saturated by multiple repetitive RF pulses). On the TOF sequence, the signal of inflowing blood appears very bright (see below). The maximal flow enhancement occurs when the vessel is perpendicular to the imaging plane.

<!> ATTENTION

TOF is one of the most useful techniques for non-contrast neurovascular and peripheral MRA
> See eBook chapter on Vascular Imaging





TOF image : Maximum Intensity Projection (MIP) of the polygon of Willis: axial (A), coronal (B) and sagittal (C) views.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 时间飞跃 (TOF) MR 血管成像 (MRA)

时间飞跃 (TOF) MRA 序列可使血管内流动血液可视化，从而实现血管成像，且**无需**注射对比剂。TOF 序列基于**流动相关增强**原理（即，新鲜血液具有较高的初始磁化强度，而静止组织因多次重复 RF 脉冲达到磁饱和）。在 TOF 序列中，血液流入信号非常高（见下文）。当血管垂直于成像平面时，血流增强效应最显著。

<!> 注意

TOF 是无对比剂神经血管和外周 MRA 最常用的技术之一 > 请参阅《血管成像》电子书章节

TOF 图像：Willis 环最大密度投影 (MIP)：轴位 (A)、冠状位 (B) 和矢状位 (C) 视图。

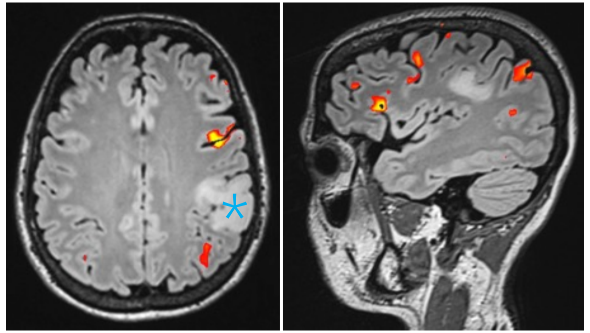
/ Functional MRI (fMRI)

Blood Oxygenation Dependent (BOLD) imaging, is the standard **functional** MRI modality, which provides information about cerebral areas that are activated while performing certain tasks. For example, it is possible to identify the areas of language in the brain. This is very useful to determine if an area is impacted by surgery or if a lesion is located in immediate vicinity of an area that needs to be resected.

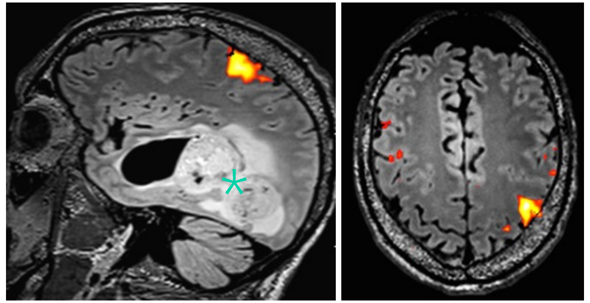
BOLD imaging is based on the principle that if a task leads to an increase in the activity of a specific brain region, there is an **initial drop in oxygenated haemoglobin and an increase in CO_2 and deoxygenated haemoglobin**. After a delay of a few seconds, the increased cerebral blood flow (CBF) delivers a **surplus** of oxygenated haemoglobin, which "washes away" deoxyhaemoglobin.

Oxygenated and deoxygenated haemoglobin differ significantly with respect to their **paramagnetic** properties.

T2* sequences are used to detect these differences, which are in the range of 1-5%.



Example of BOLD fMRI maps obtained in a patient with a high-grade glioma (blue) and silent word generation task producing activation of the left prefrontal cortex and Broca's area. Figure courtesy José Manuel Baiao Boto, Division of Neuroradiology, Geneva University Hospitals.



Example of BOLD fMRI maps obtained in a patient with a high-grade glioma (asterisk) and right-sided finger tapping. The contralateral (left) sensorimotor cortex is most strongly activated. Figure courtesy José Manuel Baiao Boto, Division of Neuroradiology, Geneva University Hospitals.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 功能性 MRI (fMRI)

血氧水平依赖 (BOLD) 成像是功能性 MRI 的基本技术，用于定位执行特定任务时激活的脑区，例如识别大脑语言区。该项技术对于评估手术是否影响某脑区或病变是否邻近需切除的脑区具有重要价值。

BOLD 成像的原理是，如果某一任务导致特定脑区活动增加，则氧**合血红蛋白减少，而 CO_2 及脱氧血红蛋白增加**。延迟数秒后，脑血流 (CBF) 增加带来过量氧合血红蛋白，从而"冲走"脱氧血红蛋白。

氧合血红蛋白与脱氧血红蛋白的**顺磁性**差异显著。

T2* 序列可检测这些差异，变化范围为 1%-5%。

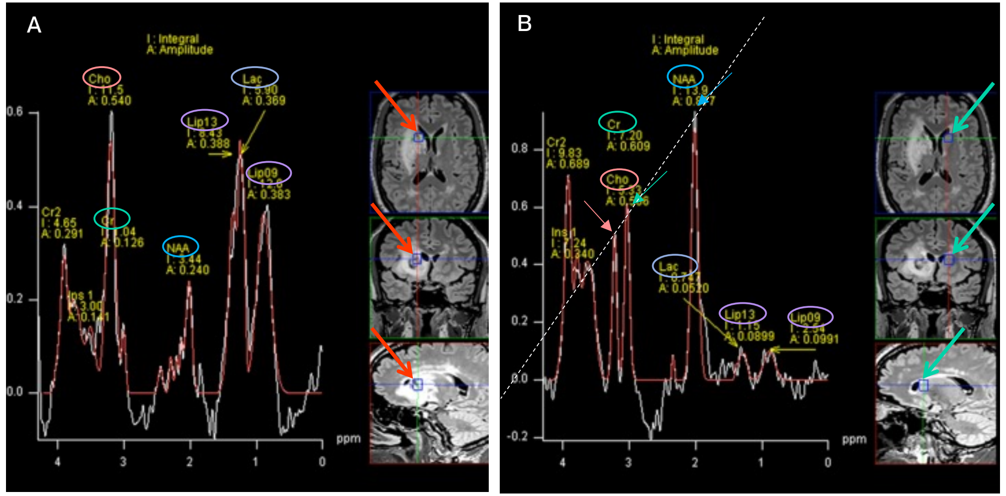
图中显示的是一名高级别胶质瘤（蓝色）患者在执行无声单词生成任务时，左侧前额皮质及 Broca 区激活的 BOLD fMRI 图示例。图片来源：José Manuel Baiao Boto，Division of Neuroradiology，Geneva University Hospitals。

图中显示的是一名高级别胶质瘤（星号）患者执行右侧手指敲击任务时获得的 BOLD fMRI图像。对侧（左侧）感觉运动皮质激活最显著。图片来源：José Manuel Baiao Boto，Division of Neuroradiology，Geneva University Hospitals。

/ MR Spectroscopy (MRS)

MR Spectroscopy (MRS) is a method to measure the chemical composition of tissue. It allows measurement of metabolites **in vivo in specific brain regions** such as N-acetyl aspartate (NAA), Choline (Cho), Creatine (Cr), and others. MRS uses the fact that the proton resonant frequency is **slightly different** for each metabolite compared to water.

MRS is **mostly used in the brain**, but it is not restricted to this area. Advances were made to increase the spatial resolution and even create metabolite maps of the brain. Most common indications for MRS include imaging of gliomas, post-radiation changes, ischemia, white matter and mitochondrial diseases. MRS increases specificity and correlates with the histologic grade of a tumour.



MRS obtained in a patient with a high-grade glioma in the right basal ganglia (red arrows) (A) showing metabolite changes. As the tumour grade increases, NAA and Cho decrease whereas lipids (Lip) and lactate (Lac) increase. Normal MRS metabolites in the left basal ganglia (green arrow), (B). Measurements on the left are used as control. Note that the normal Cho, Cr and NAA peaks are on a line which has a 45-degree angle with the x- axis (Hunter's angle). Figure courtesy José Manuel Baiao Boto, Division of Neuroradiology, Geneva University Hospitals.

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ MR 波谱 (MRS)

MR 波谱 (MRS) 是一种测量组织化学成分的方法。它可以在体内测**量特定脑区**的代谢物，如 N-乙酰天冬氨酸 (NAA)、胆碱 (Cho)、肌酸 (Cr) 等。MRS 的原理基于与水相比，不同代谢物的质子共振频率**存在的轻微差异**。

MRS **主要用于脑**，但不局限于此。技术进步提升了空间分辨率，甚至可实现脑代谢物图谱绘制。MRS 最常见的适应证包括胶质瘤成像、放疗后改变、缺血、白质疾病和线粒体疾病。MRS 具有更高的特异性并与肿瘤病理分级相关。

右侧基底节高级别胶质瘤（红色箭头）患者的 MRS (A) 显示代谢物变化。随着肿瘤级别增加，NAA 和 Cho 降低，而脂质 (Lip) 和乳酸 (Lip) 升高。左侧基底节（绿色箭头）中的正常 MRS 代谢物 (B)。左侧测量值用作对照。请注意，正常 Cho、Cr 和 NAA 峰在与 x 轴成 45 度角（Hunter 角）的直线上。图片来源：José Manuel Baiao Boto，Division of Neuroradiology，Geneva University Hospitals。

Contrast Agents in MRI

MR Imaging

CHAPTER OUTLINE:

MR 成像

章节大纲：

MRI 对比剂

/ MRI Contrast Agents

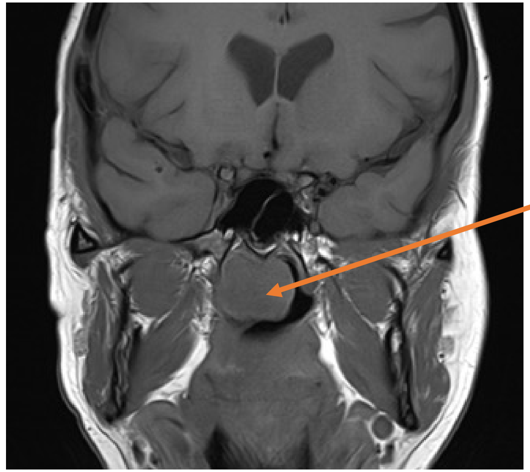
Contrast agents (CA)s used in MRI are mostly based on gadolinium chelates. Gadolinium is paramagnetic and has the property of reducing T1 relaxation of surrounding tissues, thus rendering them hyperintense on T1 contrast. At high concentrations, gadolinium-based CA also shortens T2 relaxation time. It normally stays extracellular in the circulation and microcirculation system and it is excreted by the kidneys.

<!> ATTENTION

Safety: Nephrogenic Systemic Fibrosis (NSF)

In 2006 gadolinium-based contrast agents were recognised to be the potential triggers of a late inflammatory and fibrotic disease of soft tissues in patients with severe renal function impairment: nephrogenic systemic fibrosis (NSF). Even though NSF is rare it remains mandatory to **screen patients for renal dysfunction prior to Gd-chelate administration, and to assess risk and benefits** prior to contrast agent injection.

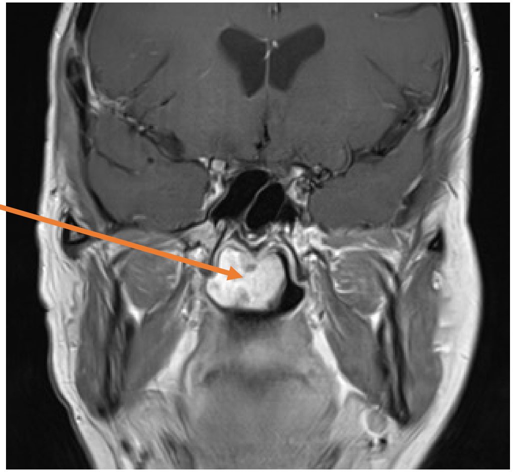
> See eBook chapter on Contrast Agents.



T1 SE

Enhancing signal in the lesion after contrast injection

注射对比剂后
病灶内的强化信号



T1 SE with Gd

使用钆对比剂后的 T1 SE

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ MRI 对比剂

MRI 中使用的对比剂 (CA) 主要基于钆螯合物。钆具有顺磁性，可通过缩短周围组织的 T1 弛豫时间，使其在 T1 对比度上呈现高信号。高浓度含钆 CA 还可缩短 T2 弛豫时间。其通常停留于循环系统及微循环的细胞外间隙，并通过肾脏排泄。

<!> 注意

安全性：肾源性系统性纤维化 (NSF)

2006 年，人们认识到含钆对比剂是重度肾功能损伤患者发生软组织晚期炎症及纤维化性疾病——肾源性系统性纤维化 (NSF) 的潜在触发因素。尽管 NSF 罕见，但在**使用钆螯合物前，必须筛查患者是否存在肾功能不全，并评估对比剂注射的风险与获益**。

> 请参阅《对比剂》电子书章节。

Gadolinium (Gd) accumulation in the central nervous system

Accumulation of Gd in central nervous system (CNS), basically in the basal ganglia, was reported in patients with multiple administrations of Gd-chelates (2014).

The trans-metalation reaction is a possible mechanism by which the Gd ion is extracted from the chelate by another cation. It has been shown that Gd-chelates with a linear configuration are more at risk to accumulate in the CNS than macrocyclic chelates > **see eBook chapter Contrast Agents**.

This is the reason why the European Medicines Agency recommended to suspend or limit the use of commercially available **linear Gd-based contrast agents**.

Even though Gd accumulation is now well described, there is **no evidence of clinical short- or long-term effects. Precaution principle has to be applied** by reducing amount and frequency of Gd injection when possible.

<∞> REFERENCE

Kanda T, Ishii K, Kawaguchi H, et al. High signal intensity in the dentate nucleus and globus pallidus on unenhanced T1-weighted MR images: relationship with increasing cumulative dose of a gadolinium-based contrast material. Radiology 2014; 270:834-841. (Landmark first report of Gd accumulation in the brain).

/ **MR** Imaging

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章节大纲：

中枢神经系统中的钆 (Gd) 蓄积

报告显示多次使用钆螯合物的患者可见 Gd 在中枢神经系统 (CNS) 中蓄积，主要累及基底节（2014 年）。

金属转移反应可能是其机制之一，即钆离子被另一阳离子从螯合物中置换提取。线性构型的钆螯合物显示较之大环型螯合物更易在 CNS 中蓄积 > **请参阅《对比剂》电子书章节**。

因此，欧洲药品管理局建议暂停或限制市场化使用**线性含钆对比剂**。

尽管钆蓄积现象已被充分认识，但**目前尚无证据显示其短期或长期的临床影响。基于预防原则，**应在可能的情况下减少钆注射的剂量与频率。

<∞> 参考文献

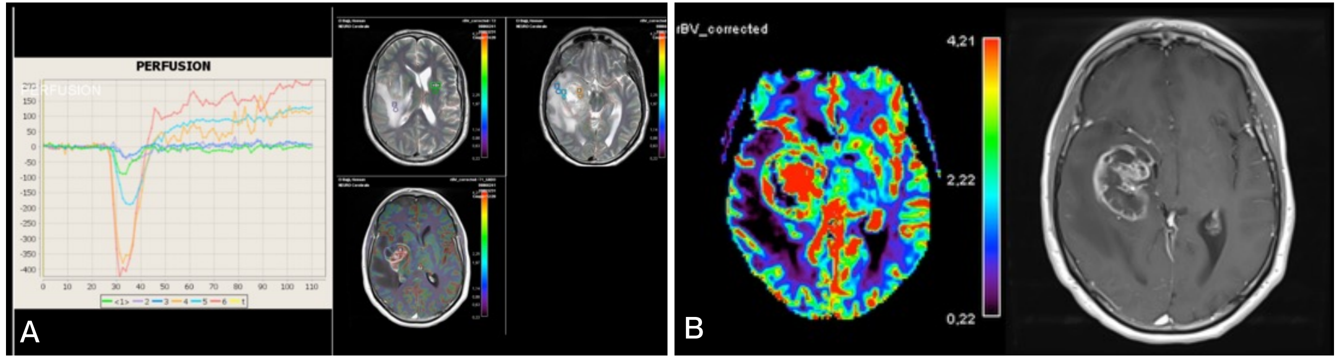
Kanda T, Ishii K, Kawaguchi H, et al. High signal intensity in the dentate nucleus and globus pallidus on unenhanced T1-weighted MR images: relationship with increasing cumulative dose of a gadolinium-based contrast material. Radiology 2014; 270:834-841. (Landmark first report of Gd accumulation in the brain).

/ MRI Perfusion Weighted Imaging (PWI)

MRI PWI encompasses different MRI techniques used to assess **the perfusion of tissues by blood**. To assess perfusion, contrast-enhanced techniques and non-contrast enhanced techniques (e.g., arterial spin labelling, ASL) can be applied.

Dynamic Susceptibility Contrast (DSC) MRI PWI relies on the signal loss induced by a bolus of Gd-based contrast agent **on T2*-weighted sequences**. The calculated parameters include a **Time signal Intensity Curve (TIC)** from which **cerebral blood volume (CBV** = volume of blood in a given brain tissue amount in ml blood/100g brain tissue), **cerebral blood flow (CBF** = CBV per unit of time, in ml blood/100g brain tissue/minute) and other parameters are calculated. These parameters are then used to create colour maps of the brain. Due to the difficulty to precisely calculate CBV and CBF, most often CBV / CBF relative to an internal control, e.g., contralateral normal white matter are calculated (rCBV and rCBF). rCBV and rCBF have no units as they correspond to ratios.

T2*-weighted DSC MRI perfusion in a patient with a glioblastoma. A. TICs obtained in different regions of interest (ROIs). B. rCBV colour map and the corresponding axial contrast enhanced T1 weighted image showing increased tumour perfusion. Figure courtesy José Manuel Baiao Boto, Division of Neuroradiology, Geneva University Hospitals.



/ **MR** Imaging

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章节大纲：

/ MRI 灌注加权成像 (PWI)

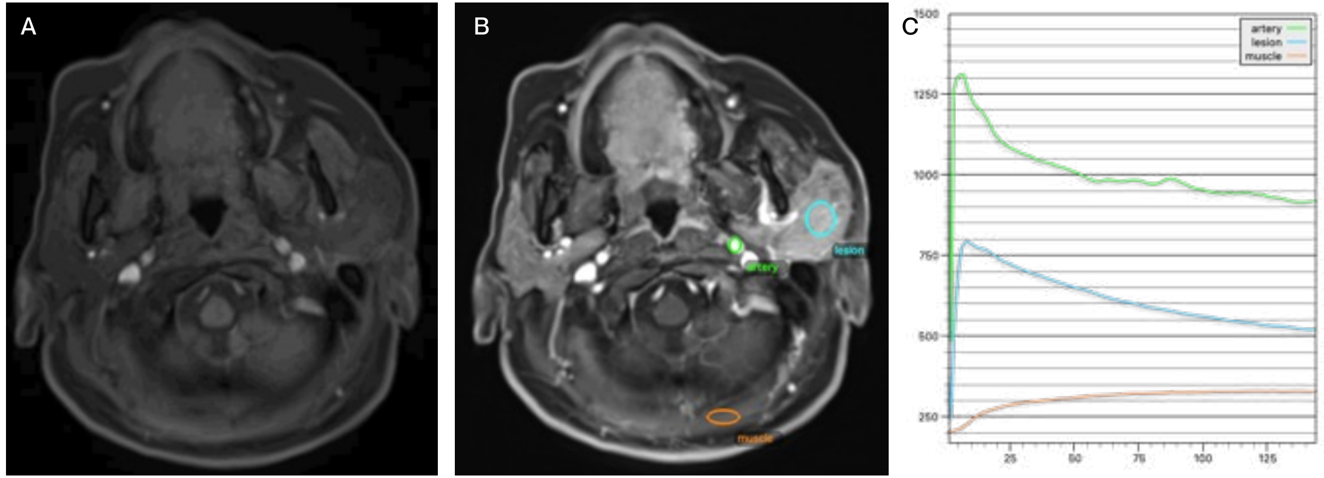
MRI PWI 包含多种评估**组织血流灌注**的磁共振成像技术。评估灌注，可以采用对比增强技术和非对比增强技术（例如动脉自旋标记，ASL）。

动态磁敏感对比 (DSC) MRI PWI 依赖于团注含钆对比剂在 **T2* 加权序列**上引起的信号丢失。计算的参数包括**时间信号强度曲线 (TIC)**，由此计算**脑血容量**（**CBV** = 一定脑组织中血液的容量，以 mL 血液容量/100 g 脑组织计）、**脑血流量**（**CBF** = 每单位时间的 CBV，以 mL 血液/100 g 脑组织/分钟计），以及其他参数。 然后使用这些参数生成大脑彩图。由于难以精确计算 CBV 和 CBF，通常计算相对于内部对照（例如，对侧正常白质）的 CBV/CBF（rCBV 和 rCBF）。rCBV 和 rCBF 为比值，无单位。

胶质母细胞瘤患者的 T2* 加权 DSC MRI 灌注图像。A. 不同目标区域 (ROI) 的 TIC。B. 显示肿瘤灌注增加的 rCBV 彩图及相应的轴位对比增强 T1 加权像。图片来源：José Manuel Baiao Boto，日内瓦大学医学院神经放射科。

Dynamic Contrast Enhanced (DCE) MRI PWI is one of the most important MRI PWI techniques. Perfusion parameters are calculated on the basis of **T1 shortening effects** due to the bolus of Gd-based contrast agent passing through tissue. The following parameters are calculated: TICs, k-trans (= volume transfer constant from blood plasma to extravascular extracellular space), fractional volume of extravascular-extracellular space, and others. TICs are very useful for the characterisation of certain tumours. For example, certain TIC types can be found only in malignant tumours whereas other TIC types only in benign lesions.

DCE MRI PWI is mainly used for oncologic imaging.



T1-weighted Dynamic Contrast Enhanced (DCE) PWI in a patient with a diffusely infiltrating left parotid tumour. A. Time resolved dynamic sequence. B. ROIs placed for measurements (carotid artery - green, parotid tumour - blue, muscle - orange). C. Time-intensity curves (TIC)s in the different regions of interest shown in B. TIC colours correspond to the ROIs indicated in B.

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章节大纲：

动态对比增强 (DCE) MRI PWI 是最重要的 MRI PWI 技术之一。灌注参数的计算是基于含钆对比剂团注通过组织时引起的 **T1 缩短效应** 计算了以下灌注参数：TICs、k-trans（= 从血浆至血管外细胞外间隙的容积转移常数）、血管外-细胞外间隙的容积分数等。TIC 对某些肿瘤的定性具有重要价值。例如，某些 TIC 类型仅见于恶性肿瘤，而其他 TIC 类型仅见于良性病变。

DCE MRI PWI 主要用于肿瘤影像学检查。

左腮腺弥漫性浸润肿瘤患者的 T1 加权动态对比增强 (DCE) PWI。A. 时间分辨动态序列。B. 测量 ROI 标记（颈动脉 - 绿色，腮腺肿瘤 - 蓝色，肌肉 - 橙色）。C. B 图所示不同目标区域的时间-强度曲线 (TIC)。TIC 颜色对应于 B 图所示的 ROI。

Artefacts in MRI

MR Imaging

CHAPTER OUTLINE:

MR 成像

章节大纲：

MRI 中的伪影

/ Artefacts in MRI

The image acquisition process can be responsible for different artifacts in the image, some can easily be addressed while other not. MRI sequence optimisation requires understanding of numerous parameters, this ability is essential to obtain images with the best mitigation of artefacts.

Recognition of these artefacts in the images is an important part of the radiologist experience!

Origin of artefacts can be separated in three categories:

- / Technique :
  - / Type of sequence
  - / Parameters

CAN BE CORRECTED

- / Patient :
  - / Motion (uncontrollable)
  - / Breathing, blood flow
  - / Implants, tattoo, piercing, ...

CAN BE MITIGATED WITH SPECIFIC TECHNIQUES

- / Hardware :
  - / Receiver coil, RF coil, gradient coils
  - / Faraday cage

HAS TO BE REPAIRED

/ MR Imaging

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/ MR 成像

章节大纲：

/ MRI 中的伪影

图像采集过程可能导致图像中出现多种伪影，有些伪影较易处理，有些则难以解决。优化 MRI 序列需要了解许多参数，这种能力对于获取伪影抑制效果最佳的图像是必备的。

识别图像中的伪影是放射科医师经验的重要组成部分！

伪影来源可分为三类：

- / 技术：
  - / 序列类型
  - / 参数

可校正

- / 患者：
  - / 运动（不可控）
  - / 呼吸、血流
  - / 植入物、纹身、（佩饰）刺孔等

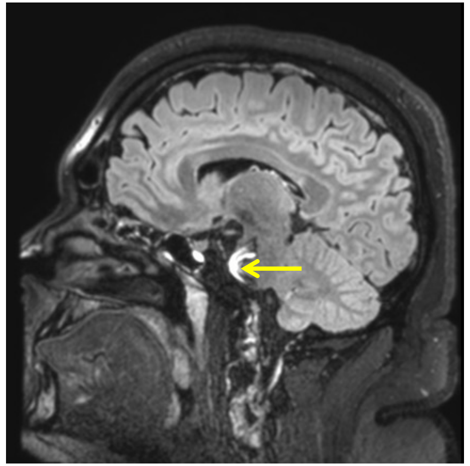
可通过特定技术减轻

- / 硬件：
  - / 接收线圈、射频线圈、梯度线圈
  - / 法拉第笼

需要修复

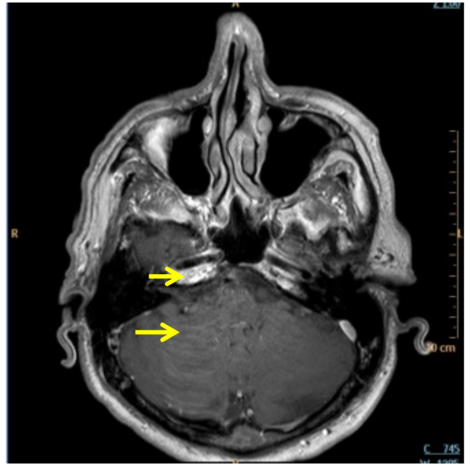
/ Artefacts: Examples

Artefact due the technique: wrong parameters of the sequence.



Fold over artefact: nose (outside of the field of view) is projected in the centre of the image!

Artefact due to the patient: blood flow in arteries.



Flow artefact: signal from blood flowing in arteries is propagated in the phase encoding direction.

Artefact due to the patient: presence of braces

Susceptibility artefact: signal loss due to presence of metal in the mouth (braces), magnetic field perturbation extends largely outside the mouth.

/ MR Imaging

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章节大纲：

/ 伪影：实例

技术造成的伪影：序列参数设置错误。

卷褶伪影：鼻部（位于视野外）被投射至图像中心！

患者造成的伪影：动脉血流。

流动伪影：动脉内流动血液的信号在相位编码方向上产生传播。

患者造成的伪影：佩戴牙套

磁敏感性伪影：口腔内金属（牙套）导致信号丢失，磁场扰动明显延伸至口腔外。

MRI Advantages and Dis-advantages

MR Imaging

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MR 成像

章节大纲：

MRI 的优缺点

/ MRI Advantages and Disadvantages

>|< COMPARE

ADVANTAGES:

+ Non-ionising modality suitable for follow-up examinations.
+ Excellent soft tissue contrast (ligaments, tendons, muscles, brain grey and white matter, ...).
+ Different type of contrast images available (sensitive to fluid, with fat suppression, ...).
+ Good image resolution, 2D images in any orientation and 3D images possible.
+ Anatomical but also functional imaging possible (diffusion, perfusion, fMRI, MRS, ...).

DISADVANTAGES:

– Not all implants are allowed in the magnetic field.
– Not suitable for claustrophobic patients (larger bore available nowadays).
– Noisy and generally long examinations.
– More expensive than CT or X-ray.
– Requires good knowledge of the technique (sequence optimisation and artefact mitigation).

/ MR Imaging

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章节大纲：

/ MRI 的优缺点

>|< 比较

优点：

+ 非电离（辐射）方式适合随访检查。
+ 软组织对比度极佳（可清晰显示韧带、肌腱、肌肉、脑灰质与白质等）。
+ 提供不同对比类型的对比图像（对流体敏感、具有脂肪抑制等）。
+ 图像（空间）分辨率良好，可（采集）任意方向的 2D 图像和 3D 图像。
+ 不仅能进行解剖成像，还可实现功能成像（扩散、灌注、fMRI、磁共振波谱成像等）。

缺点：

– 并非所有的植入物都允许进入磁场。
– 不适合幽闭恐惧症患者（目前已有大孔径设备可选）。
– 检查过程噪声较大且耗时较长。
– 比 CT 或 X 线更贵。
– 需要熟练掌握技术（序列优化和伪影抑制）。

/ Take-Home Messages

- / MRI is a non-ionising, non-invasive imaging modality.
- / It provides excellent soft tissue contrast and offers unique anatomical and functional information.
- / Some restrictions or contraindications exist for patients with implanted material or devices.
- / The main magnet is used to magnetise the tissues.
- / Radiofrequency is applied to tip magnetisation out of equilibrium states.
- / Gradients are added to encode the spatial origin of the signal.
- / Finally, the acquired signal requires a Fourier transform to obtain the final image.
- / Images can be sensitive to T1 and T2 relaxation of the tissues by appropriately tuning TE and TR of the sequence.
- / Two main type of sequences are the spin echo and the gradient echo sequences.
- / Contrast agents can be used to enhance pathology visualisation; they are mainly gadolinium-based.

/ MR Imaging

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章节大纲：

/ 核心要点

- / MRI 是一种非电离、无创的影像学检查手段。
- / 它可以提供出色的软组织对比度，并提供独特的解剖和功能信息。
- / 对于体内存在植入材料或器械的患者，存在一些限制或禁忌证。
- / 主磁体用于磁化组织。
- / 射频用于将磁化从平衡状态激发出来。
- / 通过施加梯度，可对信号进行空间编码。
- / 最后，采集的信号需通过傅里叶变换以获得最终图像。
- / 通过适当调节序列的 TE 和 TR，图像可以对组织的 T1 和 T2 弛豫敏感。
- / 两种主要序列：自旋回波序列和梯度回波序列。
- / 主要使用含钆对比剂来增强病变的显示。

/ References

Excellent websites to understand the MRI technique and all its related questions :

/ https://www.imaios.com/en/e-mri

/ https://mriquestions.com/index.html

MRI safety :

/ A Practical Guide to MR Imaging Safety: What Radiologists Need to Know
Leo L. Tsai, Aaron K. Grant, Koenraad J. Mortele, Justin W. Kung, and Martin P. Smith
RadioGraphics 2015 35:6, 1722-1737

MRI physics :

/ Plewes, D.B. and Kucharczyk, W. (2012), Physics of MRI: A primer. J. Magn. Reson. Imaging, 35: 1038-1054. https://doi.org/10.1002/jmri.23642

Sequences:

/ Jung, B.A. and Weigel, M. (2013), Spin echo magnetic resonance imaging. J. Magn. Reson. Imaging, 37: 805-817. https://doi.org/10.1002/jmri.24068

/ MR Pulse Sequences: What Every Radiologist Wants to Know but Is Afraid to Ask
Richard Bitar, General Leung, Richard Perng, Sameh Tadros, Alan R. Moody, Josee Sarrazin, Caitlin McGregor, Monique Christakis, Sean Symons, Andrew Nelson, and Timothy P. Roberts
RadioGraphics 2006 26:2, 513-537

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章节大纲：

/ 参考文献

了解 MRI 技术及其所有相关问题的优质网站：

/ https://www.imaios.com/en/e-mri

/ https://mriquestions.com/index.html

MRI 安全性：

/ A Practical Guide to MR Imaging Safety: What Radiologists Need to Know
Leo L. Tsai, Aaron K. Grant, Koenraad J. Mortele, Justin W. Kung, and Martin P. Smith
RadioGraphics 2015 35:6, 1722-1737

MRI 原理：

/ Plewes, D.B. and Kucharczyk, W. (2012), Physics of MRI: A primer. J. Magn. Reson. Imaging, 35: 1038-1054. https://doi.org/10.1002/jmri.23642

序列：

/ Jung, B.A. and Weigel, M. (2013), Spin echo magnetic resonance imaging. J. Magn. Reson.Imaging, 37: 805-817. https://doi.org/10.1002/jmri.24068

/ MR Pulse Sequences: What Every Radiologist Wants to Know but Is Afraid to Ask
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Test Your Knowledge

MR Imaging

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章节大纲：

知识测试

/ Test Your Knowledge

<?> QUESTION

1

Some objects will be attracted by an uncontrollable force into the MRI scanner bore due to the main magnetic field; these are:

- ☐ Ferromagnetic objects (Iron, nickel, cobalt and their alloys)
- ☐ Metallic objects (all that are electrically conductive)
- ☐ All medical implants without exception

/ MR Imaging

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/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

1

由于主磁体的作用，某些物体将被不可控的力吸入 MRI 扫描仪孔径内；这些物体是：

- ☐ 铁磁性物体（铁、镍、钴及其合金）
- ☐ 金属物体（所有导电物体）
- ☐ 所有医用植入物无一例外

/ Test Your Knowledge

<?> ANSWER

1

Some objects will be attracted by an uncontrollable force into the MRI scanner bore due to the main magnetic field; these are:

- ■ Ferromagnetic objects (Iron, nickel, cobalt and their alloys)
- ☐ Metallic objects (all that are electrically conductive)
- ☐ All medical implants without exception

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章节大纲：

/ 知识测试

<?> 回答

1

由于主磁体的作用，某些物体将被不可控的力吸入 MRI 扫描仪孔径内；这些物体是：

- ■ 铁磁性物体（铁、镍、钴及其合金）
- ☐ 金属物体（所有导电物体）
- ☐ 所有医用植入物无一例外

/ Test Your Knowledge

<?> QUESTION

2 Which element of the MRI system allows encoding spatial origin of the signal emitted:

- ☐ Main magnet
- ☐ Radiofrequency
- ☐ Gradients x,y,z

/ MR Imaging

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/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

2 MRI 系统的哪个元件能够编码所发射信号的空间来源：

- ☐ 主磁体
- ☐ 射频
- ☐ 梯度 x、y、z

/ Test Your Knowledge

<?> ANSWER

2 Which element of the MRI system allows encoding spatial origin of the signal emitted:

- ☐ Main magnet
- ☐ Radiofrequency
- ■ Gradients x,y,z

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

<?> 回答

2 MRI 系统的哪个元件能够编码所发射信号的空间来源：

- ☐ 主磁体
- ☐ 射频
- ■ 梯度 x、y、z

/ Test Your Knowledge

<?> QUESTION

3 The magnetisation of the tissues occurs when:

- ☐ The MRI sequence is starting
- ☐ The subject receives radiofrequency wave
- ☐ The subject is lying on the table inside the scanner bore

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章节大纲：

/ 知识测试

<?> 问题

3 组织磁化发生在：

- ☐ MRI 序列开始时
- ☐ 受试者接受射频波时
- ☐ 受试者平躺于扫描仪孔内的检查台上时

/ Test Your Knowledge

<?> ANSWER

3 The magnetisation of the tissues occurs when:

- ☐ The MRI sequence is starting
- ☐ The subject receives radiofrequency wave
- ■ The subject is lying on the table inside the scanner bore

/ MR Imaging

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/ 知识测试

<?> 回答

3 组织磁化发生在：

- ☐ MRI 序列开始时
- ☐ 受试者接受射频波时
- ■ 受试者平躺于扫描仪孔内的检查台上时

/ Test Your Knowledge

<?> QUESTION

4 The echo time TE is the time between:

- ☐ The RF excitation pulse and the RF refocusing pulse in the spin echo sequence
- ☐ The RF excitation pulse and the echo emission in the gradient echo sequence
- ☐ Two consecutive RF excitation pulses

/ 知识测试

<?> 问题

4 回波时间 TE 为以下哪两者之间的时间：

- ☐ 自旋回波序列中的 RF 激励脉冲与 RF 重聚脉冲
- ☐ 梯度回波序列中的 RF 激励脉冲与回波发射
- ☐ 两个连续的 RF 激励脉冲

/ Test Your Knowledge

<?> ANSWER

4 The echo time TE is the time between:

- ☐ The RF excitation pulse and the RF refocusing pulse in the spin echo sequence
- ■ The RF excitation pulse and the echo emission in the gradient echo sequence
- ☐ Two consecutive RF excitation pulses

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章节大纲：

/ 知识测试

<?> 回答

4 回波时间 TE 为以下哪两者之间的时间：

- ☐ 自旋回波序列中的 RF 激励脉冲与 RF 重聚脉冲
- ■ 梯度回波序列中的 RF 激励脉冲与回波发射
- ☐ 两个连续的 RF 激励脉冲

/ Test Your Knowledge

<?> QUESTION

5 The repetition time TR is the time between:

- ☐ The RF excitation pulse and the RF refocusing pulse in the spin echo sequence
- ☐ The RF excitation pulse and the echo emission in the gradient echo sequence
- ☐ Two consecutive RF excitation pulses

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/ 知识测试

<?> 问题

5 重复时间 TR 为以下哪两者之间的时间：

- ☐ 自旋回波序列中的 RF 激励脉冲与 RF 重聚脉冲
- ☐ 梯度回波序列中的 RF 激励脉冲与回波发射
- ☐ 两个连续的 RF 激励脉冲

/ Test Your Knowledge

<?> ANSWER

5 The repetition time TR is the time between:

- ☐ The RF excitation pulse and the RF refocusing pulse in the spin echo sequence
- ☐ The RF excitation pulse and the echo emission in the gradient echo sequence
- ■ Two consecutive RF excitation pulses

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<?> 回答

5 重复时间 TR 为以下哪两者之间的时间：

- ☐ 自旋回波序列中的 RF 激励脉冲与 RF 重聚脉冲
- ☐ 梯度回波序列中的 RF 激励脉冲与回波发射
- ■ 两个连续的 RF 激励脉冲

/ Test Your Knowledge

<?> QUESTION

6 T1-weighted contrast is obtained with:

- ☐ A short TE and a short TR
- ☐ A long TE and a short TR
- ☐ A long TE and a long TR

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

6 T1 加权对比度通过哪种组合获得：

- ☐ 短 TE 和短 TR
- ☐ 长 TE 和短 TR
- ☐ 长 TE 和长 TR

/ Test Your Knowledge

<?> ANSWER

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- ☐ A long TE and a short TR
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/ MR Imaging

CHAPTER OUTLINE:

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章节大纲：

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- ☐ 长 TE 和短 TR
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/ Test Your Knowledge

<?> QUESTION

7

For a T2-weighted image, a long TR is used so that the magnetisation is regrowing to its initial state at equilibrium between each successive RF pulse. How should the TE be?

- ☐ Short TE
- ☐ Long TE
- ☐ TE should equal TR/2

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

7

对于 T2 加权像，使用长 TR 使磁化在每个连续 RF 脉冲之间重新增长到平衡时的初始状态。此时 TE 应该如何设置？

- ☐ 短 TE
- ☐ 长 TE
- ☐ TE 应等于 TR/2

/ Test Your Knowledge

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/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

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/ Test Your Knowledge

<?> QUESTION

8 Which sentence is correct:

- ☐ An MRI exam is cheap and fast
- ☐ An MRI exam is long and more expensive than CT
- ☐ An MRI exam is very quiet

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

8 以下哪种说法正确：

- ☐ MRI 检查既便宜又快速
- ☐ MRI 检查耗时较长，并且比 CT 更贵
- ☐ MRI 检查很安静

/ Test Your Knowledge

<?> ANSWER

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- ☐ An MRI exam is cheap and fast
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/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

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/ Test Your Knowledge

<?> QUESTION

9 With an MRI I can get:

- ☐ Excellent soft tissue contrast but no other information
- ☐ Anatomical images, information about water diffusion, parameters related to brain activation for motor task
- ☐ Excellent bone contrast and poor discrimination of soft tissues

/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

<?> 问题

9 借助 MRI 可以获得：

- ☐ 极佳软组织对比度，但无其他信息
- ☐ 解剖图像、水扩散相关信息、运动任务中与脑激活相关的参数
- ☐ 极佳骨骼对比度，软组织分辨力差

/ Test Your Knowledge

<?> ANSWER

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/ MR Imaging

CHAPTER OUTLINE:

/ MR 成像

章节大纲：

/ 知识测试

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- ☐ 极佳骨骼对比度，软组织分辨力差

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