Centre for the Clinical Application of Particles

Nuclear diagnostics and Magnetic Resonance Imaging

Lecture 13: MRI: more on artefacts

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Outline

1. **Artefacts in Magnetic Resonance Imaging, continued**
   - Periodic motion
   - Chemical shift

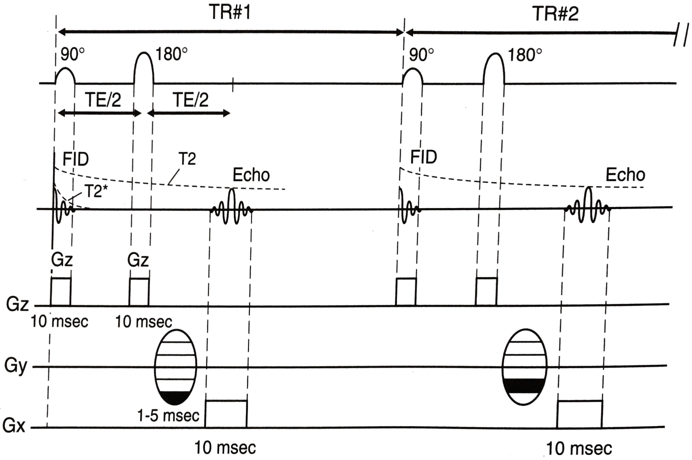
2. **Lecture summary**

3. **The exam**
   - The exam

Section 1

Artefacts in Magnetic Resonance Imaging, continued

Spatial encoding, reprise



Signal, S: $S = S(G_x, t, G_y, \tau_{pe})$

Frequency encoding in x direction:

$$\phi(G_x, x, t) = (\gamma G_x x)\, t$$

Phase encoding in y direction:

$$\Phi(G_y, y, \tau_{pe}) = (\gamma G_y y)\, \tau_{pe}$$

Transformation to k space:

$$k_x = \frac{\gamma}{2\pi} G_x t$$
$$k_y = \frac{\gamma}{2\pi} G_y \tau_{pe}$$

$$S\left(G_y, \tau_{pe}, G_x, t\right) = S(k_x, k_y) = \int_{y_{\min}}^{y_{\max}} \int_{x_{\min}}^{x_{\max}} \rho\left(x, y\right) \exp\left[-i\left(\gamma G_x t\right) x\right] \exp\left[-i\left(\gamma G_y \tau_{pe}\right) y\right] dxdy$$

Periodic motion; overview

Organs that undergo periodic motion include the heart, aorta, . . .

Frequency encoding takes place over a period of $\sim 10\,$ms when the G_x pulse is on. This corresponds to a frequency of 100 Hz; i.e. 100 cycles *per second*. Such rapid oscillations are not present in the body. Oscillations at the frequency of the heart beat, for example, lead to only small excursions while G_x is on and so lead to minor loss of detail in the image

The process of phase encoding requires multiple (N_y) repetitions to complete. While the G_y pulse itself is short, it is repeated at time intervals equal to TR

The time period relevant for phase encoding, therefore, is TR. A typical value for TR is 500 ms, corresponding to a frequency of 2 Hz. Many structures in the body, for example the heart, execute periodic motion with period comparable to TR

Periodic-motion artefacts, therefore, occur in the phase-encoding direction

Periodic motion artefact

The phase, Φ, used for spacial encoding in the phase-encoding direction is given by:

$$\Phi(G_y, y, \tau_{pe}) = (\gamma G_y y)\,\tau_{pe}$$

If the position, y of a feature undergoes periodic motion, then:

$$y \rightarrow y' = y + d_0 \sin \omega_{pma} t$$

And so the phase that enters the phase-encoding equation becomes a function of the "periodic motion artefact" frequency ω_{pma}:

$$\Phi(G_y, y, \tau_{pe}) \rightarrow \Phi'(G_y, y, \tau_{pe}, \omega_{pma}) = (\gamma G_y y')\,\tau_{pe} = 2\pi k_y y' = 2\pi k_y\,(y + d_0 \sin \omega_{pma} t)$$

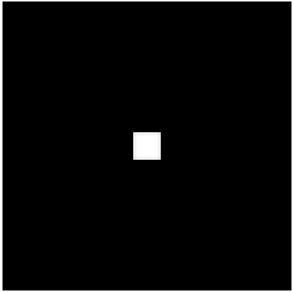
Addition of phase, leads to displacement in k space

Periodic motion artefact

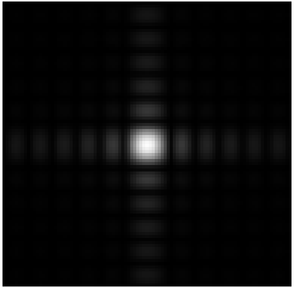
In considering the impact of the additional phase added by periodic motion, we must remember that coordinate space is represented across the k space

Consider again the square at the centre of coordinate space

Coordinate space



k space

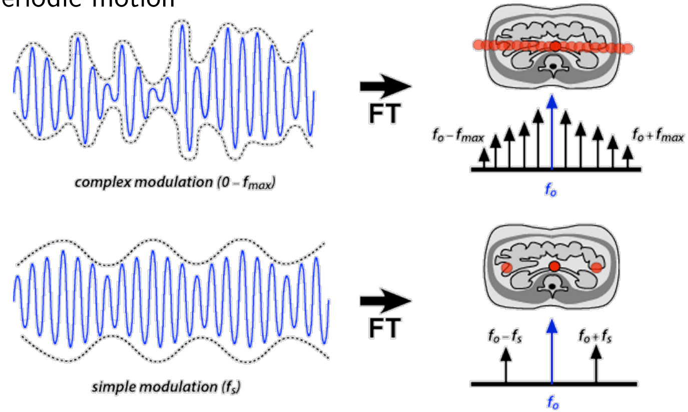


The result of the additional phase is to shift the whole pattern in k space

Periodic motion artefact

For a complete treatment, we need to look at the impact of Φ' on the encoding equation . . .

Instead, lets consider the modulation of the phase-encoding pattern that results from the periodic motion



The amplitude of the periodic shift in the y direction generated by the periodic motion is given by:

$$\delta y = \frac{\mathrm{TR}}{\tau_{pma}} \left[y_{\max} - y_{\min} \right]$$

Periodic motion: breathing and heart beat

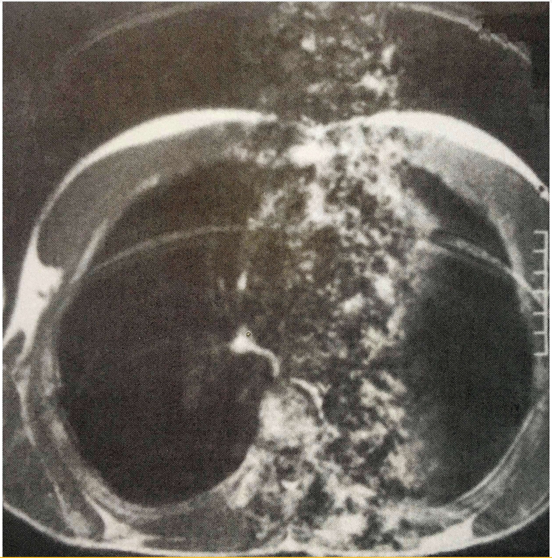


Image of chest showing ghosting arising from breathing and heart beat

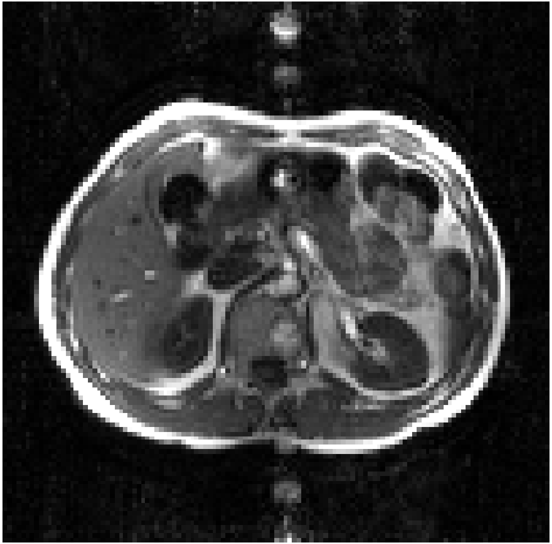
Respiratory motion causes a number of distinct images of the chest wall

Cardiac motion, more complex and multi-facetted, results in the column of overlaping images to the right of centre

In general, the more rapid the motion, the more widely spread will be the ghosts:

$$\delta y \propto \frac{1}{\tau_{pma}}$$

Periodic motion: problem



The periodic motion artefact in the image facing is caused by the periodic motion of a small region of the scan plane The imaging

parameters that were used were TE= 40 ms and TR= 100 ms

1. Estimate the period of the movement from the separation of the ghosts (assume that the field of view is 40 cm).
2. What structure in the body might give rise to this repeating feature?
3. Identify the position of the primary source of the artefact in the image.

Answer will be given in the answers to the second problem sheet.

Origin of the chemical shift artefact

The chemical shift artefact occurs when the chemical environment causes the precessional frequency for ^{1}H nuclei in different molecules to differ

The artefact can arise at tissue boundaries or can be due to a particular tissue being composed of a variety of molecules each of which contribute significantly to the signal

Consider for example, the precessional rates of ^{1}H in water and in fat in a magnetic field of 1.5 T:

- The gyromagnetic ratio for ^{1}H in water differs from that in fat by 3.5 ppm
- For water, at 1.5 T, the Larmor frequency is given by $\nu_w = \gamma B_0 = 42.6 \times 1.5 = 64\,\text{MHz}$
- 3.5 ppm of ν implies a "chemical shift" in the Larmor frequency of fat of $3.5 \times 10^-6 \times 64 \times 10^6 = 220\,\text{Hz}$
- ν_{fat} is larger than ν_w by 220 Hz at 1.5 T

Magnitude of the chemical-shift artefact

Consider an image that has $N_x = 256$ pixels in the x direction and for which the sampling time over which the frequency-encoding pulse G_x is on is 8 ms

Under these conditions, the bandwidth, BW, corresponding to the full x-coordinate range is:

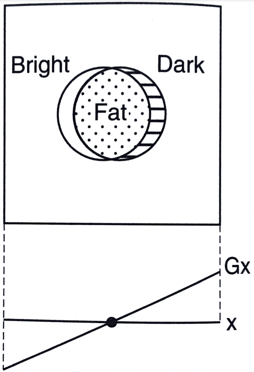
$$\mathrm{BW} = \frac{N_x}{T_S} = \frac{256}{8 \times 10^{-3}} = 32\,\mathrm{kHz}$$

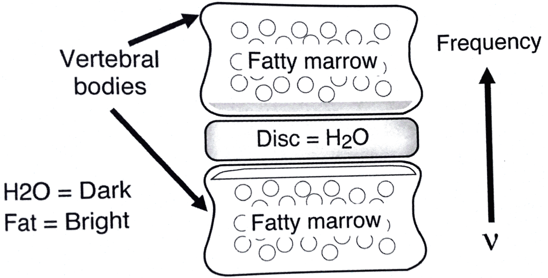
This meams that the frequency step per pixel, Δf is given by:

$$\Delta f = \frac{\mathrm{BW}}{N_x} = \frac{32 \times 10^3}{256} = 125\,\mathrm{Hz}$$

We see that Δf is smaller than the chemical shift between the Larmor frequency for fat and water at 1.5 T

Chemical shift example 1: vertebrae



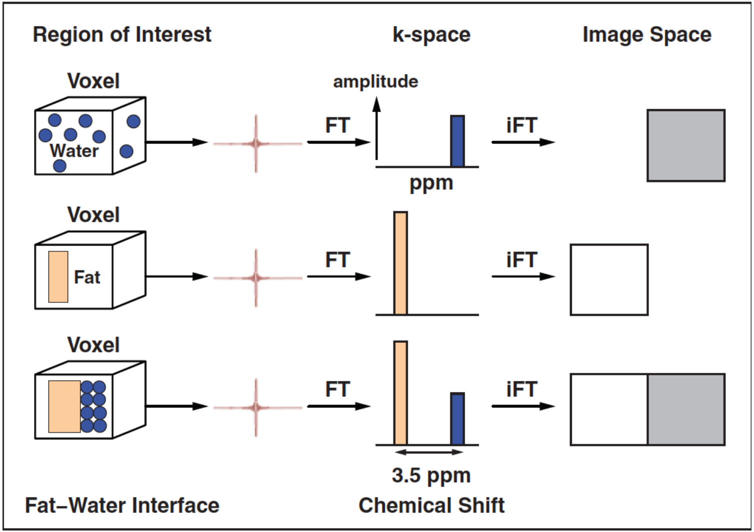


Circle of fat in water volume. Chemical shift causes fat contribution to be displaced towards lower x. Result: a bright band on one side of the fat body (signals from the water and fat overlap), dark band on the other side

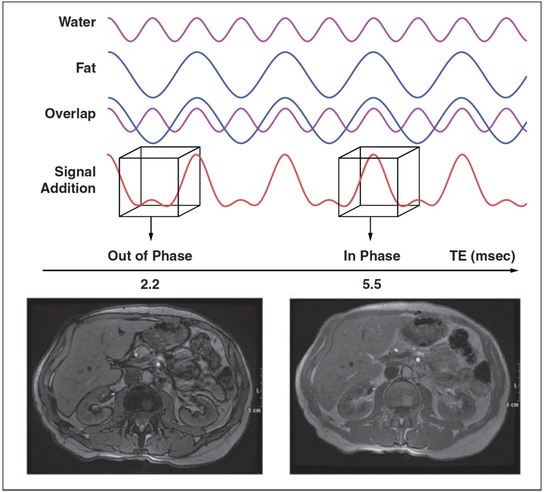
Dark band observed at bottom of "upper" fatty marrow

Bright band observed at top of "bottom" fatty marrow

Chemical shift example 2: voxel sharing water and fat



Chemical shift example 2: voxel sharing water and fat



Signal from fat and water is out of phase when TE= 2.236 ms. Signals from fat and water in single voxel therefore interfere destructively. Result is a dark band surrounding fat-water interfaces

At TE= 5.516 ms, signals are back in phase and constructive interference occurs restoring normal contrast

Section 2

Lecture summary

Summary

Periodic motion artefact:

- Occur in phase-encoding direction
- Shifts observed result from periodic displacement of response in k space
- Magnitude of periodic shift in y coordinate $\propto \frac{1}{\tau_{pma}}$

  [τ_{pma} is the period of the periodic motion]

Chemical shift artefact:

- Occurs when two tissues, or components of tissue, have closely similar Larmor frequencies
- Can be mitigated using timing in, e.g., spin-echo sequence

Section 3

The exam

The exam

Imperial College London

BSc/MSci EXAMINATION May 2019

This paper is also taken for the relevant Examination for the Associateship

MEDICAL IMAGING : ND & MRI

For Third and Fourth-Year Physics Students

31 May 2019: 11:45 to 12:45

The paper consists of two sections A & B.
Section A contains two questions [20 marks each]
Section B contains four questions [5 marks each]

*Candidates are required to answer **ALL** parts of Section A and **TWO** questions from Section B.*

Marks shown on this paper are indicative of those the Examiners anticipate assigning.

General Instructions

Complete the front cover of each of the FOUR answer books provided.

If an electronic calculator is used, write its serial number at the top of the front cover of each answer book.

USE ONE ANSWER BOOK FOR EACH QUESTION.

Enter the number of each question attempted in the box on the front cover of its corresponding answer book.

Hand in FOUR answer books even if they have not all been used.

You are reminded that Examiners attach great importance to legibility, accuracy and clarity of expression.

2019/PO3.7b 1 **Go to the next page for questions**

2020 ND&MRI exam—rubric same as in previous years

Section A — compulsory

- 1 question on nuclear diagnostics – from lectures 1 to 6
- 1 question on MRI – from lectures 7 to 13

Section B — also compulsory

- 2 questions on nuclear diagnostics – from lectures 1 to 6
- 2 questions on MRI – from lectures 7 to 13