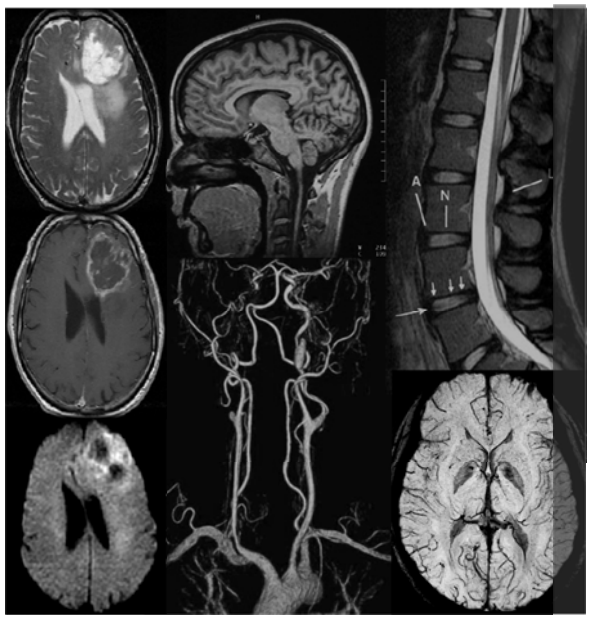

Magnetic Resonance in Medicine
Cardiac MRI

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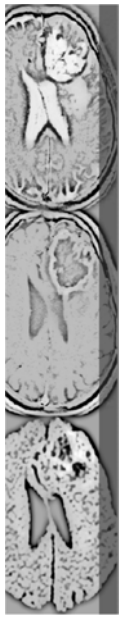
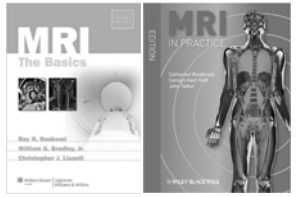


Content http://cflu.lab.nycu.edu.tw/

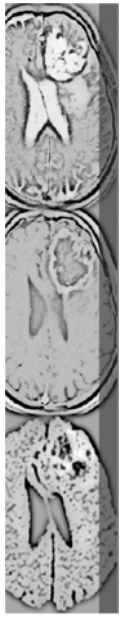
- Principles of Cardiac MRI
- **心臟磁振造影脈衝程序**

- **MRI The Basics (3rd edition)**
  - Chapter 28: Cardiac MRI
- **MRI in Practice, (4th edition)**
  - Chapter 8: Vascular and cardiac imaging



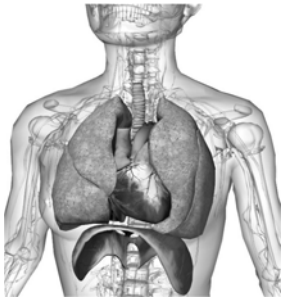
Principles of Cardiac MRI

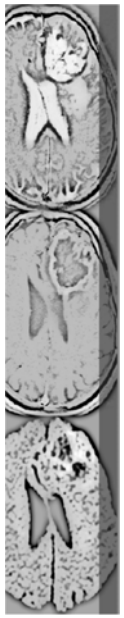
心臟磁振影像簡介



Challenges in Cardiac Imaging

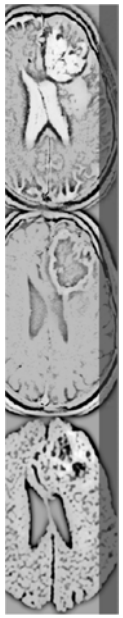
- Cardiac MRI is the most difficult MRI examination to perform.
  - Respiratory motion
  - Cardiac motion (that cannot be suspended for the image)
- Respiratory and cardiac gating techniques
  - Diaphragm position indicator
  - R wave from an electrocardiographic (ECG)





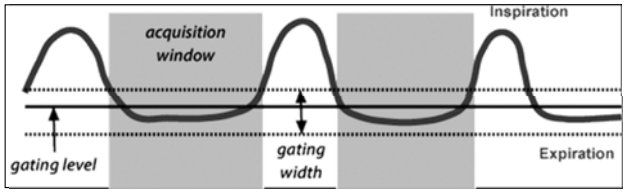
Respiratory Motion

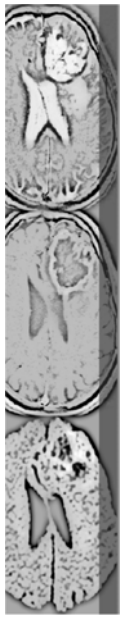
- Can be compensated by
  - breath-hold imaging
    (15~25 sec for healthy individual)
  - respiratory gating/compensation techniques
    (track the motion of diaphragm)
- Motion tracking of diaphragm
  (depth and direction)
  - Respiratory bellows around chest/abdomen
  - A navigator-echo pulse



Respiratory Gating

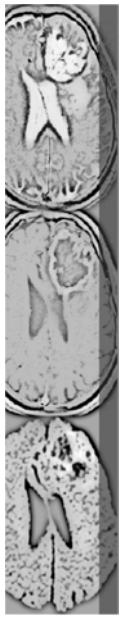
- Triggers data acquisition during expiration
- Only when least diaphragmatic movement occurs, usually the phase of end-expiration.
- May prolong imaging time by 50-300%





Gating Techniques

- Prospective gating
  - uses the impulse and based on previous preset or calculated parameters determines prospectively how k-space will be filled prior to signal acquisition.
- Retrospective gating
  - runs the pulse sequence and collects the signal regardless of the electrical or pressure impulse marker, and then either real-time or after the signals have all been obtained uses certain parameters to either accept or reject signals for inclusion into k-space and subsequent Fourier transformation.



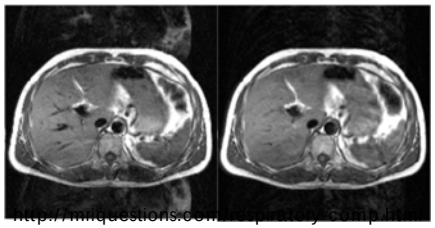
Respiratory Compensation

- Acquires data continuously throughout the respiratory cycle.
- Orders MR data according to respiratory phase
  - The low-amplitude phase-encode steps
    very sensitive to motion → acquired during expiration
  - The high-amplitude phase-encode steps
    less sensitive to motion → collected over the remaining part of each respiratory cycle.
- The time penalty is modest, perhaps only 10-15%.

Respiratory Compensation

- Centrally Ordered Phase Encoding (COPE)
- Respiratory-Ordered Phase Encoding (ROPE)
  - "Respiratory Comp" (GE, Toshiba),
  - "PEAR" (Phase Encoded Artifact Reduction, Philips),
  - "PERRM" (Phase Encode Reordering to Reduce Motion, Hitachi).

Without respiratory compensation



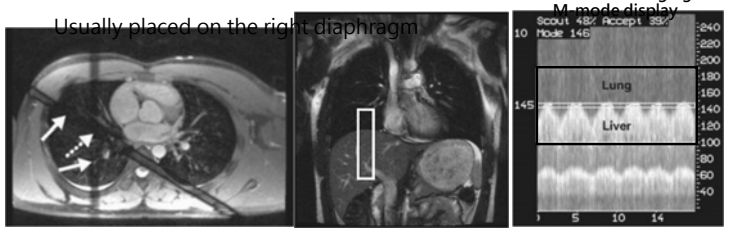
With respiratory phase reordering

Navigator Echoes

- The newest respiratory gating/compensation method without the requirement of the belts/bellows
- Uses a single RF pulse or two intersecting RF pulses to track movement

Usually placed on the right diaphragm

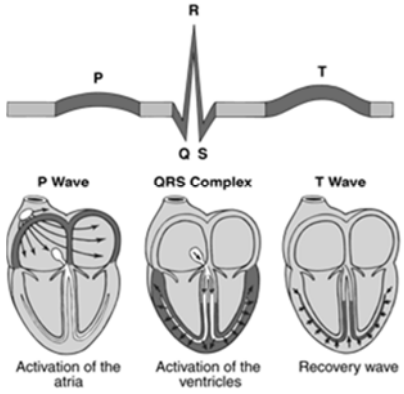
Line-scan imaging
M-mode display

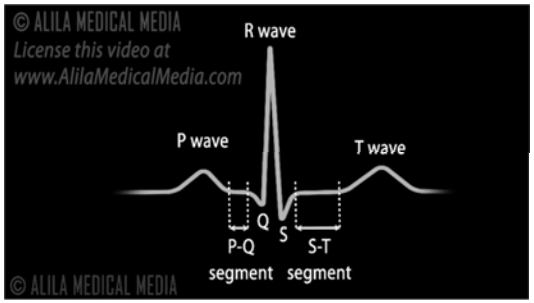


Cardiac Motion

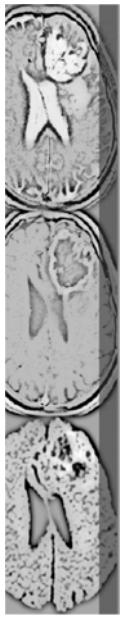
- Cardiac motion is complex with various contributions from
  - longitudinal shortening (long axis)
  - radial contraction (short axis)
  - rotational motion
- ECG gating allows the signal to be acquired in the same phase of the cardiac cycle (systole and mid-diastole).

Electrocardiogram (ECG/EKG)



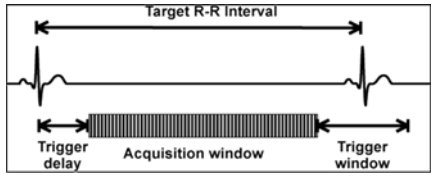


https://youtu.be/RYZ4daFwMa8

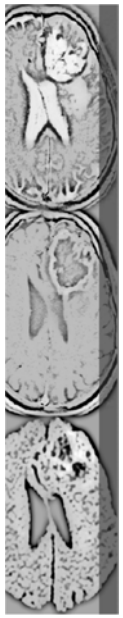


ECG R-R Interval

- ECG gating

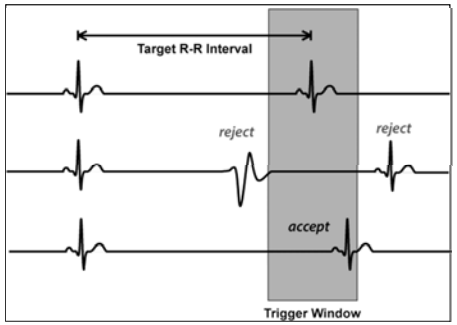


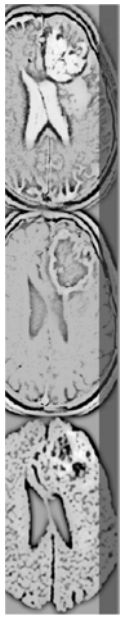
- R-R interval variability
  - Normal beat-to-beat variability
  - Premature contractions
  - Changes due to respiration especially breath-hold



Arrhythmia reject window

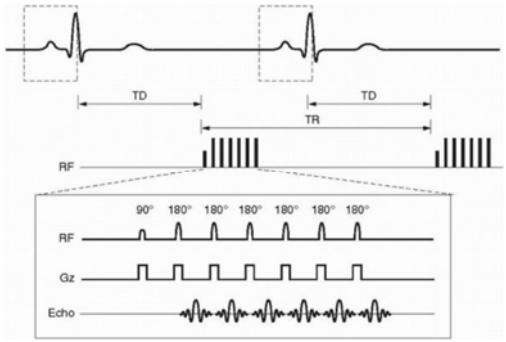
- Prevents filling k-space if R waves fall too far outside expected parameters.
- The arrhythmia reject window length may be either symmetric or asymmetric around the expected R wave.

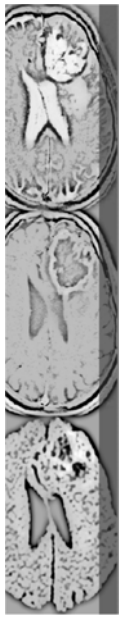




Prospective Gating

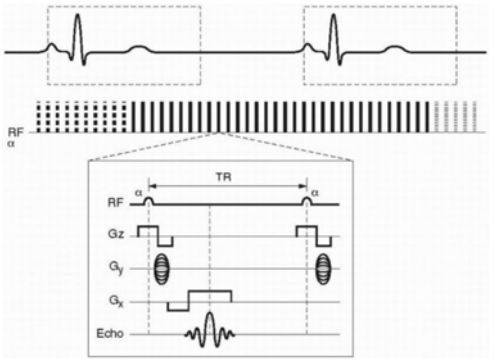
- Prospective gating uses R wave detection with a variable trigger delay (TD) and then begins collecting k-space.
- The k-space is then filled over a certain prescribed percentage of the average R-R interval (usually 80% to 90% for cine imaging).

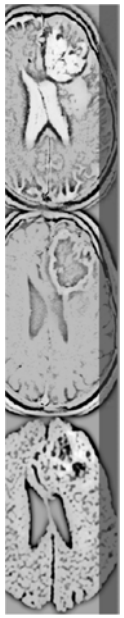




Retrospective Gating

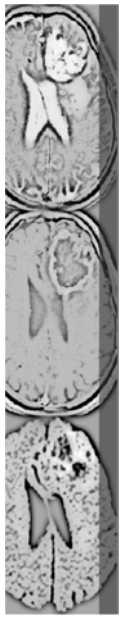
- Does not have any periods within the cardiac cycle where k-space is not being filled.
- Retrospectively determines which line of k-space corresponds with each specific cardiac phase based on the detected R waves.





Faster Imaging

- GRE or True FISP imaging with very short TRs or half-Fourier acquired single-shot turbo spin-echo (HASTE) sequences.
- Parallel imaging can reduce the time of acquisition by two to fourfold or increases spatial resolution two to four times without a time penalty.
- The major drawback to parallel imaging is decreased signal-to-noise ratio ➔ works best with sequences that have high SNR such as True FISP or postgadolinium imaging.

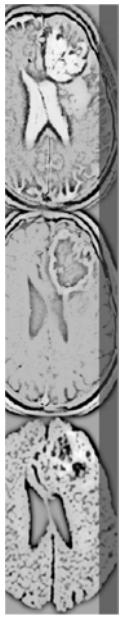


Motion in Cardiac Imaging & Solutions

- Gross patient movement
  - instruct patient to lie still, mild sedation
- Respiratory movement
  - breath-hold techniques, respiratory gating, navigator-echo gating
- Cardiac motion
  - ECG gating, pulse oximeter gating, increase NEX, single-shot technique
- Blood motion
  - flow compensation/gradient moment nulling, pulse sequences insensitive to dephasing
- Parallel imaging:
  - two to fourfold decrease in acquisition time however decreased SNR

Pulse Sequences of Cardiac MRI

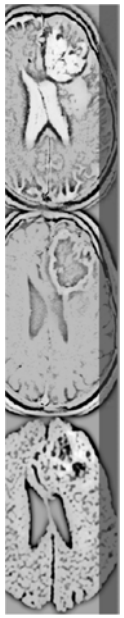
心臟磁振影像脈衝程序



General k-space Filling Strategies

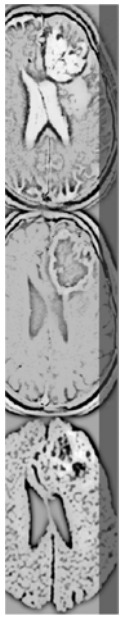
- Segmented
  - All cardiac imaging fills k-space (more than one line of k-space) in a segmented fashion during a single R-R interval.
  - The number of lines for k-space filling per R-R interval is termed views per segment (VPS).
- Single Shot
  - All k-space is filled in a single R-R interval, then this is equivalent to a single segment.

Single R-R interval vs. Single RF pulse



Static Imaging

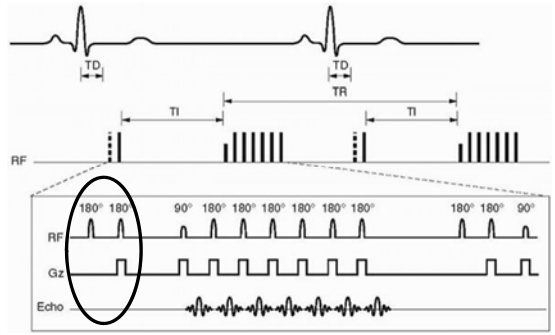
- Fast Spin Echo (FSE) and half-Fourier acquired single-shot turbo spin-echo (HASTE)
  - Good anatomic detail
  - Intrinsic dark-blood signal due to TOF loss
- FSE with ECG gating and either breath-hold or navigator-echo gating result in good image quality.
  - However, the drawback is lengthy scan times.
- HASTE sequences have shorter scan times and are usually obtained in a single R-R interval.
  - However, the SNR will be less due to 1/2 NEX signal averages.

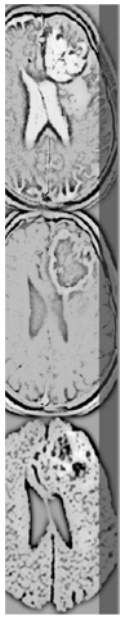


Fast spin-echo DIR sequence

- Double-inversion recovery (DIR): minimize the signal of slow blood or in-plane flow

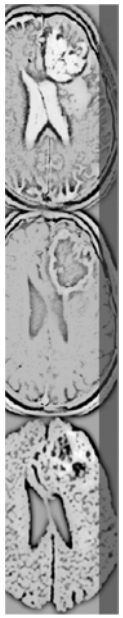
Non-selective + selective 180° RF pulses





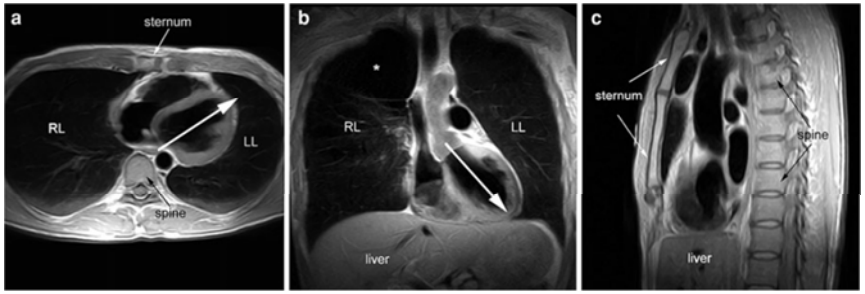
TR for FSE sequences

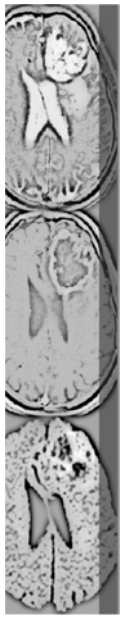
- All FSE sequences have time of repetition (TR) that approximates or exceeds the R-R time.
- For example,
  - if a patient's pulse is 75 beats/min,
  - then the R-R interval is 800 msec [(60 sec/min)/(75 beats/min) = 0.8 sec/beat], and
  - the TR would have to be a multiple of 800 msec.



DIR imaging

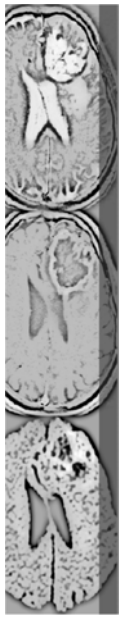
- Position of the heart in the thorax (dark-blood imaging).





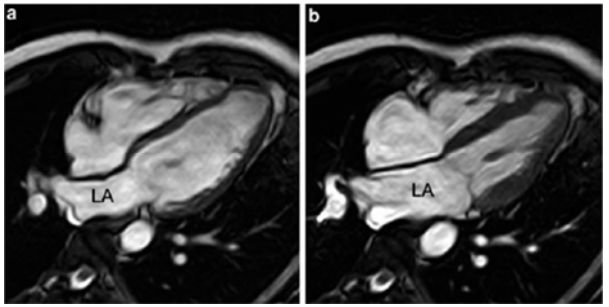
Gradient-Recalled Echo

- May not give quite the T1 or T2 weighting quality of an FSE sequence, but GRE is acquired more quickly.
- Spoiled GRE sequences typically have bright-blood signal due to flow-related enhancement (FRE).
  - Ultrashort TRs are not practical because the TR must be long enough to allow unsaturated protons to enter the imaging slice.
  - Postgadolinium GRE sequences can be performed, which further increase the blood signal

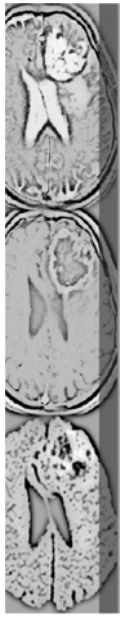


Gradient-Recalled Echo

- Left atrium at end diastole (a) and end systole (b).

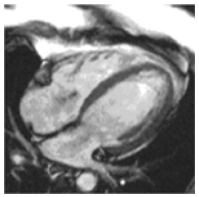


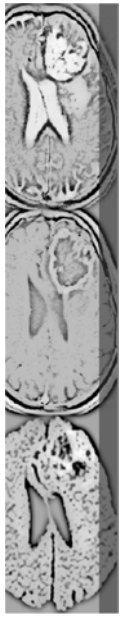
(bright-blood image)



Cine Imaging

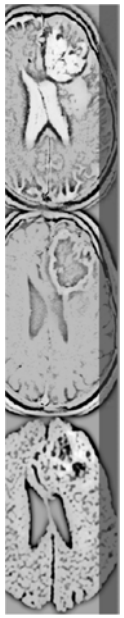
- Instead of getting a single image for a single slice, we obtain a series of images obtained at different phases within the cardiac cycle.
  - ➔ a single slice/multiphase acquisition.
- GRE and True FISP sequences provide this capability since FSE sequences take too long to acquire the required multiple phases per slice.





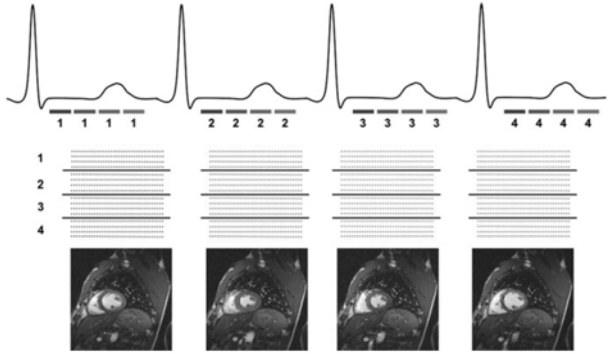
Cine Imaging

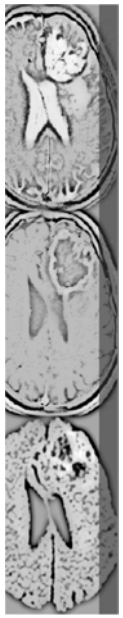
- User defines how many phases within the cardiac cycle per slice (usually 15 to 25) are acquired.
- The goal for temporal resolution between different phases should be around 50 msec.
  - For example, a patient with an R-R interval of 1000 msec (60 beats/min) with a cine sequence with 20 phases will have a temporal resolution of 1000 msec/20 phases = 50 msec/phase.



Multi-Phase Acquisition

- Each k-space is collected at a different point in the cardiac cycle. Together this data can be reconstructed into a cine image.





Cine Sequences

- This technique is most commonly used in cine sequences such as
  - gradient-recalled echo (GRE),
  - true fast imaging with steady-state precession (True FISP, Siemens),
  - FIESTA (fast imaging employing steady-state acquisition, General Electric),
  - b-FFE (balanced fast field echo, Philips) and phase contrast imaging.

THE END

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