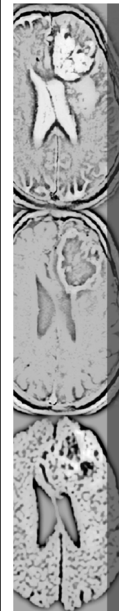


Magnetic Resonance in Medicine Cardiac MRI

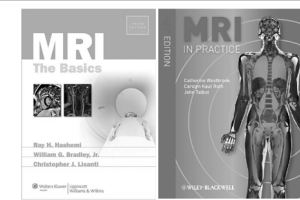
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Content <http://cflu.lab.nycu.edu.tw/>

- Principles of Cardiac MRI
- Pulse Sequences of Cardiac MRI

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



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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Principles of Cardiac MRI

心臟磁共振影像簡介

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

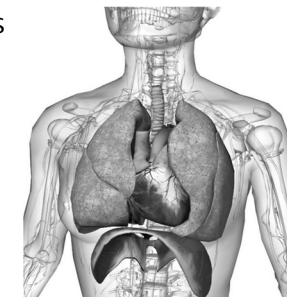
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Challenges in Cardiac Imaging

- 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)



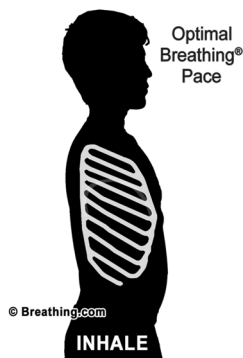
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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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



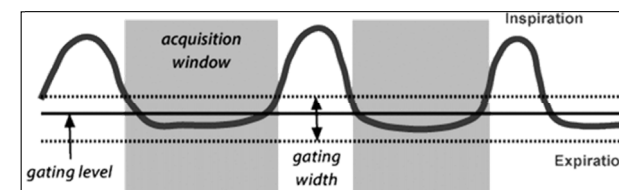
<http://cfliu.lab.nyu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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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%



<http://cfliu.lab.nyu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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Gating Techniques

- Prospective gating
 - Images are acquired at predefined points in the respiratory/cardiac cycle, usually triggered by specific events (like the end-expiration or R-wave in ECG). This method is useful for functional imaging.
- Retrospective gating
 - Continuous data acquisition throughout the respiratory/cardiac cycle, with images reconstructed later based on the bellow/ECG signal. This allows for more flexible timing and detailed analysis of the entire cycle.

<http://cfliu.lab.nyu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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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%.

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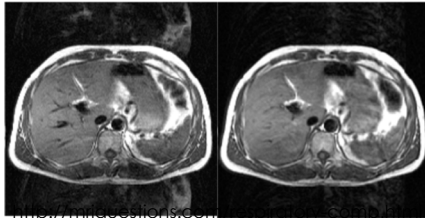
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Respiratory Compensation

- 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

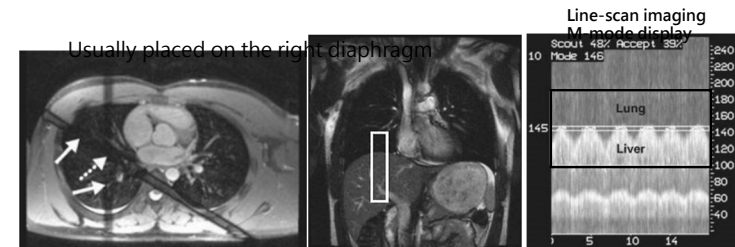
<http://cfliu.lab.nyu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

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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



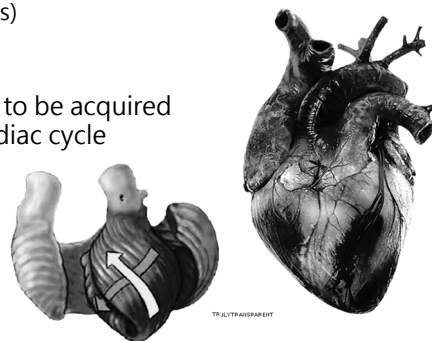
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Cardiac Motion

- 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).

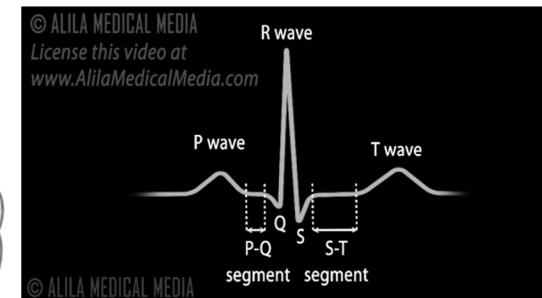
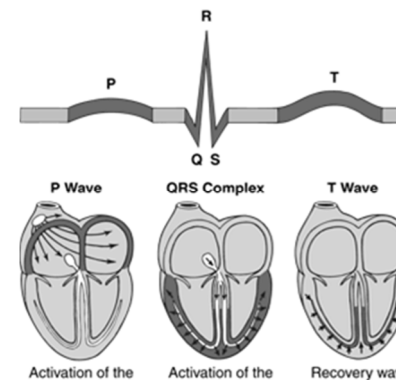


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Electrocardiogram (ECG/EKG)



<https://youtu.be/RYZ4daFwMa8>

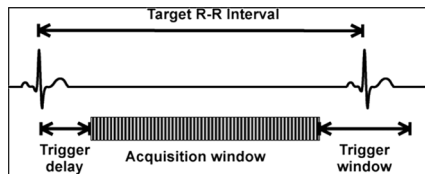
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ECG R-R Interval

- ECG gating



- R-R interval variability

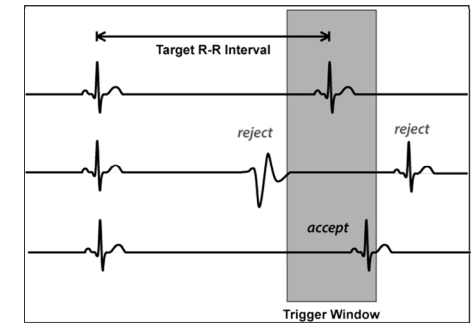
- Normal beat-to-beat variability
- Premature contractions
- Changes due to respiration especially breath-hold

Arrhythmia reject window

心律不整

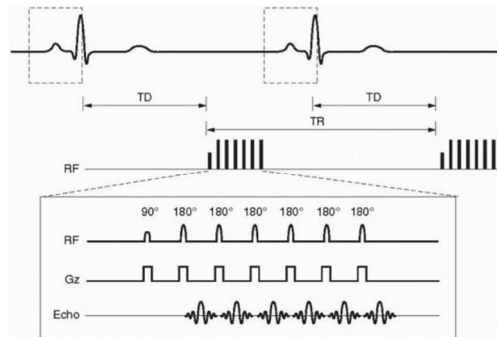
- Prevents filling k-space if R waves fall too far outside expected parameters.

- The arrhythmia reject window length may be either symmetric or asymmetric around the expected R wave.



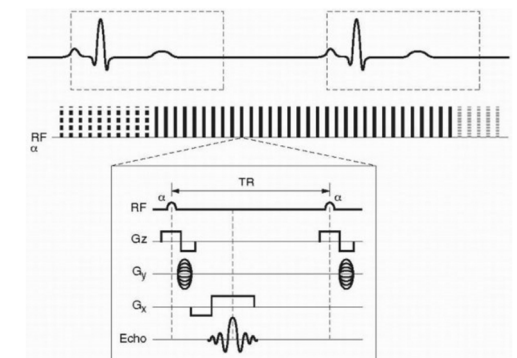
Prospective Gating

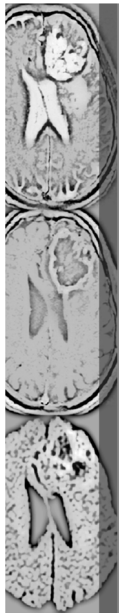
- Prospective gating uses R wave detection with a variable trigger delay (TD) and then begins collecting k-space.
- The k-space is then filled over a certain prescribed percentage of the average R-R interval (usually 80% to 90% for cine imaging).



Retrospective Gating

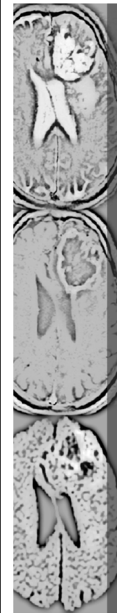
- Does not have any periods within the cardiac cycle where k-space is not being filled.
- Retrospectively determines which line of k-space corresponds with each specific cardiac phase based on the detected R waves.





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.

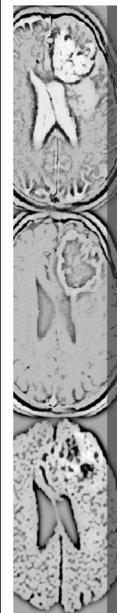


Motion in Cardiac Imaging & Solutions

- 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

心臟磁共振影像脈衝程序



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.

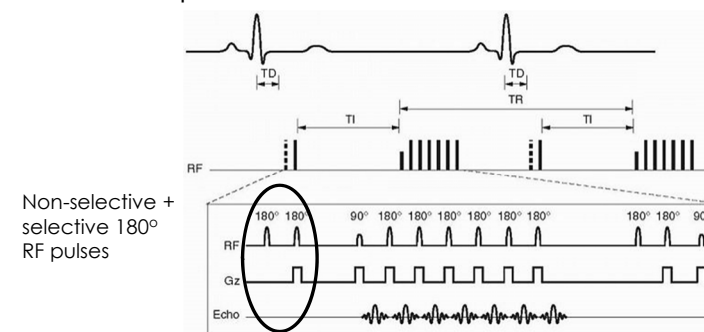
Single R-R interval vs. Single RF pulse

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

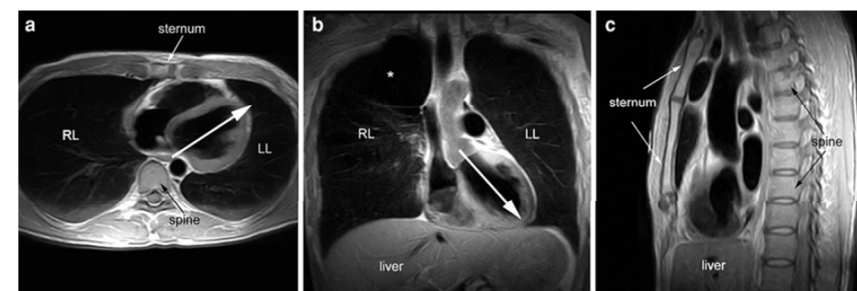


TR for FSE sequences

- 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 $[(60 \text{ sec/min}) / (75 \text{ beats/min}) = 0.8 \text{ sec/beat}]$, and
 - the TR would have to be a multiple of 800 msec.

DIR imaging

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



Cardiac MRI positioning

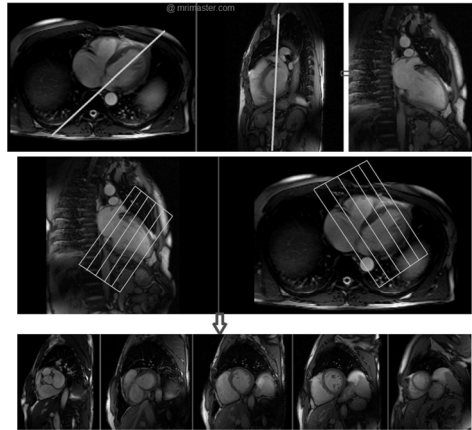
<https://mrimaster.com/plan-cardiac/>

- Dark blood axial

- Two chamber

- Short axis

- Four chamber



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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

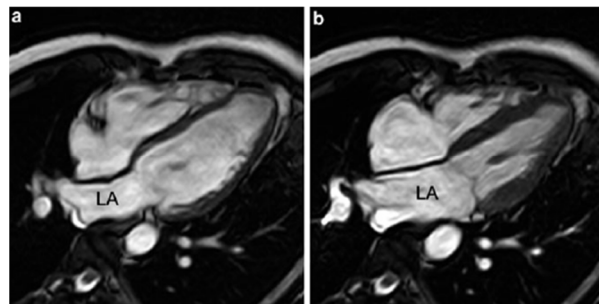
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Gradient-Recalled Echo

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



(bright-blood image)

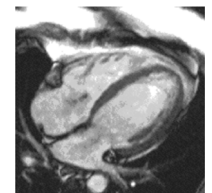
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Cine Imaging

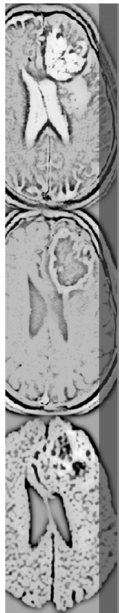
- Instead of getting a single image for a single slice, we obtain a series of images obtained at different phases within the cardiac cycle.
 - → a single slice/multiphase acquisition.
- GRE and True FISP sequences provide this capability since FSE sequences take too long to acquire the required multiple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



<http://cfliu.lab.nyu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

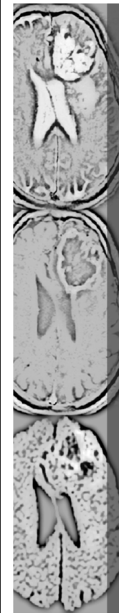
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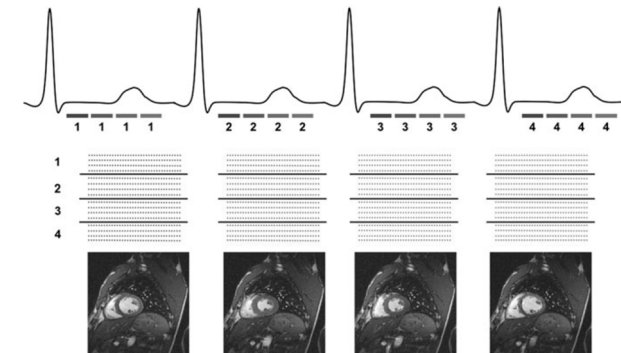
Cine Imaging

- 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 $1000 \text{ msec} / 20 \text{ phases} = 50 \text{ msec/phase}$.



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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