# An Introduction to ECG Gating for Cardiac MRI
## Part 2: The cardiac cycle and types of synchronisation

**Topic Author: Ben Statton**

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## Introduction

Although the ECG trace achieved in the MRI scanner is not of a diagnostic quality, it is good enough for the software to recognise the key features that will allow it to synchronise the image acquisition with the patient's cardiac cycle. The scanner uses the largest peak of the ECG trace, the R peak, to both trigger image acquisition and to calculate the R-R interval (the duration of one heartbeat). Depending on the type of pulse sequence used, the scanner will use prospective triggering or retrospective gating to acquire images free of cardiac motion artefact.

## Main Body

Before we discuss about how we are going to use the ECG trace to synchronise the image acquisition to patient's cardiac cycle let's consider what is happening to the heart during each portion of the ECG (Fig 1.):

1. **P Wave** - the electrical impulse originates in the sinoatrial node, and initiates a depolarisation wave that spreads across both the right and left atria. As this happens, the atria contract, pushing blood into the ventricle.
2. **PQ Segment** - this segment represents the time taken for the electrical impulse to travel from the atria to the ventricles. This delay allows for complete atrial contraction and ventricular filling.
3. **QRS Complex** - this is the most prominent feature of the ECG and is made up of three individual waves: the Q, R, and S waves. This complex represents ventricular depolarisation and it is where they begin to contract, pushing blood out to the aorta and main pulmonary artery. The R wave of this complex is what the MRI scanner uses to trigger the sequence acquisition.
4. **ST Segment** - the period when the ventricles are fully depolarised and are contracting.
5. **T Wave** – this represents ventricular repolarisation, when the ventricular cells electrically reset. During this phase, the ventricles relax, allowing them to refill with blood for the next cardiac cycle.
6. **TP Interval** – during this time, both the atria and the ventricles are relaxed and expanding.

The period of the cardiac cycle from the P to the T wave is called systole and we want to avoid acquiring static (morphology) images during this period as the myocardium is moving relatively rapidly and motion blurring on the images is likely. The TP interval is

known as diastole and it is during this period, especially mid-late diastole, that the heart is at its stillest. This is the period during which acquire static images are acquired.

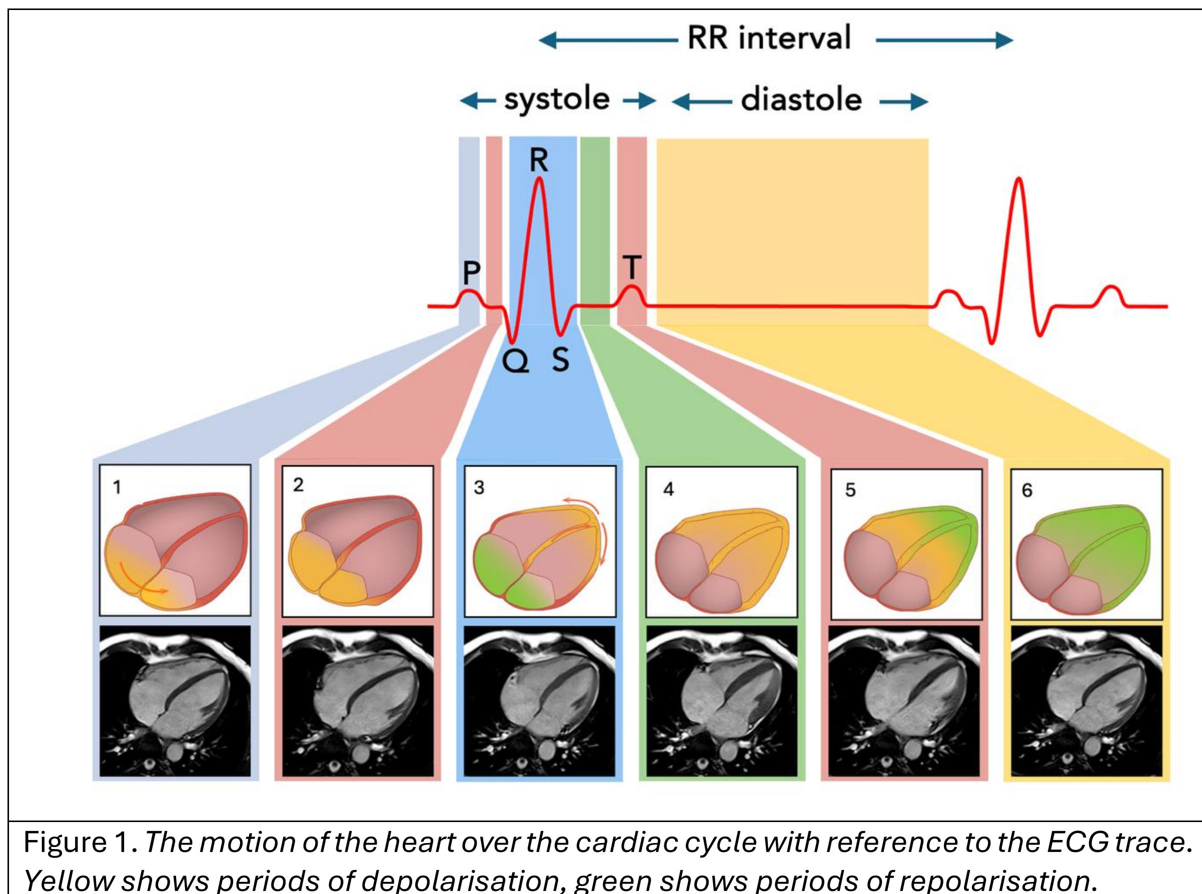


Figure 1. *The motion of the heart over the cardiac cycle with reference to the ECG trace. Yellow shows periods of depolarisation, green shows periods of repolarisation.*

Prospective Triggering

There are two ways in which we can synchronise the image acquisition with the patient's ECG. The first method, prospective triggering, is what is used for acquiring static images, eg late gad, oedema or mapping images. The R peak triggers the scanner and then after an appropriate delay (the Trigger Delay) image acquisition occurs during the diastolic portion of the cardiac cycle, ensuring that any blurring due to cardiac motion is minimised. In this way a single static slice is acquired in one breath-hold over several heart beats (Fig 2-A).

Prospective triggering can also be used for cine imaging. Again, the R peak will trigger the scanner but then acquisition will start immediately and continue for almost one heartbeat, at which time acquisition must stop for the scanner to detect and trigger from the next R peak. This continues for successive heart beats until the enough data has been sampled for one entire cine slice (Fig 2-B). The limitation of using prospective triggering for cine sequences is that the last portion of the cardiac cycle in missed and thus end-diastole and stroke volume may be underestimated from volumetric analysis using this method. However, it is more robust to variations in the R-R interval.

Retrospective Gating

The most common method for acquiring cine images is with retrospective gating. Rather than being triggered by the R peak of the ECG, the scanner acquires data continuously throughout the cardiac cycle over several consecutive heartbeat (Fig 2-C). Then during image reconstruction the data are sorted into the correct cardiac phase based on the point in the cardiac cycle during which the data were acquired. The scanner reconstruction can cope with some slightly longer and shorter beats, however if there is too much variation in the R-R interval during retrospective gating then the images will be degraded by artefact.

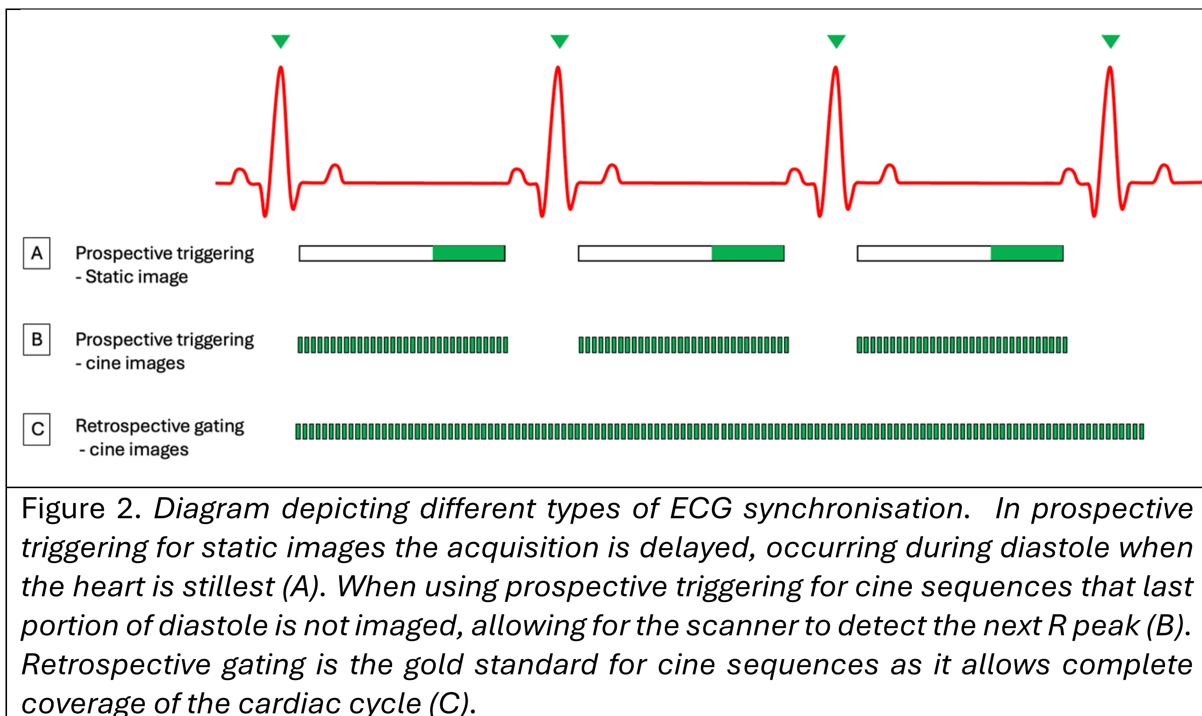


Figure 2. *Diagram depicting different types of ECG synchronisation. In prospective triggering for static images the acquisition is delayed, occurring during diastole when the heart is stillest (A). When using prospective triggering for cine sequences that last portion of diastole is not imaged, allowing for the scanner to detect the next R peak (B). Retrospective gating is the gold standard for cine sequences as it allows complete coverage of the cardiac cycle (C).*

## Conclusion

ECG synchronisation is used in CMR to allow for motion-free static images at a chosen phase of the cardiac cycle, most commonly in diastole when there is the least cardiac motion. It also allows the correct temporal sorting of dynamic cine data acquired over multiple heartbeats.

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## Further Resources

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