Cardiac Imaging

BioE – 594 Advanced Topics in MRI

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Introduction

- In the past decade, Coronary MR angiography has emerged as a ***noninvasive tool*** for diagnosing coronary artery disease.
- Although there is a rapid evolution, visualization of the whole coronary arterial tree with reproducibly high diagnostic image quality, still remains challenging.

- One of the major problems is the effective suppression of the respiratory motion.
- Three approaches have been proposed to compensate for respiratory motion:

1. Breath-hold (BH) imaging.
2. Free breathing Navigator – gated, (NAV) imaging.
3. True FISP imaging.

- Till date, most clinical trials have mostly involved the use of 2D BH or 3D- retrospective NAV for respiratory compensation.
- More recently 3D BH techniques and free breathing respiratory gated techniques with a prospective navigator algorithm have been used to improve image quality.

- The advantages of 3D techniques over 2D are ***high SNR, better ability to reduce partial effects and high spatial resolution.***

- In the discussion to be followed we have taken case studies of Coronary MR angiography (CMRA) using, BH, retrospective NAV echoes and prospective NAV echoes and compared the results for the same.

3D Respiratory – Retrospective Gated CMRA

- The aim of this study was to assess the value of CMRA using Navigator echo respiratory gating in detecting coronary artery stenosis in patients suspected with coronary artery disease using ***conventional coronary angiography*** as a ***reference.***

X-ray angiography

- Was performed via the percutaneous femoral artery approach with 5 Fr catheters using biplane equipment.
- Five imaging projections were taken from the left and right coronary arteries after manual injections of iohexol 350 mg I / ml.

CMRA Imaging

- MRI was performed with at 1.5 T whole body imaging system using a ***circularly polarized phase array coil***.
- The patients were studied in the supine position and three ECG leads were attached to the anterior chest wall.

- An ECG triggered 3D FLASH gradient echo sequence with ***respiratory gating*** and ***fat suppression*** was used.
- Respiratory gating was performed using 2 spin echo (navigator echo) signals that were located parallel to the z-axis and intersected at the dome of the right hemidiaphragm.

- Data obtained in narrow (3mm) end expiratory acceptance were ***retrospectively processed*** for image reconstruction.
- ***No velocity compensation*** was used for velocity displacements.

- The scan parameters were

1. TR = 600-800 msec (depending on the subject's heart rate).
2. TE = 2.7 msec.

- Matrix of the size 256 x 256 was used and a FOV of 300 x 300 mm^2 was used giving an in-plane resolution of 1.17 x 1.17 mm.

- After scouting, the left sinus of Valsalva was identified and the first slab was positioned along the long axis of the proximal left anterior descending (LAD) artery.
- 2 or 3 overlapping slabs were acquired to cover both right and left coronary artery tree. Slabs were overlapped by 25% to compensate for the decrease in image quality at the edge of 3D vol.

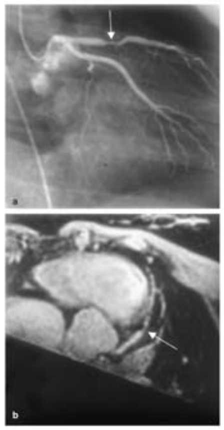


Fig. 1. Severe stenoses (arrow) in proximal left anterior descending artery is shown in conventional coronary angiography (A) and in the MRA image (B). Double oblique MPR image (TR = 800/TE = 2.7).

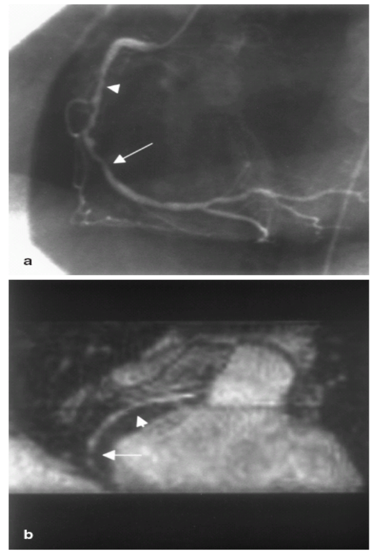


Fig. 2. A) Conventional coronary angiography of a stenosed right coronary artery. In the CMRA imaging (B) the artifacts obscure slightly the proximal part of the long stenosis (arrowhead). The distal part of the stenosis is better discernible (arrow). Double oblique MPR images (TR = 800/TE = 2.7).

Coronary MR angiography with Steady state free precession

- Steady state free precession sequences of the MR angiography are promising owing to:

1. High SNR
2. Intrinsically high contrast yielded.

MR imaging

- Patients were examined in the supine position by using a 1.5 T whole body MR imaging system.
- A ***five element cardiac synergy coil*** was used for ***signal detection***.
- Cardiac synchronization was performed by using four electrodes placed on the left anterior portion of the hemithorax (to obtain a vector electrocardiogram)

- Image acquisitions were triggered on the R-wave of the electrocardiogram.
- A rapid gradient echo sequence with a TR = 4 msec and TE= 1.3 msec with a flip angle of 55 degrees was used.

- Subsequently, a fast NAV and navigator corrected transverse low-spatial resolution 3D steady state free precession sequence with TR=3.4 msec, TE= 1.3 msec and flip angle 70 degrees was performed in the target region with the navigator positioned on the dome of the right hemidiaphragm.

Free breathing NAV MR imaging

- The identical procedure with the same spatial resolution was performed for the NAV approach, ***without sensitivity encoding***.
- Correction of breathing motion was performed with a real – time prospective navigator that had a gating window of 5 mm and a correction factor of 0.6.

- The window was placed on the dome of the right hemidiaphragm to relate the superoinferior position of the diaphragm to the superoinferior position of the proximal coronary arteries.
- Navigator efficiency was defined as the number of accepted NAV acquisitions divided by the total number of navigator acquisitions.

BH MR imaging

- BH MR imaging was performed during one end expiratory BH ***without navigator correction***.
- The acquisition duration per heartbeat was adapted with regard to the individual rest period of the coronary artery, with a predefined maximum of 150 msec.
- Increasing the sensitivity encoding reduction factor (range, 1.5-5.0) as shown in the next figure enabled us to adapt the total imaging duration to the patient's BH capability.

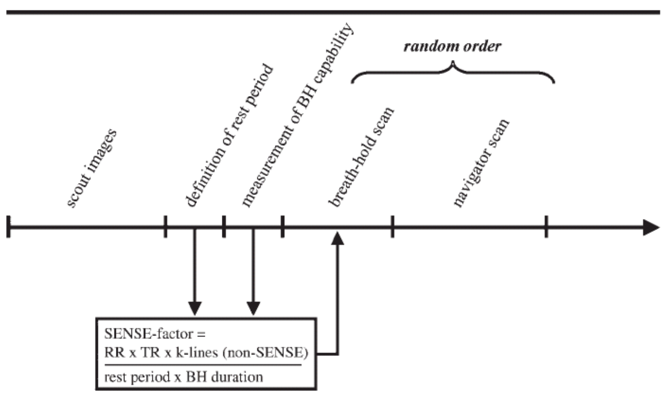


Figure 1. The course of the coronary MR angiographic examination. *RR* = R-R interval (in milliseconds), *SENSE* = sensitivity encoding, *TR* = repetition time (in milliseconds).

- 20 over contiguous sections were obtained by using a flow independent steady state free precession sequence (4.5/2.3, flip angle 90°) with a fat suppression and T2 preparation prepulse.
- In-plane spatial resolution was 1.3 x 1.3 mm with a 3-mm section thickness.

- The three-point " planscan tool" in the MR imaging system software was used for planning the optimal imaging plane of coronary sequence as follows :
- For the LCA, the first reference point was the origin of the left main artery
- The second ref point was a distal point of the LAD artery.
- 3rd ref point was chosen in the middle to distal portion of the left circumflex (LCX) segment.

Image analysis

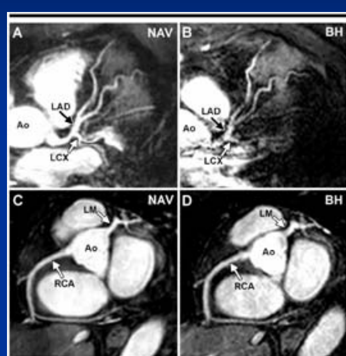


Figure 2. Images in 69-year-old woman. *A, B,* Multiplanar reformatted MR images (4.5/2.3, 90° flip angle) of LCA system acquired with NAV and BH (sensitivity encoding factor, 2.7) approaches. Note improved delineation of vessel border of LCA system in NAV image. Increased visibility of the LCX and coronary side branches on the NAV image can be appreciated. *C, D,* Multiplanar reformatted MR images (4.5/2.3, 90° flip angle) of RCA acquired with BH (sensitivity encoding factor, 2.6) and NAV approaches. Note the improved image quality beyond the crux of the RCA on the NAV image. *Ao* = aorta, *LM* = left main artery.

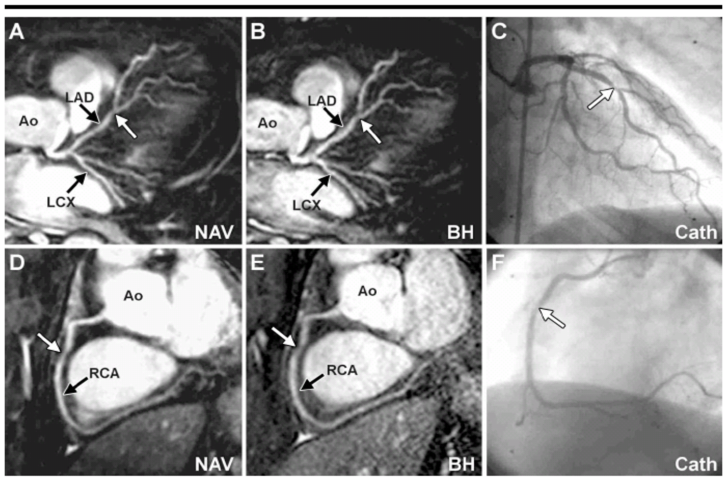


Figure 3. *A–C,* Images in 72-year-old woman. Both, *A,* NAV, and, *B,* BH (sensitivity encoding factor, 2.3) multiplanar reformatted coronary MR angiograms (4.5/2.3, 90° flip angle) show significant stenosis (white arrow) of the middle portion of the LAD artery. *C,* Conventional coronary angiogram confirms 75% stenosis (arrow) of the LAD artery. Note that the three-dimensional coronary MR angiographic data set displays the findings of biplane conventional coronary angiography in one imaging plane. *D–F,* Images in 58-year-old man. Both, *D,* NAV, and, *E,* BH (sensitivity encoding factor, 2.8) coronary MR angiograms show midarterial stenosis (white arrow) in the identical location in the RCA of the same patient. *F,* Conventional coronary angiogram shows 75% stenosis (arrow) of the midportion of the RCA. *Ao* = aorta, *Cath* = catheter.

Discussion

- We have compared individually adapted BH coronary MR angiography with free-breathing NAV coronary MR angiography by using steady-state free precession sequences.
- The parameters of ***image quality*** were ***superior*** with ***prospective NAV imaging***.

- At the comparison of the BH technique with the NAV technique, we found that the NAV technique enabled the correct diagnosis of 13% more coronary segments, resulting in ***higher diagnostic accuracy.***
- BH image quality is mainly influenced by the limited data acquisition duration, which depends on the individual BH capability & coronary artery rest period of the patient.

- For this study a low spatial resolution sequence (1.3 x 1.3 x 3 mm) was chosen to make the BH possible for most patients.
- Even though spatial resolution can be better when navigator techniques are used, the choice of using a low resolution was based on the reports of successful coronary MR angiography performed with low spatial resolution sequence and the restrictions for maximal BH duration.

- For both the approaches, BH and free breathing NAV, the rest period of the imaged coronary artery was individually determined and used to define the acquisition duration per heart beat.
- The acquisition duration was limited to a max of 150 msec because a ***longer acquisition*** leads to an ***increase in vessel blurring***, esp. in distal segments of coronary arteries owing to excessive movement.

- The use of sensitivity encoding factors ***greater than 3.5*** results in a ***decrease in SNR*** to less than 45% of the SNR in images acquired without sensitivity encoding factors.
- The sensitivity and specificity of CMRA with retrospective navigator echo respiratory triggering is only modest, i.e. the NAV approach is inferior to the BH approach.

- Low spatial resolution CAMR images obtained with a steady state free precision were nondiagnostic in 35% of patients when BH technique was used.
- Whereas, they were diagnostic in 100% of patients when free breathing NAV technique was used.

- The free breathing NAV technique was superior to the BH technique and enabled a correct diagnosis in 13% more coronary segments – even in patients with a more favorable combination of BH capability and coronary artery rest period.

- Only in a group of 18% of the total patients, who had optimal BH capability and long coronary artery rest periods did the BH and free breathing NAV techniques yield similar results.
- Thus, individual determination of ***BH capability*** and ***coronary artery rest period*** is ***essential*** for choosing the adequate breathing motion suppression technique when ***image quality and economy of time*** are also the ***considerations.***

True FISP

- Cardiac MRI is primarily driven by the conflicting requirements of high spatial resolution and short acquisition times.
- The recently introduced True FISP acquisition with its ***high signal at short TR, high inherent blood/myocardium contrast***, and ***motion insensitivity*** has been shown to be an excellent technique for ***rapid cine imaging*** of the heart.

True FISP

- True FISP (True Fast Imaging with Steady state precision) is a technique that refocuses all gradients over a repetition interval, thus permitting fast imaging with a high signal.
- FISP sequences rephase the transverse magnetization that undergoes dephasing during the during phase encoding and readout between RF pulses.
- Therefore imaging occurs when all transverse and longitudinal magnetization components are at a steady state.

- This sequence is very similar to FLASH, except that the spoiler pulse is eliminated.
- As a result, any transverse magnetization still present at the time of the next RF pulse is incorporated into the steady state.
- FISP uses a RF pulse that alternates in sign.
- Because there is still some remaining transverse magnetization at the time of the RF pulse, a RF pulse of a degree flips the spins less than a degree from the longitudinal axis.

- With small flip angles, very little longitudinal magnetization is lost and the image contrast becomes almost independent of T1.
- Using a very short TE (with TR 20-50 ms, flip angle 30-45°) eliminates T2* effects, so that the images become proton density weighted.
- As the flip angle is increased, the contrast becomes increasingly dependent on T1 and T2*.

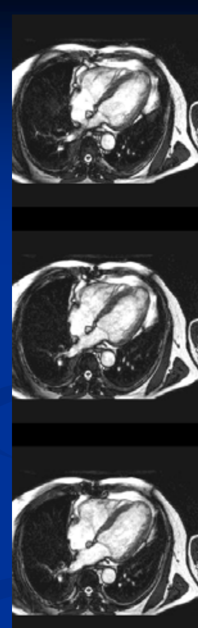
- It is in the domain of large flip angles and short TR that FISP exhibits vastly different contrast to FLASH type sequences.
- Used for T1 orthopedic imaging, cardiography and angiography.

- It is thus a coherent technique that uses a fully balanced gradient waveform.
- The image contrast with TrueFISP is determined by T2*/T1 properties and mostly depending on TR.
- The speed and relative motion insensitivity of acquisition help to make the technique reliable, even in patients who have difficulty with holding their breath.

- Recent advances in gradient hardware have led to a decreased minimum TR.
- This combined with improved field shimming capabilities and signal to noise ratio, has allowed TrueFISP imaging to become practical for whole-body applications.
- There's mostly T2* weighting.
- With the used ultra short TR-times T1 weighting is almost impossible.

- One such application is cardiac cine MR with high myocardium-blood contrast.
- Spatial and temporal resolution can be substantially improved with this technique, but contrast on the basis of the ratio of T2* to T1 is not sufficiently high in soft tissues.
- By providing T1 contrast, TrueFISP could then document the enhancement effects of T1 shortening contrast agents.

Cardiac infarct in horizontal long axis (HLA).
The 4 chamber views with overlapping slices show the left and right ventricle and the atria.



Drawback

- The drawback of this technique is the banding artifacts caused due to B0 inhomogeneity.
- The band distance is inversely proportional to the B0 inhomogeneity and repetition time

Solution:

- To use a very short repetition time by taking advantage of advanced gradient hardware and high readout bandwidth.

Real time and segmented True FISP cardiac cine using radial sampling.

- Radial sampling techniques offer a different set of tradeoffs than encountered in standard Fourier imaging ; ***undersampling*** gives rise to ***primarily reduced SNR*** and to a lesser extent a decrease in resolution; a reduced FOV does not give rise to aliasing but only to reduced SNR.

- True FISP sequences using radial trajectories were implemented on a 1.5 T MAGNETOM Sonata with a high performance gradient system, having a max grad strength of 40mT/m and a max slew rate of 200mT/msec.

- The sequence was based on a real time ungated 2DFT True FISP sequence with echo sharing to improve temporal resolution.
- View sharing is done for 50% of the views.
- The timing parameters consisted of

1. TR/TE = 3.0/1.5 msec.
2. 16 lines/seg to give effective temporal resolution of 48 ms and 24ms for segmented and shared segmented radial sequences.

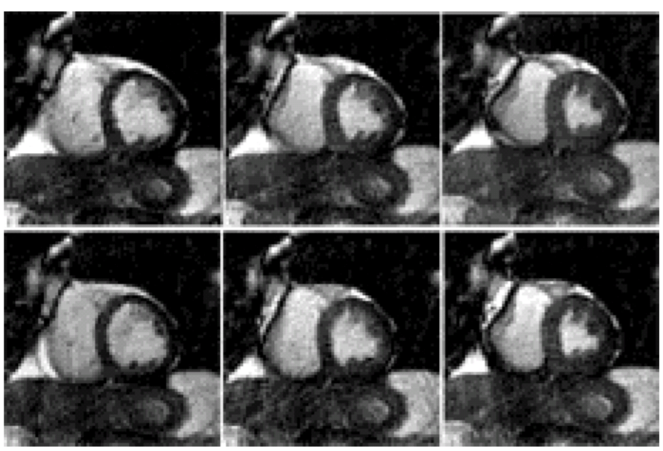


Figure 1: The images from real time radial cine sequence are shown here, at different time points. The upper row shows images from continuous sharing and the lower ones from interleaved sharing.

- Motion of the heart appeared to be asynchronous in the continuous sharing method and smooth in the interleaved sharing.
- However a slight increase in the radial streaks was observed with the interleaved sharing method.

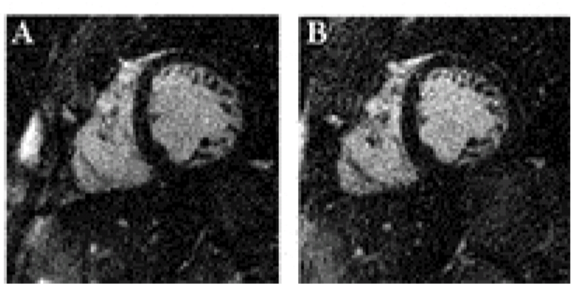


Figure 2: Short axis views using radial segmented True FISP cine sequence. (a) Continuous and (b) Interleaved segmentation. The images were reconstructed on 256x256 matrix.

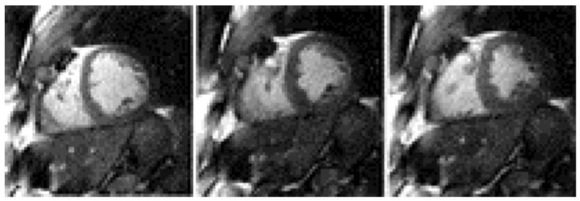


Figure 3: 256x256 resolution images from continuous shared segmented sequence, at different time points. 40 phases of cardiac cycle were obtained within 12sec of acquisition time.

Discussion

- In radial sampling techniques the image resolution is primarily dependant on the number of samples in the read direction.
- This results in the higher resolution per unit time than Fourier imaging, at the expense of SNR.
- This is advantageous in cardiac cine imaging where the temporal resolution and scan time are critical parameters.

- The decreased SNR can be compensated to some extent by using a True FISP acquisition which inherently has higher SNR.
- The number of projections can thus be optimized for SNR and minimization of the streak artifacts.

- Sharing, in the segmented sequence gives a significant ***improvement in temporal resolution*** with the image quality remaining the same or increases the number of projections collected for the same number of phases to improve the SNR of each phase.

- The results from the implementation of the real time radial sequence show that interleaved sharing is better suited for cardiac cine studies.
- Continuous sharing which is similar to the sliding window reconstruction results in alternating updating of data in horizontal and vertical directions.

- This causes the motion of the heart to appear discontinuous and asynchronous.
- In a short axis view the radial motion of the heart is such that ***k-space*** must be ***continuously updated in all directions***, as is done in the interleaved sharing approach.

- Moreover, temporal resolutions achieved here were significantly higher than those currently used, without degrading the image quality.
- Combining the advantages of True FISP and that of undersampled radial techniques for application in real time and BH segmented cardiac cine imaging is therefore feasible and appears to be very promising.

References

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