**INTRODUCTION**

Cardiac MRI (CMR) has become an important technique in the assessment of cardiomyopathies (Hundley, et al., 2010) (Wu, 2009) (DJ, et al., 2004) (WG, et al., 2007). Assessment of late gadolinium enhancement (LGE) has proved to be a diagnostic and an important prognostic tool in ischemic heart disease patients and has been trusted in making clinical decisions for suitability for coronary revascularization.

Cardiac MRI with LGE has few limitations which are mainly the time consuming protocol and interferes of image quality due to motion artifacts. Consequently, optimizing the cardiac MRI acquisition protocols was important to the shorten acquisition time still being able to achieve better quality image for diagnostic purposes.

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Proper inversion time (TI) should be accurately selected for better contrast between the normal and abnormal areas in the myocardium.

With the target of streamlining our acquisition protocol to adapt increment in CMR indications, our study’s fundamental aim was to compare the differences between 2D-PSIR (at 10 minutes) and late 2D-IR (at 15 minutes) - both qualitatively and quantitatively and to determine which one offers the better imaging and diagnostic qualities.

**MATERIAL AND METHODS**

This prospective study was conducted in the department of Radio diagnosis and Imaging, over period of 2 years. Institutional ethical committee’s permission was obtained and all the patients were informed before taking their consent. Total number of patients in our study were 40. Inclusion criteria for our study was clinically suspected cases of non-ischemic cardiomyopathies without coronary artery disease and Ischemic cardiomyopathies with coronary artery diseases.
confirmed with conventional angiography/ECG/lab reports. Exclusion criteriawas, acute myocardial infarction (requiring immediate management), deteriorated renal function, valve prosthesis & pace maker or other conditions which were interfering with the patient’s ability to comply with the examination.

**Imaging protocol**

All patients underwent a 1.5T cardiac MRI (Achieva1.5 T s, Phillips Medical Systems, The Netherlands) using 1 SENSE torso XL body coil with patient positioning being supine for all the cases. Routine conventional cine sequence were obtained followed by later gadolinium enhancement images from apex to the base of the heart the late gadolinium enhancement images were taken in short axis employing a T1-weighted 2D inversion recovery fast spin echo. Post contrast phase sensitive inversion recovery sequence at 10 and 15 minutes for 2D-PSIR and 2D-IR respectively were required in short axis view. At approximately 12 mins after injection time we acquired look locker sequence allowing selection of a T1 to null normal myocardial signal (typically 200-300 msec) , which is essentially required to achieve better image quality in case of 2D-IR sequence. Gadolinium based contrast agent at dose of 0.1mmol/kg was used in all patients.

In additional to these, LGE sequences were acquired in the two cardiac planes that is (LV long-axis, 4-chamber)

**Analysis or comparison of late PSIR and IR is done. Acquisition parameters are summarized in Table 1.**

<table>
<thead>
<tr>
<th>Sequence type</th>
<th>2D-PSIR</th>
<th>2D-IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>6.1 ms</td>
<td>6.1 ms</td>
</tr>
<tr>
<td>Flip angle</td>
<td>25°</td>
<td>25°</td>
</tr>
<tr>
<td>Field of view</td>
<td>320 mm</td>
<td>320 mm</td>
</tr>
<tr>
<td>Acquisition voxel size</td>
<td>1.60/2.11/10.00 mm</td>
<td>1.60/2.11/10.00 mm</td>
</tr>
<tr>
<td>Reconstruction matrix size</td>
<td>1.33mm</td>
<td>1.33mm</td>
</tr>
<tr>
<td>Slice number acquisition</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Acquisition time per slice</td>
<td>~10 sec</td>
<td>~10 sec</td>
</tr>
<tr>
<td>Approximate acquisition time</td>
<td>1.55m</td>
<td>1.55m</td>
</tr>
</tbody>
</table>

**LGE evaluation**

For 2D-PSIR and 2D-IR sequences assessment was done by qualitative assessment and quantitative assessment by two radiologists (one experiencedobserver-1 and one traineeobserver-2)

**Qualitative analysis**

The myocardium-LGE contrast & margin sharpness, artifacts, and overall image quality for PSIR and IR sequence were graded on a 4-point grading scale by two separate radiologists. Scoring method being, 1 for poor, 2 for fair, 3 for good and 4 for excellent quality images. Using Kendall Tau test the agreement between the two was evaluated (has to be changed). The criteria for 4 point grading system is given in table 2. [Schultz, et al., 2016]

![Fig. 1](image1) Signal intensity measurement on subendocardial enhancement (~<25% thickness) involving apical-mid basal anterior septal segment of left ventricle on VLA view of 2D-PSIR (a), 2D-IR (b) and healthy myocardium (c), with a ~4.4 mm2 ROI in the wall (LGE).

![Fig. 2](image2) In 59 year old male the signal intensity is measured on Short axis view of LV where LGE is seen in the mid anteroseptal segment with 100% myocardial extent on 2D-PSIR (a), and 2D-IR (b), with a ~4.4 mm2 ROI in the wall (LGE).
Table 2 4-point Grading system

<table>
<thead>
<tr>
<th>Score</th>
<th>LGE contrast and margin sharpness</th>
<th>Artifacts</th>
<th>Overall image quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poor</td>
<td>Severe, interfering with the evaluation</td>
<td>Poor, interfering with the evaluation</td>
</tr>
<tr>
<td>2</td>
<td>Fair</td>
<td>Moderate interfering by the artifacts</td>
<td>Fair, moderate interfering</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
<td>Mild interference</td>
<td>Good, mild interference</td>
</tr>
<tr>
<td>4</td>
<td>Excellent</td>
<td>Minimal/ No artifacts</td>
<td>Excellent, minimal to no artifacts</td>
</tr>
</tbody>
</table>

Identification of LGE was grouped into two categories, Group 1 (score 3 & 4: good to excellent images) and into group 2 (score 1 & 2: poor to fair images). In cases where score was given 2 by one observer and 3 by another, lower value was taken to avoid overestimation.

**Quantitative Assessment**

CNR value was calculated and recorded for both Late PSIR and IR sequence. Using ROI~4mm² at LGE area (basal, mid and apical region) and in normal myocardium signal intensity and its standard deviation was measured. Using the following formula CNR was calculated. (Schultz, et al., 2016)

\[
\text{CNR} = \frac{\text{LGE Signal} - \text{Myocardial Signal}}{(\text{SD of LGE} + \text{SD of Myocardium}) / 2}
\]

For each manual ROI by drawing the LGE contours was done at the same level/place in a given case for both PSIR and IR sequences. Optimal adaptation of the window settings for each sequence was performed by the same operator so as to get an optimal and reproducible visualization of the LGE.

**Statistical analysis**

To measure the concordance between superior image quality between two LGE sequences and readers Cohen’s Kappa was used [Cohen, 1960]. Hierarchical logistic regression models were used for comparisons between sequences in order to take into account two random effects and thus intra-class variability for the reader and the subject effect.

**RESULTS**

Forty patients underwent a gadolinium enhanced cardiac MRI on our 1.5T scanner over the period of 2 years. 34 patients exhibited LGE out of 40 patients. There were 15 patients of ischemic cardiomyopathy, with one being secondary dilated cardiomyopathy. Total non-ischemic cardiomyopathies were 21, of which 12 cases were HCM, 4 were RCM, 1 DCM, 1 Myocarditis and 3 were cases of Takotsubo. The age group of the patients varied from 21-80 years with a mean of 57 years. Most of the patients were between 61-70 years that is contributing to 37.5%. Out of the total 40 patients, 27 (67.5%) were males and 13 (32.5%) were females.

Out of 34, 13 cases showed sub-endocardial late gadolinium enhancement, which contributed to 38.2% of the cases, 9 showed transmural enhancement (26.4%), 17 mid wall (50%) and 2 epicardial (5.8%).

**Comparison between 2d PSIR and 2d-IR sequence:**

**Qualitative evaluation**

Assessment of overall image quality on basis of sharpness & contrast and artifacts showed that late 2D-PSIR sequences were significantly superior to 2D-IR sequences. Qualitative evaluation’s result with a 4-level scale was summarized in Table 3 and 4. Inferential statistical analysis results are listed in Table 5. 2D-PSIR sequences are superior to 3D-IR. Qualitative variability for PSIR and IR images was; there was only significant disagreement between the two post contrast MRI sequences. 2D-PSIR sequence shows significantly higher number of images with better image quality (good to excellent) than images which were obtained by 2D-IR sequence.

**Table 3 Qualitative evaluation**

<table>
<thead>
<tr>
<th></th>
<th>2D-PSIR</th>
<th>2D-IR</th>
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<tbody>
<tr>
<td>Good to excellent</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>Poor to fair</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>34</td>
</tr>
</tbody>
</table>

**Table 4 Descriptive analysis of qualitative evaluation**

<table>
<thead>
<tr>
<th></th>
<th>2D-PSIR</th>
<th>2D-IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharpness &amp; contrast</td>
<td>3.03±0.63</td>
<td>2.16±0.71</td>
</tr>
<tr>
<td>Artifacts</td>
<td>2.08±0.6</td>
<td>1.01±0.5</td>
</tr>
<tr>
<td>Overall image quality</td>
<td>3.12±0.6</td>
<td>2.16±0.63</td>
</tr>
</tbody>
</table>
Disagreement was due to patchy enhancement in the LV mid-wall involving antero-septal segment on a) 2D-PSIR and b) 2D-IR images. Certain patients with hypertrophic cardiomyopathy showed a strong agreement between the two readers. However, there was a slight disagreement between the two readers on terms of artifacts and overall image quality. Kappa tests showed a strong agreement between the two readers, whereas there was a slight disagreement between the two readers concerning the sharpness and margins. Quantitative assessment confirmed the superiority of 2D-PSIR over 2D-IR. Mean Contrast-to-noise ratio (CNR) for 2D-PSIR was 20.77±12.12 and for IR was 10.03±8.85. There was a significant difference between their mean value with PSIR showing significantly higher values, almost more than twice the value obtained by IR sequences.

Quantitative assessment confirmed the superiority of 2D-PSIR to 2D-IR (Table 6). Mean Contrast-to-noise ratio (CNR) for all the 34 cases for 2D-PSIR sequence was 20.77±12.12 and for IR was 10.03±8.85. There was a significant difference between their mean value with PSIR showing significantly higher values, almost more than twice the value obtained by IR sequences.

Table 6: Quantitative evaluation

<table>
<thead>
<tr>
<th>CNR</th>
<th>2D-IR</th>
<th>2D-PSIR</th>
</tr>
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<tbody>
<tr>
<td>Mean of difference</td>
<td>8.5±10.3</td>
<td>16.9±13.2</td>
</tr>
<tr>
<td>Credible interval</td>
<td>0.7575</td>
<td>0.9763</td>
</tr>
<tr>
<td>Likelihood</td>
<td>0.0553; 0.1595</td>
<td>0.9763; 2.4142</td>
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</table>

Interobserver agreement

Kappa tests showed a strong agreement between the two readers on terms of artifacts and overall image quality, however there was a slight disagreement between the two readers concerning the sharpness and margins (0.6694 for 2D-PSIR sequence and 0.4583 for the 2D-IR sequence). Disagreement was due to images being scored 3 by one and 4 by the other one. Diagnostic quality image scored as 3/4 and poordiagnostic image quality scored as 1-2 were correctly assessed by both observers.

DISCUSSION

In our study, we collated data from different LGE sequences and showed superiority at quantitative and qualitative levels for the late-PSIR over the late IR sequences. These results were in accordance with previous studies which were also carried out on 1.5 Tesla, the significance and importance of PSIR in LGE imaging was well-established [(Chen, et al., 2013) (Kino, et al., 2011) (Kino, et al., 2009) (Robert, et al., 2013) (Elgeti, et al., 2007) (Huber, et al., 2006)]. Studies were carried out at 3T, by Kido, et al., 2014. These studies evaluated 56 patients, and showed noteworthily difference in overall margin sharpness and artefacts. Quantitative and qualitative assessment showed significant difference between their mean value with PSIR showing significantly higher values, almost more than twice the value obtained by IR sequences.

Quantitative analysis confirmed the superiority of 2D-PSIR to 2D-IR (Table 6 & Table 7 for Inferential analysis results for the quantitative evaluation). Mean Contrast-to-noise ratio (CNR) for all the 34 cases for 2D-PSIR sequence was 20.77±12.12 and for IR was 10.03±8.85. There was a significant difference between their mean value with PSIR showing significantly higher values, almost more than twice the value obtained by IR sequences.

Quantitative evaluation

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Inappropriate selection of the inversion time (TI) results in incomplete suppression of the mycardium. Most common error is the selecting a shorter TI, resulting in a subendocardial “ring of hypointensity” and a mid-myocardial zone of hyperintensity. These artifacts mimic true mid-myocardial delayed enhancement that is seen in pathologies like sarcoidosis or DCM. In cases of restrictive cardiomyopathies where suppression of abnormal myocardium (amyloidosis is the prototypical example) causes hypointensity of abnormal myocardium. This will result in the poor quality of delayed enhancement images that is a hallmark of patients with amyloidosis hence important potential pitfalls of LGE result from incorrect inversion time selection. First, incorrect nulling of the myocardium reduces...
the conspicuity of true myocardial delayed enhancement, potentially interfering with the diagnosisof underlying pathology, resulting in a false negative result and secondly, incomplete nulling due to a short inversion time, if not recognized as artifact, can be erroneously interpreted as diffuse mid-myocardial LGE, leading to a false positive result. The interpreting radiologist must be familiar with the appearance of deviations of the TI selection, and be aware of underlying conditions, particularly amyloidosis, that can cause difficulty in selecting the correct TI time. (David, et al., 2015)

Typical clinical scenario TI is selected to provide maximal contrast between normal and abnormal myocardium by completely nulling any signal from normal myocardium. TI selection determines the sensitivity for the detection of myocardial damage. It enables restoration of the voxel polarity since images are acquired in alternating heartbeats using a phase-sensitive reconstruction to rectify the tissue signal intensities caused secondary to inaccurate TI selection. The PSIR sequence counter balance any cutback in CNR due to TI changes and maintains signal as well as contrast consistent during scanning, avoiding the need for a narrow definition of optimal TI.

Accurate measurement and quantification is possible when there is a good contrast difference between normal and abnormal area with well defined margins and high signal intensity incomparsion to normal remote myocardium.

Thus late 2D-PSIR-breath hold sequence shows high spatial resolution, better image quality on terms of margin, artifacts and over-all image quality being acquired in a lesser duration of time without missing out any LGE areas.

In our study, late 2D PSIR at 10 minutes showed a high likelihood (100%) of being superior to late 2D-IR acquired at 15 minutes, in terms of LGE margin sharpness, CNR and overall image quality.

Bayesian inference analysis indicates superiorstatistic power and gives a probability evaluation of the qualitative difference between the sequences, a binary clustering of qualitative assessment data (score 1 and 2 grouped in category 2, score 3 and 4 grouped in category 1) with concordance analysis showing astring agreement between the two radiologists. This result needs to be put intoperspective with the number of categories, which were two in our study, in case of increase in categories there is a lower concordance. Reason for slight disagreement in our study was predominately between scores of 3 and 4, which does not affect nor hamper the diagnostic value of the image quality.

CONCLUSION

Our study shows that on a 1.5T scannerlate 2D-PSIR sequences were significantly superior to 2D-IR in terms of qualitative &quantitative assessment of LGE. PSIR revealed a better imaging quality with higher diagnostic confidence than IR images in terms of artifacts, sharpness and overall quality.

PSIR has advantage over IR sequence in imaging infiltrative cardiomyopathies secondary to amyloidosis where the normal blood pull nulling before the myocardium is altered resulting in a false inversion time (TI)

It over comes one of the major drawbacks of IR sequence, its dependency on look locker sequence and saves times by avoiding need of repetitive acquisition of looksequence in order to acquire early (5mins) and late (10-15mins) LGE images.

Since PSIR is not dependable upon the timing (TI) of myocardial nulling it surpasses the limitation faced by IR sequences in terms of over all image quality which is hampered due to manual errors in proper selection of TI for IR sequence acquisition.

References


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