

The Quantification of Aortic Stenosis using Breath hold and Conventional Gradient Echo MR techniques

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Introduction The quality of velocity measurements at stenotic orifices using MR phase contrast techniques can be adversely affected by fluid turbulence and acceleration. Therefore, it is clinically important to validate these MR techniques if an accurate stenosis grading is to be obtained.

Materials and Methods MRI was performed on a 1.5 T whole-body imaging system (Gyrosan, Philips, Netherlands) using a cardiac surface coil. Fast field echo (FFE), and single breath-hold, turbo fast field echo (TFE) velocity encoded sequences were used *in vitro* to image steady flows through two stenoses. The working fluid was a gadolinium doped aqueous solution of glycerine. Transverse images of the stenotic flow were obtained at the orifice. Through plane MR mean velocity was measured by superimposing circular regions of interest over the orifice area. True orifice velocities were measured using a calibrated rotometer.

Results Figure 1 shows that the FFE technique significantly underestimated the orifice velocity whereas the breath-hold sequence showed very good correlation to the true orifice velocities for both the degrees of stenoses. Breath-hold Q-flow is an accurate method to quantify non-turbulent flows but shows temporal (phase) variation under turbulent conditions even though no signal loss is present (low echo time). Although the FFE method is accurate in non-turbulent regions it consistently under performs

when turbulent-related phase dispersion occurs at the edges of the orifice.

Conclusion Breath-hold is both accurate and fast technique that could be used clinically to quantify aortic stenosis at the level of the orifice.

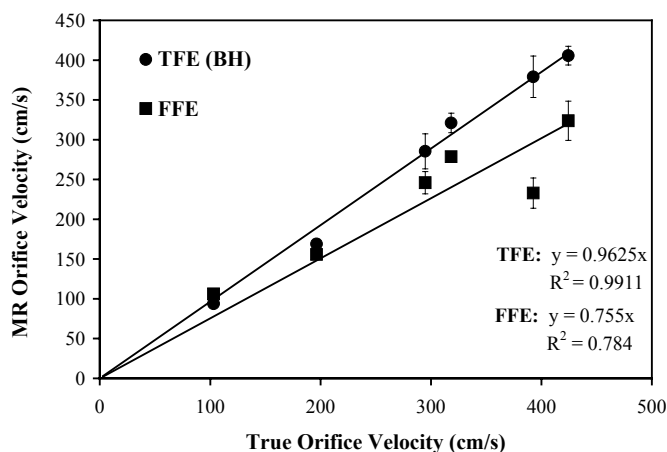


Fig.1. TFE & FFE orifice velocity (mean \pm SD) compared to the true value.

Comparison of FSE and SSFSE in the Determination of Left Ventricular Mass

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Introduction The accurate assessment of left ventricular mass is an important prognostic indicator in a number of cardiac diseases and has been determined using both spin echo and cine gradient echo imaging techniques. Black-blood fast spin echo (BB-FSE) is a widely used technique for morphological imaging of the heart that allows a single slice to be acquired in a breath-hold. However, full LV coverage requires multiple breath-holds with the potential for variation in each breath-hold position.

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Recently, black-blood single-shot FSE (BB-SSFSE) sequences have been proposed for morphological cardiac imaging [1] that can allow full LV coverage to be obtained within a single breath-hold. It is hypothesised that LV mass measurements obtained using the single-shot technique should reduce measurement variation.

Methods Ten normal volunteers (4 male and 6 female, age range 25-49, mean age 40.4±8.5 years) were imaged twice using a commercial BB-FSE sequence with each slice acquired in a separate breath-hold, and an in-house developed inner-volume [2] BB-SSFSE sequence with all slices being acquired in a single breath-hold. All subjects were also imaged using a conventional breath-held cine imaging sequence. The BB-FSE and BB-SSFSE images were manually analysed using the MASS software (Medis, Leiden, NL). The cine sequences were analysed using an in-house software package [3].

Results The mean LV masses were 141.2±22.5g, 140.5±20.5g and 141.4±16.0g for the BB-SSFSE, BB-FSE and cine sequences respectively. The results from comparisons of paired acquisitions are shown below.

| Measurement | P value | Difference ∓ 1 s.d. (g) |
|---------------------|---------|----------------------------|
| BB-FSE – BB-SSFSE | 0.777 | -0.65 ∓ 7.07 |
| BB-FSE – BB-FSE | 0.473 | -1.72 ∓ 7.26 |
| BB-SSFSE – BB-SSFSE | 0.876 | 0.29 ∓ 5.73 |
| BB-FSE– Cine | 0.15 | -3.46 ∓ 6.95 |

Conclusion There is no significant difference between the measurements of LV mass obtained using BB-FSE, BB-SSFSE or cine imaging. The mean difference in LV mass however is smallest for the repeated BB-SSFSE sequence indicating that

obtaining all images in a single breath-hold can reduce the measurement variability. BB-SSFSE is therefore proposed as a rapid and reproducible method for the determination of LV mass.

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Development and Evaluation of Interactive SSFSE for Cardiac and Abdominal MR Imaging

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Introduction Recently MRI system vendors have introduced interactive imaging capabilities that permit "fluoroscopic" type investigations. These techniques have primarily been based upon gradient-echo (GE) sequences due to their short acquisition times. However a number of artefacts, as well as a restricted range of contrast manipulations, can limit the applicability of interactive GE imaging in the chest and abdomen. Single-shot fast spin echo (SSFSE) imaging sequences can overcome a number of these problems and we have developed SSFSE sequences

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that provide interactive control of image geometry and contrast.

Methods We interfaced a commercial SSFSE sequence to a proprietary interactive imaging system (i/Drive Pro Plus, GE Medical Systems, Milwaukee, WI). The interactive interface allows the scan plane to be tilted, translated and rotated. Facilities also exist for arbitrary oblique or 2/3-point slice prescription as well as interactive modification of slice thickness and field-of-view. Contrast manipulation was effected through the incorporation of dynamic phase-encode reordering and toggling of a fat saturation pulse. Further image quality improvements were obtained by providing fast magnetisation recovery [1] and variable repetition time (TR). For cardiac applications the sequence was modified to incorporate ECG triggering and black blood preparation [2]. Spatial resolution was maintained and image aliasing artefacts reduced by incorporating the inner-volume imaging concept [3].

Results The interactive imaging capabilities were optimised and evaluated in a number of clinical areas including MR cholangio-pancreatographic (MRCP) projection imaging, cardiac scan plane localisation and general morphological cardiac and abdominal imaging.

Conclusion Interactive MR imaging using SSFSE produces more diagnostic quality images in a shorter period of time than conventional, i.e. non-interactive, methods, however the diagnostic efficiency is currently lower. Nevertheless, the ability to rapidly “toggle” contrast may benefit any imaging regime requiring multiple image weightings, i.e. fat suppression, proton density, T1 and T2, potentially improving diagnostic confidence.

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A flow phantom for catheter tracking under MR

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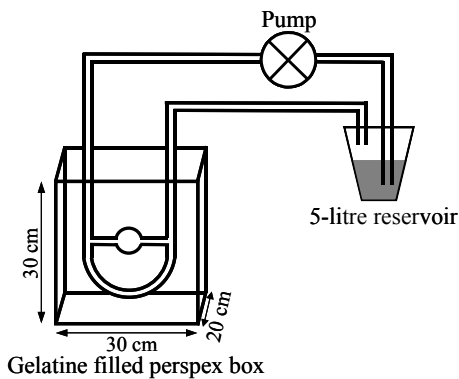
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Introduction Development of passive catheter tracking is a prerequisite for interventional cardiac MRI. Preliminary experiments on a static phantom were unsatisfactory due to turbulent flow induced by catheter motion. This abstract describes a phantom with continuous pulsatile flow that can be used for more realistic catheter tracking experiments.

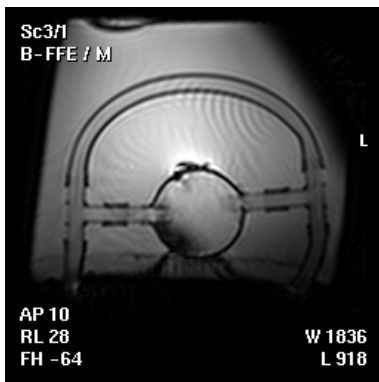
Methods The phantom (Fig 1.A) consists of a plastic U-bend (20mm i.d.) with a cavity (10cm diameter sphere) connected to it in parallel to simulate the heart. It is encased in Perspex box filled with gelatine slightly doped with copper sulphate. It is connected to a pulsatile blood pump (model 1423, Harvard Apparatus, MA, USA) placed in a purpose-built Faraday cage and a 5-litre reservoir of water doped with copper sulphate. A stroke volume of 50ml and a 50bpm heart rate were used. Scanning was carried out on a 1.5T Philips Intera MR scanner in conjunction with a four-element body array coil. A 6F

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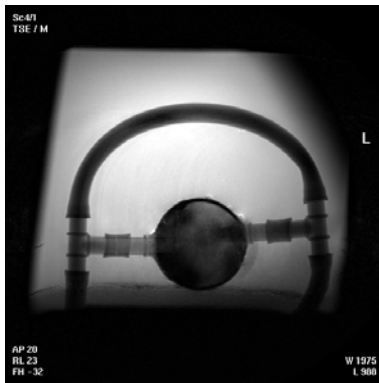
catheter sheath was introduced to the input pipe 10cm from the gelatine surface and 6F Berman catheters were used with the balloon filled with CO₂.



1A. Schematic of the phantom set-up



1B. Steady State Free Precession image of the phantom



1C. Spin Echo image of the phantom.

Results The pump used in this phantom replicates in-vivo flow conditions (heart rate, stroke volume, and waveform). Fig 1B & 1C show typical SSFP and spin echo images of the phantom. In preliminary experiments, using a single slice SSFP sequence (TE 1.87 ms, TR 3.8 ms) it was possible to follow the catheter balloon along the U-bend and to guide it into the cavity.

Conclusions Preliminary experiments using the flow phantom were promising. We have shown that SSFP sequences can be used to achieve adequate tracking of a standard catheter in an environment approximating in-vivo conditions.

Rapid Analysis of Geometric Distortions using Harmonic Phase (HARP) Analysis

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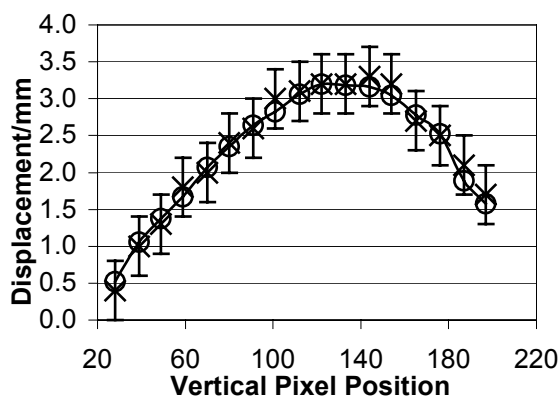
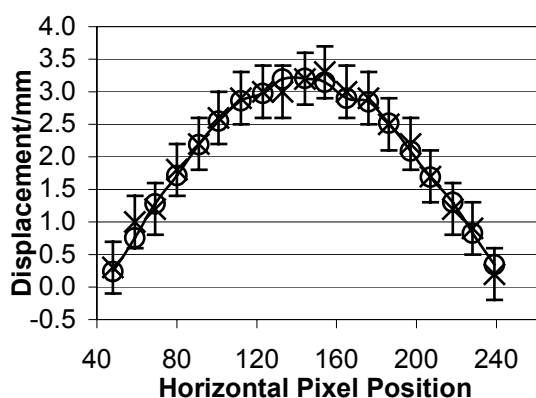
Introduction Magnetic resonance (MR) images need to be geometrically accurate, especially if they are to be used for radiotherapy treatment planning. Distortions can arise from either gradient non-linearities or static field (B_0) inhomogeneities^[1]. Harmonic Phase analysis (HARP)^[2] is used to assess the degree of distortion in MR imaging, principally that arising from B_0 inhomogeneities. The analysis was incorporated into a computer program written in IDL to allow rapid assessment of distortion with minimal input from the user.

Methods The program required two images of a 2D grid phantom, taken at two different bandwidths. The magnitude of distortion in each image depends upon the inverse of the bandwidth with the difference in distortion between the two images being proportional to the B_0 inhomogeneity. The technique was validated using two spin-echo images with bandwidths of ± 15.7 and ± 3.7 kHz. The images were analysed automatically using the HARP software and manually using software callipers on a commercial image analysis workstation. The manual measurements were made by measuring the displacement of intersection points of the grid between the two

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images. Manual analysis took approximately 40 minutes to analyse a single line of grid points; in comparison the HARP analysis took 30 seconds to analyse the entire image.

Results Plots of the displacement calculated by both methods taken horizontally and vertically across the phantom are shown in Figures 1 and 2 (O: HARP measurements, X: manual measurements). It can be seen that there is good agreement between the two measurements (N/S, paired-sample t-test).



Conclusion These results demonstrate the viability of using this method to measure geometric distortion. The method is fast and provides a continuous measurement of distortion over the whole area of the phantom, not just at the intersection points of the grid. It is possible that this technique can be extended to measure distortions resulting from gradient non-linearities.

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MR Imaging of Carotid Atheroma.

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Carotid atherosclerosis has been identified as one of the leading causes of stroke, which in turn is the leading cause of morbidity and mortality in the industrialised world. Studies have shown that atherosclerosis starts at an early age and progresses in an asymptomatic manner over decades. A stroke occurs when a *vulnerable* atherosclerotic plaque ruptures resulting in vessel occlusion or distal embolisation. Recently it has been shown that plaque rupture often occurs in mild to moderately stenosed atherosclerotic lesions that would not be considered “high-risk” on the basis of conventional techniques such as X-ray angiography that only evaluates the vessel lumen. Consequently there is considerable interest in being able to identify vulnerable plaque. High-resolution black-blood MRI has already been demonstrated as an excellent technique for prospectively defining internal plaque morphology. Initial comparisons of multi-contrast MRI images with histology show good agreement in the characterisation of various plaque constituents [1,2]. Dynamic contrast-enhanced imaging also shows changes in the vessel wall that may be indicative of plaque neovascularity [3], whilst other experiments

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have identified the potential for ultra-small paramagnetic iron oxide (USPIO) particles to demonstrate macrophage phagocytosis as a sign of inflammatory plaque activity [4]. MRI can also provide detailed haemodynamic information that can be used as the basis for computational fluid dynamics (CFD) modelling, allowing the prediction of wall shear stress all points on the lumen surface. Differences in wall shear stress may also help predict disease progression or risk of plaque rupture [5]. Therefore there is considerable promise in the ability of MRI to predict whether a given atherosclerotic plaque is likely to rupture or remain quiescent. The ability to accurately quantify carotid plaque burden should also improve the assessment of the effectiveness of various lipid-lowering treatments over time. This type of non-invasive serial imaging could also improve our understanding of early plaque formation [6].

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Characterisation of Complicated Carotid Plaque with Magnetic Resonance Direct Thrombus Imaging in Patients with Cerebral Ischaemia.

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Introduction Thromboembolic disease secondary to complicated carotid atherosclerotic plaque is a major cause of cerebral ischaemia. Methods of detecting the presence of high risk plaque currently rely on the detection of carotid stenosis. A stenosis of > 70% is usually required before any intervention is carried out however a large proportion of patients suffer irreversible cerebral ischaemia as a result of lesser degrees of stenosis. Diagnostic techniques that can identify non-stenotic high risk plaque would therefore be beneficial.

Method There is a predictable change in the T1 of blood as it undergoes clotting, with the resultant substantial reduction in T1 producing high signal intensity on T1-weighted images. We have used this effect to produce direct clot images using a T1 weighted 3D technique that suppresses the signal from fat and nulls that from blood. This imaging

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technique is capable of detecting methaemoglobin within recent thrombus. We used this as a marker of complicated plaque and compared its accuracy with histological examination of surgical endarterectomy specimens in sixty three stroke patients. The excised arteries were also imaged in vitro on a 12T MR microscope using a 3D spin-echo sequence with a non-selective inversion pulse with a TI to null formalin.

Results 44 out of the 63 specimens were histologically defined as complicated (type VI plaque). Magnetic resonance direct thrombus imaging (MRDTI) demonstrated three false positives and seven false negative results, giving a sensitivity and specificity of 84%, negative predictive value of 70 % and positive predictive value of 93%.

Conclusion MRDTI of the carotid vessels in patients suffering from cerebral ischaemia is an accurate means of identifying histologically confirmed complicated plaque. The high contrast generated by short T1 species within the plaque allows for ease of interpretation making this technique highly applicable in the research and clinical setting for the investigation of carotid atherosclerotic disease.

A Volume-Selective 3D Turbo Spin Echo Sequence for Vessel Wall Imaging and Distensibility Measurement

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Introduction Previous work on MR vessel wall imaging includes chemical shift imaging [1] and T₁, T₂ and proton density weighting to characterize lipid,

fibrous cap and calcification[2]. Typically images are 2D, full FOV. A volume-excitation GRASE technique has been described, acknowledging problems with 2D RF[5]. We developed robust volume-selective 3D TSE sequence using orthogonal slice selection gradients for the 90° and 180° RF pulses[3]. Dark blood preparation, fat suppression and variable echo times produce contrast and definition of the vessel wall [4]. The reduced phase-encode FOV allows significantly more k_z steps in the same scan-time. We have acquired high resolution images of the carotid artery wall in 3D and measured distensibility.

Method The carotid artery in 10 healthy subjects was imaged. A true resolution of 0.47 x 0.47mm in plane was typical, with 28 slices (2mm thick) or 12 slices (1mm) for the vessel in-plane. A FOV of 120 x 24mm and echo train length of 7 was used (70ms) for the 3-5 minute scans. The short acquisition window allowed diastolic and end-systolic imaging without blurring. For end-systolic imaging the dark blood preparation was at the end of the preceding cardiac cycle. For T1 contrast TE=9ms and TR=RR; PD/T2 weighting uses TE=27ms and 74ms, TR=2RR. The vessel wall thickness was measured and distensibility was quantified from lumen areas.

Results and Discussion Average wall thickness was 0.8mm, and the change in area, 4.7 mm². The 3D volume selective images provided detailed structural information at high resolution along a length of vessel wall. Dark blood was effective for systolic imaging (variability in inversion time) and also for in-plane imaging in a modified form.

Conclusions A volume-selective method was developed providing larger coverage of the vessel than a 2D full FOV image, maintaining SNR. We measured wall thickness and distensibility in the carotid artery, imaging at different times in the cardiac

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cycle, showing regional changes in the vessel wall structure and function.

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The quantification of the pulmonary autograft size mismatch, and dilatation following the Ross procedure using MRI

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Introduction The Ross procedure is a complex operation, and knowledge of the effects of valvular size mismatch needs to be known. The aim of this work was to use modern MRI techniques to measure the effect the higher pressure system has on the morphology of the pulmonary autograft.

Method The study consisted of 6 male and 2 female patient's aged between 13 to 35 years (mean 22

years). Imaging was performed using an ACS-NT Philips (Philips Medical Systems, Best, The Netherlands) 1.5T MRI scanner. Following a survey scan, 6 sagittal (coronal for the AV) cine gradient echo slices perpendicular to the valve with a 256 x 192 matrix, FOV = 266mm, slice thickness = 4 mm and number of signal averages = 2.

Results There was no increase in diameter at the pulmonary valve (PV) annulus when implanted into the higher pressure systemic system. Also, the PV annulus maintained its dilatation post-operatively. There was no change in the maximum diameter measurement at the sinus, sinotubular junction and in the main root of the autograft. However there was an increase in the minimum measurement which significantly reduced the dilatation at the sinus, sinotubular junction and in the main root post-operatively.

Conclusion The pulmonary autograft increased in diameter, but decreased in dilatation at the sinus, sinotubular junction and in the main root. This is believed to be the direct result of being implanted into the systemic system. However, there was no significant change in diameter or dilatation at the autograft annulus.