Assessing 3D resolution of DCE-MRI for optimization and standardization of breast screening protocols

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Introduction
Large multi-centre clinical trials have demonstrated the value of MRI breast screening [1,2], which demands high spatial resolution imaging. Spatial resolution of 3D fat-suppressed Dynamic Contrast Enhanced (DCE) pulse sequences depends on a variety of parameters. In particular, the type of k-space coverage and data truncation affect image resolution, with additional significant impact from the specific algorithm used for parallel imaging. Parity of protocols across screening centres is highly desirable to ensure optimal accuracy of disease detection. The objective of this work therefore was to implement techniques to compare the resolution of different 3D DCE breast MRI sequences, and propose methods to provide quality assurance for breast screening programmes.

Materials and Methods
This study was undertaken at 1.5T (Philips Intera). We compared the image quality achieved with two different k-space sampling patterns, radial [Rad] and linear [Lin], on a widely used breast screening sequence: a fat-suppressed Segmented Spoiled Grad-Echo (Philips THRIVE). Read-Out (RO) direction was Anterior/Posterior (AP) and the two Phase-Encoding (PE) directions were Right/Left (RL) and Foot/Head (FH). SPAIR for fat-suppression and a SENSE parallel imaging factor of 2 in RL direction were used. The reconstructed voxel was (1.25x1.25x1 mm) for both protocols and Echo Time (TE) was set to "shortest" to keep the temporal resolution (55 s) constant, resulting in TE=1.8 for [Rad] and TE=2.0 ms for [Lin]. The spatial resolution of the images acquired with the two protocols was then evaluated in 3D both with test objects and in a clinical setting.

Test Object Imaging: We used Perspex objects immersed in $CuSO_4$ solutions, with T1 ranging from 70 to 700 ms.

1) A cube provided a Modulation Transfer Function (MTF) for each of the three main axes. Analysis was performed using conventional methods and in-house software.

2) A plate with holes to be visually resolved (1, 1.5, 2, 3, 5 mm diameter) provided a direct assessment of resolution in the Axial and Sagittal planes.

Clinical Breast Examinations. Two groups of subjects were studied:

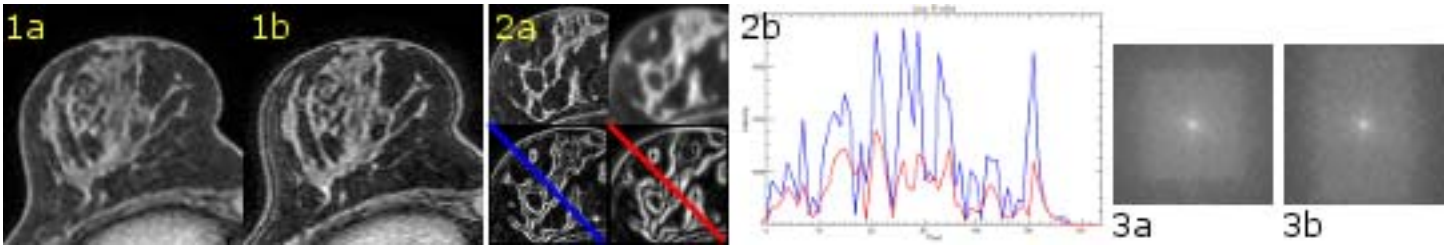
A) Five volunteers were scanned both with [Rad] and [Lin] in direct succession, with the same position and shimming. These datasets are therefore directly comparable, but the examination was undertaken without contrast injection.

B) Six patients had multiple examinations with the two different protocols, and a single dose of intravenous contrast agent (DOTAREM). However, the position of the patient in two separate examinations was not exactly reproducible.

Clinical Image Analysis: Image processing was performed both in the spatial and Fourier domain in all three imaging planes. A sub-volume containing one breast was selected and representative slices were extracted, paired by [Rad] and [Lin]. For group B) the disease-free breast was chosen and images were paired by corresponding structures.

Space Domain: Edge Analysis. A Sobel operator [3,4] (Fig. 2a) was applied to the images to enhance edges, and line profiles covering the whole image were extracted and integrated. The sum of the integrals across the image was used as metric, a greater integral being an indication of better sharpness (Fig. 2b). Different contrast brings a confounding contribution to the integral of an image processed with a derivative filter; therefore contrast was matched in paired images using their histogram (Histogram Matching algorithm [3]).

Fourier Domain: Power Spectrum Analysis. The 2D Fourier Transform of the magnitude images was computed to generate a 2D spatial frequency spectrum [5] (Fig. 3). The intensity of paired spectra was scaled using the center of the Fourier plane as normalization value. An incrementing threshold was then applied to the 2D spectrum, covering the whole intensity range, and each resulting distribution was fitted with an ellipse. Finally, the major and minor axis values of the ellipse were plotted versus threshold to enable quantitative analysis.



Figures. *Fig. 1*: Protocol [Rad] (*1a*) and [Lin] (*1b*) on a volunteer scan. *Fig. 2*: Sobel filter applied to an artificially blurred image (*2a*); histograms are matched and profiles are extracted (*2b*). *Fig. 3a,b*: Fourier transforms of *1a,b* respectively, showing the different truncation in the RO direction (vertical).

Results
Test Object Imaging: Considering all three directions, resolution in [Lin] was superior to [Rad]. In the RO direction MTF extended to higher spatial frequencies for [Lin], due to the different truncation resulting from the increased TE (Fig. 3). Regarding the PE directions, MTF was superior for [Lin] only in the FH direction. An improved sharpness was also observed for [Lin] in the images of the structured object, and in the Sagittal plane (FH) only [Lin] was able to resolve the smallest structure (1 mm), thus confirming the results found in MTF analysis.

Clinical Breast Examinations: In Spectrum Analysis, higher spatial frequencies were better represented in the RO direction for [Lin]. Improvement in both PE directions was found, which was only partially observed in MTF analysis. The main contribution to profile integral in Edge Analysis was found to be limited to contrast - increased for [Lin] - indicating that the differences in pure image sharpness are too small to be appreciated by a direct analysis of anatomical structures. The results obtained with both methodologies are reproducible and consistent for all patients and volunteers, for each slice and across slices along the entire volume selected.

Discussion and Conclusions
All the methodologies proposed indicate better image quality for [Lin], with improved contrast and resolution. However, greater noise and water-fat separation artifacts, due to TE being slightly out of phase, were observed. The consistency of results obtained between Test Object and Clinical Data validates the Image Analysis approaches, which can be successfully used to compare imaging protocols, and have the important advantage of being applied directly to the anatomical images that clinical users acquire. These methodologies were found to be robust and reproducible, and are therefore candidates to become quality assurance tools. Further work is required to find reference values and enable absolute measurements.

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