A validation dataset to assess pitfalls in DCE MRI image processing

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Introduction and Aim

DCE (dynamic contrast enhanced) MRI has been introduced in clinical practice for assessment of vessel hyper-permeability in various diseases. Scanner workstations, commercial specialised software or in-house developed software is used to analyse the uptake of the contrast agent in the tissue and create parametric colour maps. From a quality assurance point of view, little is done to insure the correct processing of the data despite the fact that the community has expressed the need for benchmarking datasets and validation tools for image processing tasks.

We have created software to produce DICOM compatible simulated DCE MRI series with user defined curve characteristics (from now on referred to as validation dataset). In this paper we show how the validation dataset was produced and used to validate or find pitfalls in the different software packages used at our institutions, particularly when used with noisy datasets.

Methods

A series of curves are produced by our software program according to user defined settings for arterial input function (AIF), temporal sampling, slope variations and Gaussian noise levels. The concept of the ACR BI-RADS lexicon [1] has been adopted by which, after a bolus injection, we expect an initial phase with a variety of washin slopes (see Figure 1C open dots), followed by a delayed phase ranging from washout to persistent uptake (see Figure 1A). Two variables, the washin slope (dotted fat arrow) and the washout slope (dotted and lined slim arrow), are allowed to vary in ten different steps. Different combinations of washin slope and washout slope are used to create a DCE MRI validation sub-pattern as seen in Figure 1Bα.

We also allow for fast and slow kinetics (fast, medium, slow) by extending the time of the washin phase. This is done by subdividing each patch of the sub-pattern into 3 stripes. The curves in those stripes reach the same level of initial enhancement at different time points. The washout characteristics are kept the same. This is shown as a magnification in Figure 1C. We also show the curves associated with the stripes as full dots in Figure 1C (short arrow).

In the final validation dataset, the sub-pattern is repeated four times by adding increasing levels of Gaussian noise in every pixel in every time point. On the top left corner of the validation dataset, an AIF can be entered as some of our in-house grown software programs do need such information as a reference for kinetic analysis. For the experiment presented here, we have used a matrix size 256x256 (sub-pattern size 100x100 pixels and patch size 10x10 pixels), temporal sampling 9 seconds, 30 repetitions, baseline signal 100 for three time points, washin phase during 4 time points, washin slope variation between 30 and 85 degrees, washout slope variations are limited by the washin slope, noise levels given as standard deviation of the Gaussian noise distribution were 20, 30, 40 resulting in SNR of 14-31dB, 10-27dB and 8-25dB in sub-pattern β, γ and δ of Figure 1B.

Results

The validation dataset allows for the assessment of the algorithms used to produce commonly computed colormaps like washin, washout, time to peak etc. A washout/washin colour map of the first sub-pattern which has no noise is shown as an insert in Figure 1A/1C. Our results show that algorithms can be biased by unexpected components, such as in Figure 2A, where an early enhancement map is shown being is influenced by the contribution of the delayed phase. Other algorithms show wrong results when introducing noise, such as in Figure 2B, where the washout was computed by finding the maximum difference in signal intensity between two consecutive time points. The washout colour map shown in Figure 2C has been computed with an algorithm using all the time points of the delayed phase to calculate the washout. It performs well under noisy conditions. Other results are related to the sensitivity of the algorithm to noise for particular curve shapes, such as in Figure 2C, where the washout colour map suffers from noise particularly on the left side of the sub-pattern, which means in areas with high washout. The time to peak colour map shown in Figure 2D is more subject to noise in the central stripe of the sub-pattern which represents flat washout. Further results (not shown here) demonstrated over- or under-ranging of the colour maps and a shift of the values towards higher values with increasing noise levels.

Conclusions

This is the first time a validation dataset is proposed to validate software for the analysis of DCE MRI. It can be used for qualitative, quantitative but also curve classification algorithms. Using a validation dataset has allowed us to gain deeper understanding of both the algorithms used commercially and those developed in-house. We have been able to correct bias and polarisation in our own algorithms and in the future we will be able to optimise the filtering of noise and the use of colours in the colour maps.

Following our investigations, we recommend that every user of DCE MRI analysis software, understands exactly the results of the image processing algorithms with a validation dataset before proceeding to the analysis of patient data.

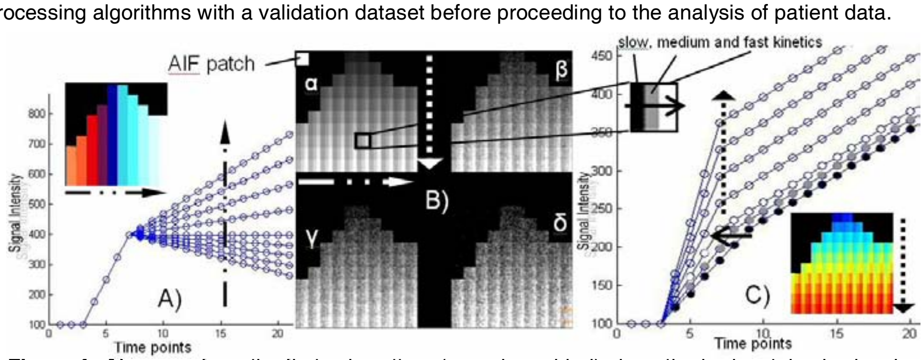

Figure 1: A) curves from the first sub-pattern (no noise added) along the horizontal axis showing a range of washout slopes for a fixed washin slope; also shown is a colour washout map **B)** validation dataset at time point 7 including 4 different repetition of the same sub-pattern at different noise levels; **Bα)** no noise; **Bβ)** SNR of 14-31dB **Bγ)** SNR of 10-27dB **Bδ)** SNR of 8-25dB **C)** curves from the first sub-pattern (no noise added) along the vertical axis, open dots: showing a different washin slope (fast component) for a fixed washout slope, full dots: showing for the lowest washin slope the fast, medium and slow kinetic component; also shown is a colour washin map

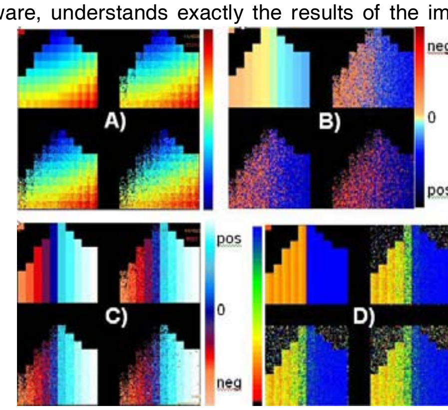

Figure 2: A) early enhancement colour map suffering from washout bias **B)** washout colour map (simple algorithm) with wrong results under noisy conditions **C)** washout colour map (complex algorithm) affected by noise in the washout area of the sub-pattern **D)** time to peak image showing the central stripe, i.e. flat washout, to be more affected by noise.

References 1) BI-RADS Atlas, ACR, 2003