Optimal processing to derive static PC-MRA from time-resolved 3D PC-MRI data

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Introduction: In order to analyze vascular malformations, MR-Angiograph (MRA) is widely applied in the clinical routine. While most applications are based on contrast-enhanced MRA, 3D Phase Contrast PC-MRA has proven to be a useful alternative. 3D PC-MRA can provide detailed information on vascular geometry without the need for exact bolus timing and may offer additional information on flow direction. However, most PC-MRA implementation used non-gated acquisition and thus time-averaged blood flow which can result in artifacts for pulsatile flow. Long scan times and lack of respiration control limited most applications of 3D PC-MRA to cranial vessels. In recent studies, improved time-resolved 3D CINE PC MRI techniques using ECG gating and respiration control (flow sensitive 4D MRI) have been successfully applied for the analysis of pulsatile 3D blood in the aorta [4]. Such techniques offer the opportunity for the detailed analysis of 3D blood flow [1-3], but also allow deriving additional information on vascular geometry such as time-averaged 3D PC-MRA. The purpose of this study was to evaluate several new algorithms for the optimal extraction of PC-MRA data from flow-sensitive 4D MRI. All algorithms could be combined with additional noise masking and static tissue-removal. Results of all algorithms were compared and were evaluated based on data sets with different SNR.

Methods: All experiments were preformed using a clinical routine 3T MR-System (TRIO, Siemens, Germany). For 3 normal volunteers respiration controlled and ECG gated flow sensitive 4D MRI data were acquired in a sagittal oblique slab with the following parameters: rf-spoiled gradient echo sequence (spatial resolution 3.5 x 1.6 x 3 mm^3, temporal resolution 48.8 ms, venc=150cm/s). To evaluate the effect of different SNR on PC-MRA quality, data acquisition was initially performed without contrast agent. In subsequent session measurements were repeated following administration of standard contrast-agent (Gd-BOPTA, Multihance®, Bracco, 0.1 mmol/kg) and a blood-pool contrast agent (MS 325, Vasovist®, Schering AG, 0.03 mmol/kg), respectively. All studies were approved by the local ethics committee and written informed consent was obtained from all subjects. The calculation of PC-MRA from flow sensitive 4D MRI data was performed according to the scheme illustrated in Fig.1. Eight different strategies for the calculation of time-averaged 3D PC-MRA ($I^{PC\text{-}MRA}$) were implemented and compared (see Table 1). The algorithms can be divided into three basic types: (i) using absolute velocity, magnitude weighting for each time frame and sum of squares (eq. 1-2), (ii) using temporal absolute velocity average with magnitude weighting (eq. 3-7), (iii) piecewise pseudo complex difference (eq. 8). PC-MRA was calculated from each data without applying any pre-processing and after noise masking and static tissue removal. Maximum intensity projections (MIP) were generated for all calculated 3D PC-MRA data sets. Vessel background contrast was quantified for all algorithms using ROI analysis of vessel lumen and background signal.

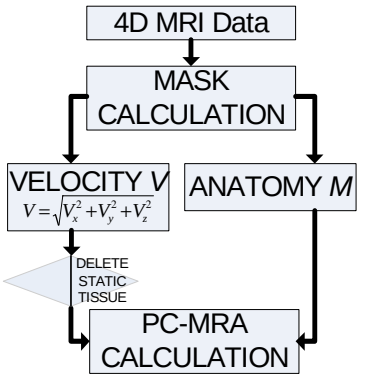


Fig.1 *Data pre-processing workflow. To improve PC-MRA noise masking was used based on thresh-holding of magnitude data (M) and the standard deviation (V_{std}) of the velocity-time course in each voxel [6]. Static tissue was identified by a lower thresh-hold of V_{std} [5, 6].*

$$(1)\ I^{PCMRA}=\sqrt{\sum_{i=1}^{N}\left(V_i * M_i\right)^2}$$
$$(2)\ I^{PCMRA}=\sqrt{\sum_{i=1}^{N}\left(V_i^2 * M_i\right)^2}$$
$$(3)\ I^{PCMRA}=\overline{V} * \overline{M}$$
$$(4)\ I^{PCMRA}=\overline{V} * \overline{M^2}$$
$$(5)\ I^{PCMRA}=\overline{V^2} * \overline{M^2}$$
$$(6)\ I^{PCMRA}=\overline{V * M}$$
$$(7)\ I^{PCMRA}=\overline{V * M^2}$$
$$(8)\ I^{PCMRA}=\begin{cases} M\sin\left(\frac{\pi V}{venc}\right) & V<venc \\ M & otherwise \end{cases}$$

$V_i=\sqrt{V_{i,x}^2+V_{i,y}^2+V_{i,z}^2}$

x, y, z *velocity direction*

$\overline{V}=\frac{1}{N}\sum_{i=1}^{N}V_i$

$i=1,..N$ *number of time frames*

Tab.1 *List of used equations for PC-MRA calculation*

Fig 2: *Lumen-background contrast for all 8 algorithms.*

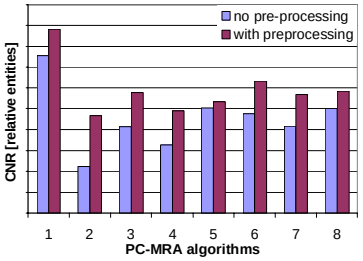
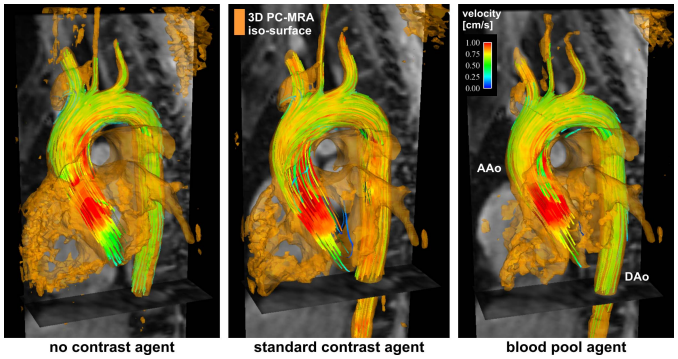


Fig. 3: *3D flow visualization in thoracic aorta using stream-lines and iso-surface rendering of PC-MRA data. Best result, i.e. only minor background PC-MRA signal was achieved for blood pool agents.*



Results: Fig.4 shows results for PC-MRA calculation based on flow-sensitive 4D-MRI after the injection of standard contrast agent. Comparing data without (upper row) and after pre-processing (lower row) it is evident that PC-MRA profits from applying noise masking and removing static tissue. Note that algorithms 4, 5 and 7 provide good background suppression even without pre-processing. From figure 4 it is evident that best background suppression was achieved by algorithms 2, 5 and 7, while algorithms 1 and 6 demonstrated more homogenous aortic lumen. These findings are also reflected in the quantitative lumen-background contrast analysis in fig. 2 with maximum contrast for good lumen depiction in combination with high background suppression for algorithms 1, 6 and 7. Based on these results, equation (7) was used to assess the SNR dependency of the derived 3D-PC angiograms and to evaluate its performance in conjunction with 3D blood flow visualization. Figure 3 shows results of iso-surface rendered 3D-PC-MRA data and 3D stream-lines derived from the same flow-sensitive 4D MRI data based on intrinsically different SNR. Improved quality of the 3D aortic surface for data including contrast agent can clearly be appreciated.

Discussion: The results of this study indicate that a time-averaged static 3D PC angiography can be derived from flow sensitive 4D-MRI data. Even for data acquired without contrast agent injection it is possible to calculate vessel geometry, although the application of contrast agent provides considerably improved image quality. Future work includes development of more automated algorithms which provide background and static tissue suppression without manual thresh-hold definition. Optimal processing may be achieved with a combination of algorithms 1, 6 and 7 which provided the best lumen contrast and background suppression.

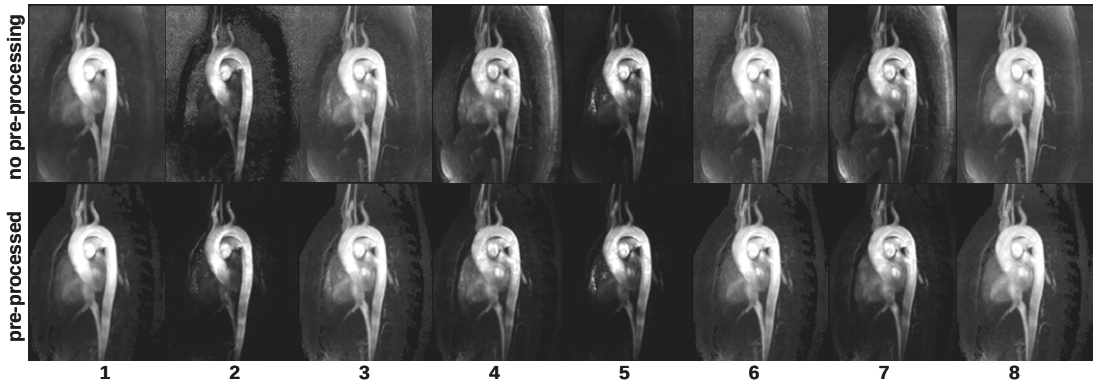


Fig. 4 *PC-MRA calculations, performed on one data set (Multihance) using different algorithms 1-8 as listed in table1*

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