Determination of the vascular input function using magnitude or phase-based MRI: influence on dynamic contrast-enhanced MRI model parameters in carotid plaques

Poster No.: B-0118
Congress: ECR 2013
Type: Scientific Paper
Authors: R. van Hoof\textsuperscript{1}, M. Truijman\textsuperscript{1}, E. Hermeling\textsuperscript{1}, R. van Oostenbrugge\textsuperscript{1}, R. J. van der Geest\textsuperscript{2}, M. J. A. P. Daemen\textsuperscript{3}, J. E. Wildberger\textsuperscript{1}, W. Backes\textsuperscript{1}, M. E. Kooi\textsuperscript{1}; \textsuperscript{1}Maastricht/NL, \textsuperscript{2}Leiden/NL, \textsuperscript{3}Amsterdam/NL

Keywords: Head and neck, Vascular, MR, MR-Diffusion/Perfusion, Contrast agent-intravenous, Arteriosclerosis

DOI: 10.1594/ecr2013/B-0118

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method is strictly prohibited. You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Purpose

An important cause of stroke is carotid atherosclerosis\[^1\]. Currently the treatment of patients with carotid atherosclerosis is based on patient's symptoms and the degree of stenosis. Vulnerable atherosclerotic plaques in the carotid artery are more likely to cause ischemic cerebrovascular events\[^2\], compared to their more stable counterparts. An important feature of vulnerable plaques is increased plaque microvasculature. For this reason, it is of great interest to visualize these vulnerable plaques with increased plaque microvasculature.

Dynamic Contrast Enhanced-MRI (DCE-MRI) has been shown to allow non-invasive assessment of the microvasculature within carotid atherosclerotic plaques\[^3-6\]. DCE-MRI is based on the principle that after injection of a bolus contrast agent, leakage of the contrast agent from the microvasculature into the plaque tissue will lead to signal enhancement over time (figure 1). This signal enhancement can be assessed quantitatively using a two compartment model. This model consists of a plasma compartment and an extracellular extravascular space and has several solutions (e.g. Tofts\[^7,8\], Extended Tofts\[^7,8\], Patlak\[^9\] and Extended Graphical\[^10\]), depending on certain model assumptions.

One important aspect for quantitative analysis of the microvasculature of atherosclerotic carotid plaques is a reliable vascular input function (VIF). For this, a conversion from the MR signal to concentration of the CA is needed. For this, two different methods are available:

1. The first method is based on the modulus MR-signal. In this method the concentration is related to the relative signal enhancement based on the signal equation for a steady state spoiled gradient echo sequence\[^11,12\].

2. The second method is based on the phase MR-signal\[^13,14\]. For this, the change in susceptibility caused by the contrast agent is related to the change in phase signal, which has been shown to be a linear relationship\[^14-16\].

In several animal\[^17\] and human studies\[^18,19\], it has been demonstrated that a phase-based VIF (ph-VIF) is less sensitive to flow artefacts compared to magnitude-based VIF (m-VIF). The purpose of the current study is

1. to compare m-VIF and ph-VIF for the analysis of carotid atherosclerotic plaques.
2. to investigate the influence of different VIFs on DCE MRI model parameters in carotid plaques.
Fig. 1: Typical 3T MR images from an atherosclerotic carotid plaque. A) post-contrast T1-weighted QIR for anatomical reference. Dynamic contrast-enhanced MR images showing signal enhancement over time due to leakage of contrast agent from microvasculature into the plaque tissue (B-D). B) before injection of contrast agent, C) 2 minutes after contrast injection and D) 5 minutes after contrast injection.

© Radiology, Maastricht University - Maastricht/NL
Methods and Materials

**MRI Acquisition.**

21 patients with 30-99% carotid stenosis underwent an ECG gated 3T DCE MRI (T₁W 3D FFE with a flip angle of 35°) on a 3 Tesla MR system using a dedicated 8-channel carotid RF coil.

Four patients were scanned with a high temporal resolution (approx. 4 seconds) (TR/TE = 23.15/3.17 ms) but lower spatial resolution (in-plane acquired/reconstructed resolution 1.56/0.45 mm²). A saturation slab was placed 15 mm cranial to the imaging slice in order to suppress magnitude MR signal of blood in the internal jugular vein before contrast injection.

The other 17 patients were scanned using a lower temporal resolution (approx. 20 seconds) (TR/TE = 11.61/5.65 ms) and higher spatial resolution (in-plane acquired/reconstructed resolution: 0.63/0.25 mm²).

**Data Analysis.**

The four dynamic acquisitions with a high temporal resolution scans were used to construct group-averaged m-VIF and ph-VIF [11], while the other 17 dynamic acquisitions with a high spatial resolution were used for calculation of $K^{\text{trans}}$ (measure of plaque microvasculature) using the Patlak model and group averaged m-VIF and ph-VIF. Pearson's correlation between $K^{\text{trans}}$ parameters as determined using both the VIFs was calculated.

**Calculations.**

To investigate flow influence on m-VIF, first, the m-VIF was calculated from the signal intensity-time curves by neglecting flow and by assuming a steady state as is common in literature. Second, the effect of Poiseuille flow on the m-VIF was estimated by calculating the average relative signal enhancement of the jugular vein based on the concentrations as derived from the dynamic phase images using the Bloch Equations, incorporating the (local) blood velocity and a cranially positioned spatial saturation slab at a distance of 15 mm from the imaging slice.
Results

VIF Curves and $K^{\text{trans}}$ parameter influence

Determination of the m-VIF in both the jugular veins of one subject was not possible due to MR inflow effects, which resulted in absence of a first pass peak, while the first pass peak was clearly visible in the phase images. Determined group averaged VIFs are shown in figure 3. Calculated peak concentrations of jugular vein m-VIFs were on average 4-fold lower than for the jugular vein ph-VIFs ($p<0.001$) when neglecting flow and assuming a steady state, resulting in different $K^{\text{trans}}$ values determined using the group averaged m-VIF and ph-VIF.

Despite these differences, strong and significant correlation between $K^{\text{trans}}$ was found (Figure 4, Pearson's correlation 0.91, $p<0.001$).

Calculations.

Taking into account a theoretical Poiseuille flow with a maximum velocity of 10 cm/sec, it is shown (figure 4) that there is a strong influence of the local blood velocity on the signal enhancement. For voxels near the vessel wall (i.e. with a low local blood velocity) signal saturation occurs, resulting in absence of the first pass peak. While for voxels in the centre of the vessel the first pass peak is seen.
Fig. 2: Dynamic-contrast enhanced MRI images showing the carotid artery (red contour) and jugular vein (green contour) before (A) and immediately after (B) administration of the contrast agent. Due to a cranially positioned saturation slab the MR signal in the jugular vein is suppressed in absence of the contrast agent.

© Radiology, Maastricht University - Maastricht/NL
Fig. 3: General VIFs determined from the jugular vein using phase (black solid line) and magnitude (blue dashed line) based methods. Each VIF was constructed by performing a fit using a slightly adapted equation introduced by Parket et al.[11]

© Radiology, Maastricht University - Maastricht/NL
**Fig. 4:** Effect of local blood flow velocity on magnitude MR signal enhancement as a function of Gd concentration. Near the vessel wall (i.e. where a low local blood velocity is observed) the magnitude signal is saturated, resulting in absence of a clear first pass peak. Closer to the centre of the vessel, saturation of the magnitude signal is absent.

© Radiology, Maastricht University - Maastricht/NL
Fig. 5: $K_{\text{trans}}$ parameter as determined using m-VIF and ph-VIF from carotid artery, showing a strong, significant correlation (Pearson's rho 0.91). Identity line is shown as a dotted line.

© Radiology, Maastricht University - Maastricht/NL
Conclusion

Our results show a strong influence of flow on the magnitude-based method for determination of the Gd concentration-time curve, even with the use of a saturation slab, leading to a large underestimation of the peak Gd concentration compared to phase-based methods. The VIFs leaded to different $K_{\text{trans}}$ values. Despite this, a strong significant correlation between the $K_{\text{trans}}$ parameters using both VIFs was found. Calculations showed:

1. a large influence of the Poiseuille flow on the (average) relative signal enhancement;
2. that the discrepancy between the magnitude-based VIF and phase-based VIF can be explained by flow effects.

Because of the flow effects on magnitude-based vascular input functions, we advise to use a phase-based method VIF for quantitative DCE MRI analysis.
References


This research was supported by the Center for Translational Molecular Medicine and the Dutch Heart Foundation (PARISk).
Fig. 6

© CTMM, Center for Translational Molecular Medicine

funded by the
dutch heart foundation

Fig. 7

© Dutch Heart Foundation
Personal Information

- Raf H.M. van Hoof, MSc; Department of Radiology, Maastricht University Medical Center, Maastricht, The Netherlands; r.vanhoof@maastrichtuniversity.nl
- Martine T.B. Truijman, MD; Department of Radiology and Clinical Neurophysiology, Maastricht University Medical Center, Maastricht, The Netherlands; martine.truijman@mumc.nl
- Evelien Hermeling, PhD; Department of Radiology, Maastricht University Medical Center, Maastricht, The Netherlands; e.hermeling@maastrichtuniversity.nl
- Robert J. van Oostenbrugge, MD; Department of Neurology, Maastricht University Medical Center, Maastricht, The Netherlands; r.vanoostenbrugge@mumc.nl
- Rob J. van der Geest, PhD; Department of Radiology, Leiden University Medical Center, Leiden, The Netherlands; R.J.van_der_Geest@lumc.nl
- Mat J.A.P. Daemen, PhD; Department of Pathology, Academic Medical Centre, Amsterdam, The Netherlands; m.j.daemen@amc.uva.nl
- Joachim E. Wildberger, PhD MD; Department of Radiology, Maastricht University Medical Center, Maastricht, The Netherlands; j.wildberger@mumc.nl
- Walter H. Backes, PhD; Department of Radiology, Maastricht University Medical Center, Maastricht, The Netherlands; w.backes@mumc.nl
- M. Eline Kooi, PhD; Department of Radiology, Maastricht University Medical Center, Maastricht, The Netherlands