

Differentiation of spinal cord arteries and veins based on temporal separation with Dynamic Contrast-Enhanced MR Angiography

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Introduction

Imaging of the arteries supplying the spinal cord can provide important information for surgery where blood supply is at risk, e.g. during thoraco-abdominal aortic aneurysm (TAAA) repair. The largest anterior radiculomedullary artery supplying the thoraco-lumbar spinal cord is called the Adamkiewicz artery (AKA). Its diameter ranges from 0.5 to 1.2 mm, which demands a high spatial resolution for imaging. Due to anatomical similarity (hairpin course) with the great radiculomedullary vein (GRV), which can be located anteriorly or posteriorly, differentiation between arteries and veins has to be based on time differences of contrast agent arrival. Temporal resolution should not exceed the arterio-venous time window, which is about 10 s [1]. Keyhole imaging [2] improves temporal resolution in Dynamic Contrast-Enhanced MR Angiography (DCE-MRA), but causes intensity reduction and object blurring [3]. These image quality decreasing effects are expectedly more pronounced in small objects like spinal cord vessels because of their relatively strong representation in the periphery of k-space.

The purpose of this study was to demonstrate the feasibility to dynamically resolve the AKA from the GRV in patients using keyhole DCE-MRA. In advance to the patient study a computer simulation was performed to investigate the effects of keyhole fraction on the visibility of vessels as a function of diameter.

Methods

In keyhole imaging a full k-space matrix is acquired before contrast enhancement (reference acquisition). For subsequent (keyhole) acquisitions, only a fraction of central k-space (keyhole fraction, F_{key}) is acquired in the phase-encoding directions. The outer k-space is then completed with data from the reference acquisition.

Computer simulation: The 1D k-space model for contrast-enhanced acquisition by Maki [4] was extended to a 2D model whose configuration highly matches the cranio-caudal orientation of the targeted spinal cord vasculature and the MR read-out direction. Signal amplification within the keyhole fraction was set to 10, which is based on k-space analysis of spinal cord angiograms in TAAA patients [5]. After inverse Fourier transformation the mean intensity in the vessel was calculated. In addition the full-width-at-half-maximum (FWHM) was determined to quantify vessel blurring. Vessel diameter (d) was expressed in voxels.

Patient study: 5 TAAA-patients and 5 healthy volunteers were examined using a 1.5 T MR system equipped with a phased-array spine coil (Philips Medical Systems, Best, The Netherlands). A 3D FFE technique was used, with the following scan parameters: TR/TE 5.2/1.7 ms, FA 30°. Cranio-caudal FOV was 490 mm. Depending on patient anatomy, rectangular FOV was 35 - 45 % and 30 - 34 sagittal slices were used. Measured voxel size was 1.2x1.5x1.4 mm. Keyhole fraction was set to 55 %, and random central k-space filling was applied. The resulting acquisition time per dynamic phase was 6 - 8 s. A bolus of 45 mL Gd-DTPA was injected intravenously at 3 mL/s immediately after acquisition of the reference scan (11 - 15 s). Curved multiplanar reformatting was used to optimally display the AKA and GRV.

Results

Computer simulation: Signal loss (figure 1) and vessel blurring (figure 2) due to a small F_{key} was most obvious in small vessels. For small vessels ($d = 1$) signal intensity almost linearly increases with F_{key} . To obtain 80 % of the maximal signal intensity for $d = 1$, F_{key} has to be 70 %, whereas for $d = 3$, a keyhole fraction of 20 % would be enough.

Patient study: In all subjects dynamic differentiation of the AKA and GRV was achieved (figure 3). Enhancement of the GRV occurred at least one dynamic phase (6 - 8 s) later than AKA enhancement in both patients and volunteers. The GRV was observed anteriorly in 4 and posteriorly in 6 subjects.

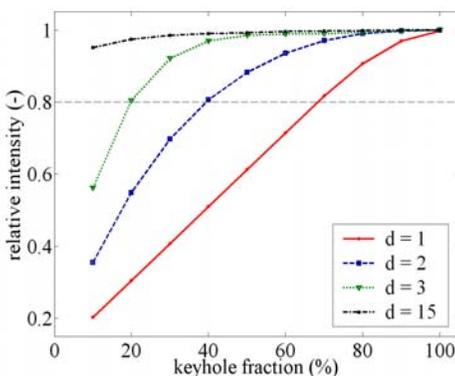


Figure 1: Relative intensity as function of keyhole fraction and vessel diameter (d), expressed in voxels.

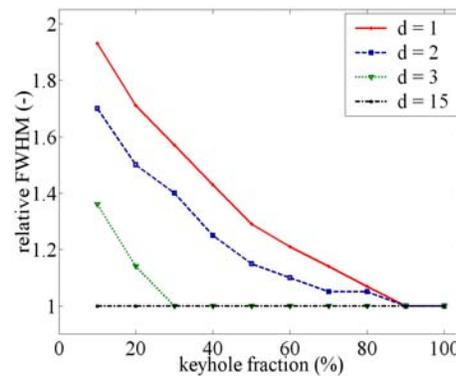


Figure 2: Full-width-at-half maximum as function of keyhole fraction and vessel diameter (d), expressed in voxels.

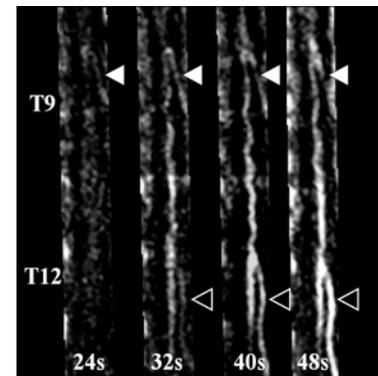


Figure 3: Coronal multiplanar reformations of the anterior spinal cord surface at different time frames after contrast agent injection. After 24 s only the AKA (white arrowhead) can be discerned. Enhancement of the GRV (black arrowhead) is depicted one phase later (32 s).

Discussion and conclusion

From the computer simulation it was determined that the keyhole fraction should be taken as large as possible, to depict small vessels without exceeding the arterio-venous time window and avoiding severe signal intensity losses and vessel blurring.

In conclusion, using keyhole DCE-MRA it is possible to dynamically resolve the arteries and veins of the spinal cord and to differentiate the AKA from the GRV.

References

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