Accuracy and reproducibility of breath-hold velocity-encoded MRI with spiral k-space sampling in the right coronary artery using 3T MRI

A. Brandts[1], S. Roes[1], J. Doornbos[1], A. de Roos[1], M. Stuber[2], and J. Westenberg[1]

[1]Radiology, Leiden University Medical Center, Leiden, South-holland, Netherlands, [2]Radiology, Johns Hopkins University Medical School, Baltimore, United States

Background

High field MRI enables image acquisition at submillimeter spatial resolution, which is mandatory for reliable flow assessment in small vessels such as the coronary arteries. Breath-hold velocity-encoded coronary flow measurements have previously been obtained with MRI. (1-2) However, both accuracy and reproducibility have not been ascertained yet. Therefore, the purpose of this study was to evaluate the accuracy and reproducibility of 3T breath-hold velocity encoded coronary flow measurement with spiral k-space sampling in vitro and in vivo in humans.

Methods

Coronary flow assessment was performed using a velocity-encoded MRI cine sequence with spiral k-space sampling (FOV=250x250mm^2, acquired matrix=320x320, reconstructed matrix 384x384, acquired spatial resolution=0.78x0.78x8mm^3, reconstructed spatial resolution 0.65x0.65x8.00 mm^3, TR=33ms, TE=3.5ms, flip angle=20°, spiral acquisition window=26ms, spiral interleaves=12). A 3T MRI scanner (Achieva, Philips, Best, NL) with a 6-element cardiac coil for signal reception was used. The accuracy of this technique was first tested in a phantom study and the reproducibility was subsequently tested by repeated acquisitions in 15 healthy adult subjects. In the phantom setup, 10 constant flow rates (ranging from 0.9ml/s to 7.3ml/s) were applied to a straight tube with a diameter of 4 mm. The tube was positioned inside a water tank. The flowing water through the tube was doped with gadolinium to shorten T1. The spiral velocity-encoded sequence was performed perpendicular to the phantom and the flow through the tube was measured by integrating the velocity values over the lumen. The velocity sensitivity (V_{enc}) was adjusted for each acquisition according to the expected maximal velocity, and ranged from 15cm/s to 150cm/s. Background correction (i.e. to correct for local phase offset errors) was performed from using a velocity measurement in a region-of-interest placed in the surrounding water near the phantom. The flow measurements were compared with volumetric flow measurements recorded distal to the phantom. Fifteen healthy subjects (7 women) with mean age 25 ± 4 years were enrolled. Each subject was placed in the supine position. Scout scans were performed to determine the 3D course and orientation of the proximal right coronary artery (RCA). The breath-hold (11-23sec) velocity-encoded spiral cine acquisition was localized perpendicular to the RCA in a straight segment near to the origin. V_{enc} of 35cm/s was used and in case of aliasing, the acquisition was repeated with adjusted V_{enc}. For reproducibility measurements, the full acquisition procedure was repeated including repositioning of the volunteer in the scanner. Coronary velocity maps were analyzed using the software package FLOW (Version 3.0, Medis, Leiden, The Netherlands). For each cine frame, the maximum velocity (V_{max}) in the lumen was determined. In order to compensate for through-plane motion and phase errors that are superimposed to coronary flow velocity, the velocity was also measured in an ROI at the basal level of the lateral wall of the right ventricle (mean area 1.13 cm^2). The mean velocity in this area was subtracted from the velocity measured in the RCA. In V_{max}-graphs, peak systolic velocity (PSV) in cm/s, time of PSV (TSV) in ms, peak diastolic velocity (PDV) in cm/s, time of PDV (TDV) in ms, meanV_{max} (V_{max} averaged over the cardiac cycle) per cardiac cycle and the total amount of coronary flow (ml/cycle) were determined (see Figure 1 for definitions of these parameters). The pulsatility in the V_{max}-pattern (i.e. a measure for discriminating the systolic and diastolic peaks in the velocity-graph) is also expressed as a ratio of the PSV and PDV to the mean V_{max} and the ratio between the peak systolic and diastolic velocity (PSV/PDV) is given. The repeated acquisitions were compared using the paired *t*-test and the reproducibility of coronary flow assessment was evaluated using intraclass correlation coefficients (ICCs) for absolute agreement.

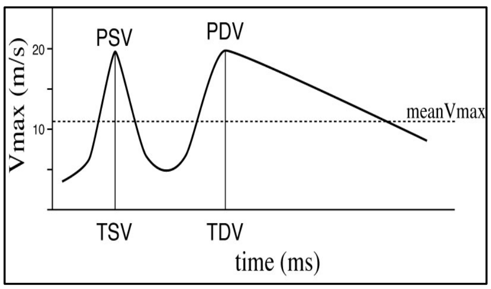

Figure 1. Modeled maximal velocity graph for RCA.
PSV: peak systolic velocity (PSV) in cm/s
TSV: time of PSV in ms
PDV: peak diastolic velocity in cm/s
TDV: time of PDV in ms
meanV_{max}: V_{max} averaged over the cardiac cycle

Results

Phantom experiments showed that the velocity-encoded sequence with spiral k-space sampling is accurate within 7% of the applied flow rates between 0.9ml/s and 7.3ml/s with no significant bias. A strong correlation between volumetric flow and MRI-measured flow was found (ICC=0.99). Three volunteers were excluded for further analyses due to poor image quality and ECG-triggering problems. In the remaining 12 volunteers, the flow assessment in the RCA was successfully repeated. In general, the measured V_{max}-pattern in the RCA with a distinct systolic peak and a peak with a more gradual decrease in diastole is in line with previous echo Doppler studies in healthy volunteers.(3) Comparison of the V_{max}-patterns after repeated acquisition was performed and the results are presented in Table 1. The mean difference between the repeated acquisitions was not significant for any of the parameters describing the velocity pattern. A good agreement was found between the repeated acquisitions as all ICCs were significant for all parameters describing the velocity pattern, except the PDV/ meanV_{max}.

Conclusion

Consistent with the in vitro findings in this study, 3T velocity-encoded in vivo human MRI with spiral k-space sampling is an accurate and reproducible method for the assessment of flow velocity patterns in the right coronary artery.

Table 1. MRI results of the parameters describing the coronary velocity pattern

	PSV (cm/s)	TSV (ms)	PDV (cm/s)	TDV (ms)	meanV_{max} (cm/s)	PSV/meanV_{max}	PDV/meanV_{max}	PSV/PDV	Flow (ml/cycle)
Mean ± SD	20 ± 9	69 ± 28	20 ± 7	390 ± 77	11 ± 5	1.9 ± 0.6	1.9 ± 0.4	1.0 ± 0.3	16.2 ± 6.8
Paired t-test									
mean diff± SD	0.9 ± 9.8	-5.5 ± 12.9	2.9 ± 6.9	9.1 ± 39.4	1.4± 5.0	-0.3 ± 0.5	-0.3± 0.5	0.1 ± 0.4	-0.3 ± 6.8
95% CI	5.3 to 7.1	-13.6 to 2.7	-1.4 to 7.2	-15.9 to 34.1	-1.7 to 4.6	-0.6 to 0.1	-0.4 to 0.3	-0.4 to 0.1	-4.6 to 4.0
p-value	0.75	0.17	0.17	0.44	0.33	0.10	0.85	0.29	0.87
ICC	0.74	0.95	0.77	0.94	0.70	0.79	0.51	0.67	0.77
p-value	(p= 0.02)	(p<0.001)	(p=0.01)	(p<0.001)	(p=0.03)	(p=0.005)	(p=0.14)	(p=0.04)	(p=0.01)

PSV: peak systolic velocity (PSV) in cm/s; TSV: time of PSV in ms; PDV: peak diastolic velocity in cm/s; TDV: time of PDV in ms; meanV_{max}: V_{max} averaged over the cardiac cycle; PSV/meanV_{max}: measure for discriminating the systolic peak in the velocity-graph; PDV/ meanV_{max}: measure for discriminating the diastolic peak in the velocity-graph; PSV/PDV: ratio between systolic and diastolic peak velocity; Flow: the total amount of coronary flow (ml/cycle). * Mean and standard deviations (SD) are given for the flow parameters. Repeated acquisitions were compared using the paired *t*-test, mean difference (mean diff) and SDs, 95% Confidence intervals (95% CIs) and p-values were given. The reproducibility of coronary flow assessment was evaluated using intraclass correlation coefficients (ICCs) for absolute agreement, ICCs and p-values were given.

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