Assessment of Bolus Injection Protocol with Appropriate Concentration for Quantitative Assessment of Pulmonary Perfusion by Dynamic Contrast-enhanced MR Imaging

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Introduction: Quantitative assessment of dynamic contrast-enhanced MR imaging for evaluation of regional pulmonary perfusion have been suggested as useful (1-3). However, some investigators have suggested the difficulty of direct application of indicator dilution techniques to contrast-enhanced, first-pass dynamic MR imaging experiments for quantitative assessment of regional pulmonary perfusion parameters, although these principles have been frequently used to determine regional perfusion (4, 5). We hypothesized that a bolus injection protocol with appropriately small amounts of gadolinium contrast media can provide accurate and repeatable pulmonary perfusion parameters. The purpose of the present study was to determine the bolus injection protocol with appropriate concentration for quantitative assessment of dynamic contrast-enhanced pulmonary MR imaging, when compared with nuclear medicine study.

Methods and Materials: Forty consecutive patients (20 men, 20 women; age 39 to 78 years; mean age 72 years) with BACs (mean diameter 12 mm; range 8-30 mm) underwent 3D dynamic contrast-enhanced MR imaging with three different concentration protocols (*protocol A*: 0.1mmol/mL, *B*: 0.3mmol/mL and *C*: 0.5mmol/mL), Doppler cardiac echography and perfusion single-photon emission tomography (SPECT). Dynamic perfusion MRIs (TR 2.7 ms/ TE 0.6 ms/ flip angle 40°,) were acquired with a 3D radio-frequency spoiled gradient-echo (GRE) sequence on a 1.5 T MR scanner (Gyroscan Intera; Philips Medical systems, Best, The Netherlands) using a phased-array coil. Dynamic contrast-enhanced MR imaging was performed in two times in each subjects. From each signal intensity-time course curve, pulmonary blood flow (PBF), pulmonary blood volume (PBV) and mean transit time (MTT) maps were generated by deconvolution analysis, indicator dilution theories and the central volume principle on a pixel-by-pixel basis. Then regional pulmonary perfusion parameters were determined by ROI measurements. Regional pulmonary blood flow assessed perfusion SPECT and cardiac echography ($PBF_{Perfusion\ SPECT}$) was also calculated according to the ROI measurements.

All patients were divided into two groups (less than 70 kg [<70 kg] and equal to or more than 70 kg [≥70 kg] groups). Correlations, mean differences and limits of agreement between regional blood flow of dynamic MR imaging (PBF_{MR}) using three different bolus protocols in addition to PBF_{SPECT} were statistically compared in both patient groups. The coefficients of reproducibility of regional pulmonary perfusion parameters between first and second examinations using three different protocols were also statistically compared in both patients groups.

Results: Correlations, mean differences and limits of agreement between regional blood flow of dynamic MR imaging (PBF_{MR}) using three different bolus protocols in addition to $PBF_{Perfusion\ SPECT}$ were shown in Table 1 and 2. Each correlation between PBF_{MR} and PBF_{SPECT} was excellent ($p<0.05$). PBF_{MR} using *protocol B* in <70 kg group and *protocol C* in ≥70 kg group showed no significant difference compared with $PBF_{Perfusion\ SPECT}$ in both groups, although PBF_{MR} using the other protocols in both groups showed significant difference compared with $PBF_{Perfusion\ SPECT}$ ($p<0.0001$).

Pulmonary perfusion parameters in first and second examination in each group was shown in Table 3 and 4. Limits of agreements and coefficients of reproducibility in *protocol B* in < 70 kg group and *protocol C* in ≥ 70 kg group were smaller than those of the other protocols and small enough for clinical purposes.

Conclusion: Appropriate concentration of bolus injection protocol for 3D dynamic MR imaging provides accurate and reproducible assessments of regional pulmonary perfusion parameters.

Table 1. Average of PBF_{MR} and $PBF_{Perfusion\ SPECT}$, correlation coefficient, and the limits of agreement between both PBF in <70 kg group.

	Protocol A	*Protocol B*	*Protocol C*
r	0.97	0.99	0.98
PBF_{MR} (mean±standard deviation [ml/100ml/min])	78.1±21.8*	124.3±43.7	165.1±54.6*
$PBF_{Perfusion\ SPECT}$ (mean±standard deviation [ml/100ml/min])	126.5±44.6	126.5±44.6	126.5±44.6
Mean difference between both PBF (ml/100ml/min)	-48.4	-2.3	38.7
Upper limits of agreement (ml/100ml/min)	-1.8	12.7	64.8
Lower limits of agreement (ml/100ml/min)	-95.0	-17.3	12.8

*: Significant difference with PBF_{SPECT} ($p<0.05$).

Table 2. Average of PBF_{MR} and $PBF_{Perfusion\ SPECT}$, correlation coefficient, and the limits of agreement between both PBF in ≥ 70 kg group

	Protocol A	*Protocol B*	*Protocol C*
r	0.94	0.96	0.98
PBF_{MR} (mean±standard deviation [ml/100ml/min])	76.9±32.3*	108.0±36.8*	126.6±44.9
$PBF_{Perfusion\ SPECT}$ (mean±standard deviation [ml/100ml/min])	124.9±46.0	124.9±46.0	124.9±46.0
Mean difference between both PBF (ml/100ml/min)	-48.1	-16.9	1.7
Upper limits of agreement (ml/100ml/min)	-6.5	15.7	20.7
Lower limits of agreement (ml/100ml/min)	-89.7	-49.5	-17.3

*: Significant difference with PBF_{SPECT} ($p<0.05$).

Table 3. Average of 1st and 2nd measurement and repeatability coefficient of each pulmonary MR perfusion parameters in < 70 kg group.

	Protocol A	*Protocol B*	*Protocol C*
$PBF_{MR\ 1st}$ (mean±standard deviation [ml/100ml/min])	77.7±24.7	122.9±44.3	206.8±66.6
$PBF_{MR\ 2nd}$ (mean±standard deviation [ml/100ml/min])	77.7±25.9	122.9±44.5	206.8±66.9
Mean difference between both PBF (ml/100ml/min)	-0.1	0.0	-0.1
Coefficient of reproducibility (ml/100ml/min)	17.6	11.8	20.0
$PBV_{MR\ 1st}$ (mean±standard deviation [ml/100ml])	5.9±2.5	10.7±5.7	21.9±11.0
$PBV_{MR\ 2nd}$ (mean±standard deviation [ml/100ml])	5.9±2.5	10.0±5.7	21.6±9.9
Mean difference between both PBF (ml/100ml)	0.0	0.0	-0.3
Coefficient of reproducibility (ml/100ml)	1.8	1.4	2.2
$MTT_{MR\ 1st}$ (mean±standard deviation [sec])	4.5±0.5	4.6±0.9	6.0±1.1
$MTT_{MR\ 2nd}$ (mean±standard deviation [ml/100ml])	4.5±0.7	4.6±0.9	6.0±0.9
Mean difference between both MTT (sec)	0.0	0.0	0.0
Coefficient of reproducibility (sec)	1.0	0.4	0.8

PBF_{MR1st}: Pulmonary blood flow assessed by MR in first time

PBF_{MR2nd}: Pulmonary blood flow assessed by MR in first time

PBV_{MR1st}: Pulmonary blood volume assessed by MR in first time

PBV_{MR2nd}: Pulmonary blood volume assessed by MR in first time

MTT_{MR1st}: Mean transit time by MR in first time

MTT_{MR2nd}: Mean transit time assessed by MR in first time

Table 4. Average of 1st and 2nd measurement and repeatability coefficient of each pulmonary MR perfusion parameters in ≥ 70 kg group.

	Protocol A	*Protocol B*	*Protocol C*
PBF_{MR1st} (mean±standard deviation [ml/100ml/min])	74.7±29.4	111.4±33.7	127.1±41.7
$PBF_{MR\ 2nd}$ (mean±standard deviation [ml/100ml/min])	74.6±30.7	111.3±34.2	127.2±41.9
Mean difference between both PBF (ml/100ml/min)	0.1	0.1	-0.1
Coefficient of reproducibility (ml/100ml/min)	21.6	16.4	12.6
$PBV_{MR\ 1st}$ (mean±standard deviation [ml/100ml])	5.3±2.6	8.5±3.3	10.2±4.3
$PBV_{MR\ 2nd}$ (mean±standard deviation [ml/100ml])	5.4±2.9	8.6±3.0	10.2±4.3
Mean difference between both PBF (ml/100ml)	0.1	-0.1	0.0
Coefficient of reproducibility (ml/100ml)	2.2	1.6	1.4
MTT_{MR1st} (mean±standard deviation [sec])	4.2±0.7	4.5±0.5	4.7±0.5
MTT_{MR2nd} (mean±standard deviation [ml/100ml])	4.2±1.0	4.5±0.5	4.7±0.6
Mean difference between both MTT (sec)	0.0	0.0	0.0
Coefficient of reproducibility (sec)	1.4	0.8	0.4

PBF_{MR1st}: Pulmonary blood flow assessed by MR in first time

PBF_{MR2nd}: Pulmonary blood flow assessed by MR in first time

PBV_{MR1st}: Pulmonary blood volume assessed by MR in first time

PBV_{MR2nd}: Pulmonary blood volume assessed by MR in first time

MTT_{MR1st}: Mean transit time by MR in first time

MTT_{MR2nd}: Mean transit time assessed by MR in first time

References

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