의학석사 학위논문

Validation of Flow Independent Dark Blood Delayed Enhancement Magnetic Resonance Imaging Technique in a Canine Model of Myocardial Infarction

개의 심근경색 모델을 이용한 Flow Independent Dark Blood Delayed Enhancement 자기공명영상의 특성 평가

2012 년 08 월

서울대학교 대학원

의학과 석사과정

허 세 범

A thesis of the Degree of Master of Science

개의 심근경색 모델을 이용한 Flow Independent Dark Blood Delayed Enhancement 자기공명영상의 특성 평가

Validation of Flow Independent Dark Blood Delayed Enhancement Magnetic Resonance Imaging Technique in a Canine Model of Myocardial Infarction

August 2012

The Department of Radiology,
Seoul National University
College of Medicine
Saebeom Hur

개의 심근경색 모델을 이용한 Flow Independent Dark Blood Delayed Enhancement 자기공명영상의 특성 평가

지도교수 박 재 형

이 논문을 의학석사 학위논문으로 제출함
2012 년 7 월

서울대학교 대학원
의학과 영상의학전공
허 세 범

허세범의 의학석사 학위논문을 인준함

2012 년 7 월

위 원 장	손 대 원	(인)
부위원장	박 재 형	(인)
위 원	정 진 욱	(인)

Validation of Flow Independent Dark Blood Delayed Enhancement Magnetic Resonance Imaging Technique in a Canine Model of Myocardial Infarction

by
Saebeom Hur

A thesis submitted to the Department of Radiology
in partial fulfillment of the requirement of the
Degree of Master of Science in Radiology at Seoul
National University College of Medicine

July 2012

Approved by Thesis Committee:

Professor Dae-Won Sohn Chairman
Professor Jae Hyung Park Vice chairman
Professor Jin Wook Chung

ABSTRACT

Validation of Flow Independent Dark Blood Delayed Enhancement Magnetic Resonance Imaging Technique in a Canine Model of Myocardial Infarction

Purpose: To validate new magnetic resonance imaging (MRI) technique of Flow Independent Dark Blood Delayed Enhancement (FIDDLE) technique using ex-vivo imaging and 2,3,5-triphenyltetrazolium chloride (TTC) pathologic specimen and to compare signal intensities of infarcted myocardium over both blood cavity and remote normal myocardium in comparison with the conventional delayed enhancement cardiac MRI in a canine model of myocardial infarction.

Materials and Methods: Branches of left coronary arteries in seven dogs were occluded by endovascular glue (N-butyl-2-cyanoacrylate) injection. Contrast-enhanced MRI in a single short-axis slice was obtained at 3-T MRI scanner in all animals at 10, 20, 30, and 40 minutes after gadolinium administration using two different sequences of conventional delayed enhancement and FIDDLE a week after the modeling procedure. Ex-vivo MRI and TTC staining of the postmortem heart were performed in two animals. The signal intensities of the infarcted myocardium, normal myocardium and blood pool in left ventricular cavity and image noise was measured in two image datasets. Contrast-to-noise ratio (CNR) of the infarction to normal myocardium (CNR_{ItoN}) and that of infarction to blood

pool (CNR_{ItoB}) for both image datasets were calculated and compared. Sharpness of infarction margin, conspicuity of subendocardial portion of the lesion, and homogeneity of normal myocardium were assessed qualitatively.

Results: Delayed enhancement of infarcted myocardium presented in both image datasets of all seven animals and was confirmed by ex-vivo MRI and TTC stained gross pathology in two animals. The mean values of CNR_{ItoN} were 1.99 times higher in conventional delayed enhancement images than in FIDDLE images with statistical significance (all, p=.018). On the other hand, mean values of CNR_{ItoB} were 2.12 times higher in FIDDLE than in conventional delayed enhancement images but statistical significance was seen only at 10 minutes after contrast injection (P=.028). In the qualitative study, FIDDLE images were superior for subendocardial lesion conspicuity but inferior for margin sharpness and homogeneity of normal myocardium.

Conclusions: Ex-vivo MRI and TTC staining confirmed that FIDDLE technique well depicted infarcted myocardium without false positive hyperenhancement. FIDDLE technique is expected to enable better detection of subendocardial infarction for its higher CNR of infarcted myocardium over blood cavity by nulling blood cavity signal effectively.

Keywords: myocardial infarction, delayed enhancement, MRI, black-blood, canine model

Student number: 2010-23707

CONTENTS

Introduction

According to a recent epidemiological update, coronary heart disease is one of the leading cause of death, which causing approximately one of every six deaths in the United States (1). Detection of small silent myocardial infarction in patients without typical symptoms is crucial because those have similar poor prognosis with patients with typical coronary attack and the proper medical or interventional treatment might improve the prognosis significantly (2).

Delayed contrast-enhanced magnetic resonance imaging (MRI) has played an important role in detection of small myocardial infarction as it is capable of high spatial resolution and is able to assess the presence of viable portion in infarcted myocardium with high contrast (3). However, the bright signal intensity of blood in left ventricular cavity, which is dependent on concentration of the contrast media, can potentially mask small foci of myocardial infarction. To overcome this problem, various MR techniques were suggested including dark blood-pool delayed enhancement technique with double inversion recovery, which uses a slice-selective inversion pulse followed by a precisely timed nonselective inversion pulse (4). The weak point of this technique is that the nulling of blood signal is based on the flow of the blood and the slow-flow blood in the apex or the dysfunctional ventricle can show bright signal intensity. On the other hand, Flow Independent Dark Blood Delayed Enhancement (FIDDLE) sequence, a new MRI technique, renders blood very dark in the reconstructed image whereas

small subendocardial infarcts are clearly visualized due to their stark contrast relative to the dark blood pool without requiring blood flow to achieve dark blood (Figure 1) (5).

The purpose of this study was to validate new MRI technique FIDDLE using ex-vivo imaging and 2,3,5-triphenyltetrazolium chloride (TTC) stained pathologic specimen and to compare signal intensities of infarcted myocardium over both blood cavity and remote normal myocardium in comparison with the conventional delayed enhancement cardiac MRI in a canine model of myocardial infarction.

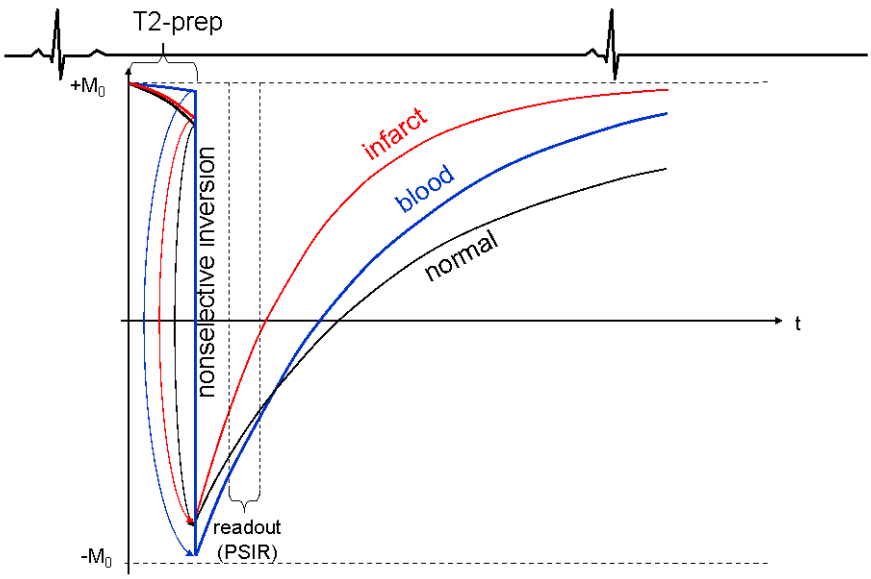

Figure 1. Relaxation curves of normal myocardium (black), infarcted myocardium (red), and blood with contrast agent present (blue). Blood and myocardium experience a T2-preparation or MTC-preparation immediately followed by non-selective inversion pulse. Data readout occurs between the dashed vertical lines and requires a phase-sensitive reconstruction (5).

Materials and Methods

All animal studies were approved by our Institutional Animal Care and Use Committee (approval number: 12-0146) and complied with the "Guidelines for the Care and Use of Laboratory Animals" (National Institutes of Health (NIH) publication no. 80-23, revised 1985).

A Canine Model of Myocardial Infarction

Seven mongrel dogs (25 to 30 kg) were anesthetized, intubated, and mechanically ventilated using ventilator (Aespire 300; Datex-Ohmeda, Helsinki, Finland). All animals received prophylaxis with antibiotics every four hour. Catheter sheaths were placed in the left common carotid artery (5-F) after surgical dissection. After this, the animals underwent heparinization (2,000 IU, intravenously). A 5-F Cobra catheter (Cook, Bloomington, Indiana, USA) was advanced through the common carotid artery into left main coronary artery under the fluoroscopic guidance. A diagonal artery from left anterior descending artery or an obtuse marginal artery from left circumflex artery was selected with microcatheter and occluded permanently by 0.2-0.3 ml of glue (N-butyl-2-cyanoacrylate) and iodized oil (Lipiodol; Andre Gurbet, Aulnay-sous-Bois, France) mixture (ratio=1:3). The left common carotid artery was ligated at proximal and distal to the puncture site after removal of the sheath and the subcutaneous tissue and skin was closed with continuous suture.

MRI Acquisition

All MRI scans were performed a week after the myocardial infarction modeling using a 3.0-T clinical MR system (Magnetom Trio; Siemens, Erlangen, Germany). All animals were placed in left decubitus with a spine coil wrapped around the chest and anesthetized, intubated and mechanically ventilated using isoflurane in a ventilator (Aespire 300, Datex-Ohmeda, Helsinki, Finland) during the scanning. Respiration rate was set to be 8 times a minute with tidal volume of 200 ml. Temporal scan was obtained at each four different time point of 10, 20, 30 and 40 minutes after a 0.2 mmol/kg intravenous injection of gadolinium diethylenetriamine penta-acetic acid (Gd-DTPA) (Magnevist, Berlex Laboratories, Montville, New Jersey, USA) using both conventional delayed enhancement and FIDDLE sequence with following parameters: echo time of 2.28 ms, repetition time of 600 ms, 7 mm slice thickness/no gap, 172 × 250 mm field of view, 256 × 139 image matrix, 15° flip angle and 1 number of signals averaged. Two image datasets were obtained alternatively at the single short axis slice which represents the infarcted lesion best. The inversion recovery time (TI) was adjusted to null the signal intensity from normal myocardium and blood pool in left ventricle throughout each scan by a radiologist who is an expert in cardiovascular imaging with 10 years of experience, as its optimal value is dependent on the concentration of the contrast agent in myocardium and blood (6).

Ex-vivo MRI Acquisition and Postmortem TTC staining

Two animals among seven were available for postmortem study. They were euthanized with phenobarbital. 0.3 mmol/kg of contrast media (Gd-DTPA) and heparin (2,000 IU) were infused through IV route 10 minutes before the injection of KCl to induce fatal ventricular fibrillation. The heart was excised and washed out of blood by gentle rinsing with tap water. After dry-off, the postmortem heart was filled with perfluorocarbon solution (PF-5058, 3M, St. Paul, Minnesota, USA), hanged to the lid of the plastic jar and placed in 3-T clinical MR system (Magnetom Trio; Siemens, Erlangen, Germany) with head coil (7). MR scans were performed using regular 3D gradient-echo delayed enhancement sequence with following parameters: echo time of 2.2 ms, repetition time of 850 ms, 0.7 mm slice thickness/no gap, 98 × 130 mm field of view, 176 × 132 image matrix, 40° flip angle and 7 number of signals averaged. After image acquisition, the heart was frozen and sectioned into 5-mm-thick short-axis slices and incubated in 2% TTC solution for 20 min at 38℃ to delineate viable myocardium (8, 9). Each slice was photographed with a digital camera. The location of TTC negative area was confirmed as the reference standard for the myocardial infarction.

Analysis of MRI data

All measurements were performed at phase sensitive inversion recovery images of both image datasets using a commercially available workstation

(XW6200; Hewlett-Packard, CA, USA) with the PACS software (Maroview 5.4; Infinitt, Seoul, Korea). Regions of interest (ROIs) were selected for infarcted area, normal myocardium and blood pool in left ventricular cavity to measure signal intensity. Standard deviation of the ROIs placed at blood pool was used as a representative value for image noise. A radiologist who had 5 years of experience in cardiovascular imaging performed all the image analysis and ROI measurement.

The Contrast-to-noise ratio (CNR) of the infarction to normal myocardium (CNR_{ItoN}) and that of infarction to blood pool (CNR_{ItoB}) for both sequences were calculated by using the following equations, respectively (4).

$$\mathbf{CNR_{ItoN}} = \frac{\text{mean signal intensity of infarction} - \text{mean signal intensity of normal myocardium}}{\text{image noise}}$$

$$\mathbf{CNR_{ItoB}} = \frac{\text{mean signal intensity of infarction} - \text{mean signal intensity of blood in left ventricle}}{\text{image noise}}$$

Qualitative Study

Two radiologist reviewed images of both FIDDLE and conventional delayed enhancement sequences and evaluated image parameters including sharpness of infarction margin, conspicuity of subendocardial portion of the lesion, and homogeneity of normal myocardium and scored them in consensus. During the review, the observers were allowed to change window width and level of the images.

Conventional delayed enhancement MRI acquired 20 minutes after the

administration of the contrast media was assumed to be the reference standard image. All parameters were assessed on a five-point scale in comparison with the reference standard image; score 5, definitely superior to the reference; score 4, slightly superior; score 3, equivalent; score 2, slightly inferior; and score 1, definitely inferior. All image reviews were performed on PACS software (Maroview 5.4, Infinitt) running on a workstation (XW6200, Hewlet-Packard, CA, U.S.A), with 2048 × 1536-pixel 20.8-inch monochrome liquid crystal display monitors (ME315L; Totoku Electric, Tokyo, Japan)

Statistical analysis

Mean CNR_{ItoN} and CNR_{ItoB} at each time point for conventional delayed enhancement and FIDDLE images were compared using paired Wilcoxon signed-rank test. For evaluation of changes in CNR at each time point, analysis of variance (ANOVA) on rank test (Friedman test) was performed, with delay time serving as the analysis of variance factors (10). Mean scores of parameters of the qualitative study for both sequences were calculated. A P value less than 0.05 was considered to be significant. Statistical analysis software (SPSS for Windows, version 17.0, SPSS, Chicago, IL; SigmaPlot 12.3, Systat Software, San Jose, CA) was used for all statistical analyses in our study.

Results

A Canine Model of Myocardial infarction and MRI Acquisition

Obtuse marginal branches or distal portion of left circumflex artery were occluded in 6 animals, while a diagonal branch from left anterior descending artery was occluded in one animal. All animals were survived from the myocardial infarction modeling procedure and underwent MRI scanning successfully.

Ex-vivo MRI Acquisition and Postmortem TTC staining

The segmental distribution, size and shape of the myocardial infarctions in MR were confirmed to be well matched to those of TTC stained gross pathologic specimen in two animals (Figure 2). Neither enhancement techniques showed false positive myocardial hyperenhancement in normal myocardium.

Analysis of MRI data

Total of seven hyperenhanced myocardial infarction at the territory of the occluded arteries (3 posterior, 2 lateral, 1 anterior wall and 1 apex) were present in all seven animals for both conventional delayed enhancement and FIDDLE sequences.

The mean inversion time, signal intensity, the image noise, and calculated CNR_{ItoN} and CNR_{ItoB} at 10, 20, 30 and 40 minutes of delay time for both conventional delayed enhancement and FIDDLE were listed in the table 1. The mean CNR_{ItoN} values were 1.99 times higher in conventional delayed enhancement MRI than in FIDDLE with statistical significance (P=.018 for each time point). On the contrary, CNR_{ItoB} values were 2.12 times higher in FIDDLE than in conventional delayed enhancement MRI; however, statistical significance was seen only at 10 minutes with P value of 0.028 (Figure 3). CNR values were not significantly different at various delay times in both MR sequences.

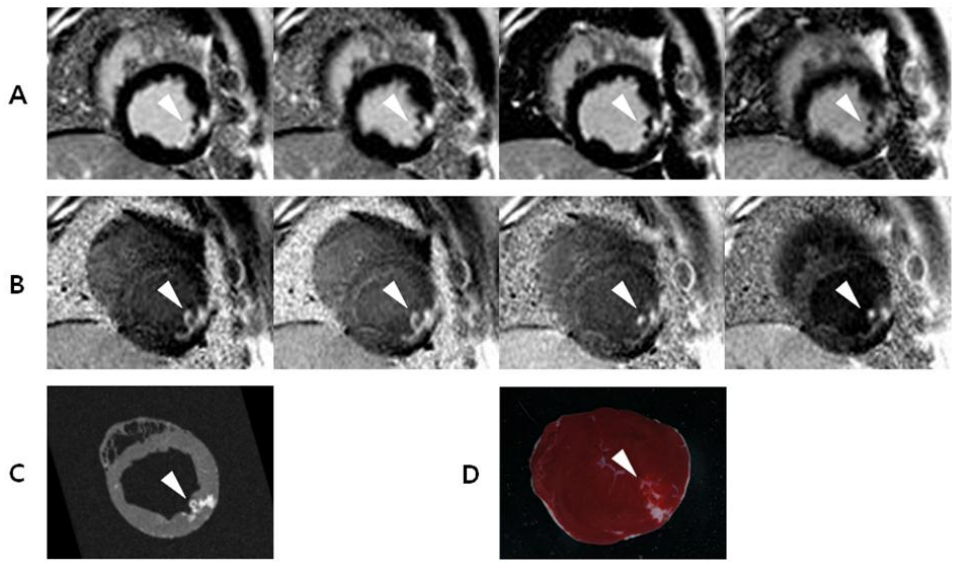

Figure 2. Singe slice short-axis images at 10, 20, 30, and 40 minutes after the contrast media injection using conventional delayed enhancement sequence (A) and FIDDLE sequence (B) showed hyperenhancing lesion in the lateral wall of left ventricle. The Ex-vivo scan (C) and TTC stained gross specimen (D) confirmed the location and shape of the myocardial infarction. Subendocardial portion of the myocardial infarction (arrowhead) is more easily identifiable in the FIDDLE image datasets.

	Conventional Delayed Enhancement			
Delay Time (min)	10	20	30	40
Inversion Time (ms)	288.57 ± 10.79	321.43 ± 8.57	378.57 ± 10.79	401.43 ± 14.55
SI of Infarct	2372.71 ± 31.16	2448.57 ± 45.91	2530.43 ± 11.03	2485.14 ± 43.25
SI of Normal Myocardium	1935.57 ± 45.01	1986.43 ± 33.78	2130.29 ± 37.24	2121.43 ± 27.56
SI of Blood Pool	2364.71 ± 45.19	2347.29 ± 36.11	2422.29 ± 26.61	2382.57 ± 29.38
Noise	18.92 ± 1.60	21.98 ± 3.50	21.80 ± 2.31	23.31 ± 2.30
CNR of Infarct to Normal Myocardium	23.66 ± 1.96	23.89 ± 4.12	20.13 ± 3.15	16.20 ± 2.17
CNR of Infarct to Blood Pool	0.61 ± 1.93	5.23 ± 1.44	5.42 ± 1.24	4.38 ± 1.63
Sharpness of Infarction Margin	3.29	3.00	2.43	2.14
Conspicuity of Subendocaridal Infarction	2.43	3.00	2.71	2.71
Homogeneity of Normal Myocardium	3.14	3.00	3.14	2.71
	FIDDLE			
Delay Time (min)	10	20	30	40
Inversion Time (ms)	138.57 ± 9.62	160.71 ± 9.29	231.43 ± 18.05	241.43 ± 14.05
SI of Infarct	1923.00 ± 29.09	1947.43 ± 44.84	2046.57 ± 51.19	2119.14 ± 45.80
SI of Normal Myocardium	1732.86 ± 39.23	1745.29 ± 50.06	1790.86 ± 77.43	1902.86 ± 31.13
SI of Blood Pool	1790.71 ± 34.44	1795.29 ± 41.51	1805.00 ± 90.04	1936.57 ± 40.24
Noise	19.30 ± 2.42	21.36 ± 3.19	26.18 ± 5.73	20.99 ± 2.36
CNR of Infarct to Normal Myocardium	10.64 ± 1.78	10.33 ± 2.12	9.87 ± 1.52	11.25 ± 1.54
CNR of Infarct to Blood Pool	7.44 ± 1.94	7.97 ± 1.52	8.48 ± 1.41	9.28 ± 1.53
Sharpness of Infarction Margin	2.29	2.57	1.86	1.71
Conspicuity of Subendocaridal Infarction	3.43	3.71	3.00	2.71
Homogeneity of Normal Myocardium	1.71	2.00	1.43	1.57

SI:signal intenstiy; CNR:contrast-to-noise ratio; FIDDLE: Flow Independent Dark Blood DeLayed Enhancement

Table 1. Inversion time, signal intensity, image noise and contrast-to-noise ratio measured from the two datasets

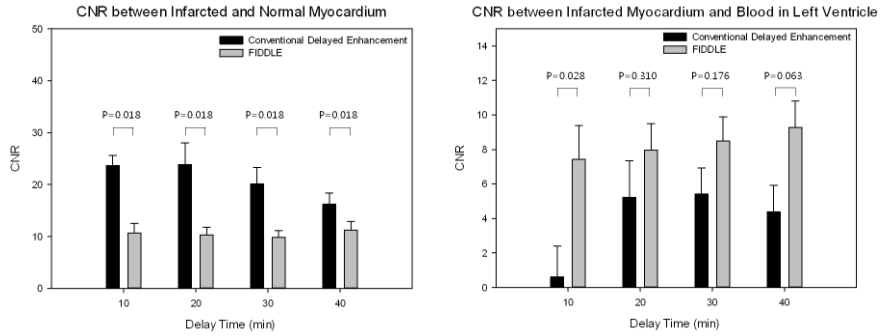

Figure 3. (A) The mean CNR_{ItoN} values were 1.99 times higher in conventional delayed enhancement MRI than in FIDDLE (P=.018 for each time point) with statistical significance. (B) CNR_{ItoB} values were 2.12 times higher in FIDDLE than in conventional delayed enhancement MRI; however, statistical significance was seen only at 10 minutes with P value of 0.028.

Qualitative study

The result of the qualitative study was summarized in table 1. Sharpness of the infarction margin and homogeneity of signal intensity of normal

myocardium were superior in early phases of conventional delayed enhancement sequence to late phase or FIDDLE sequence. Conspicuity of subendocardial portion of the lesion was superior in early phase of FIDDLE to the conventional delayed enhancement images or late phase of FIDDLE (Figure 4)

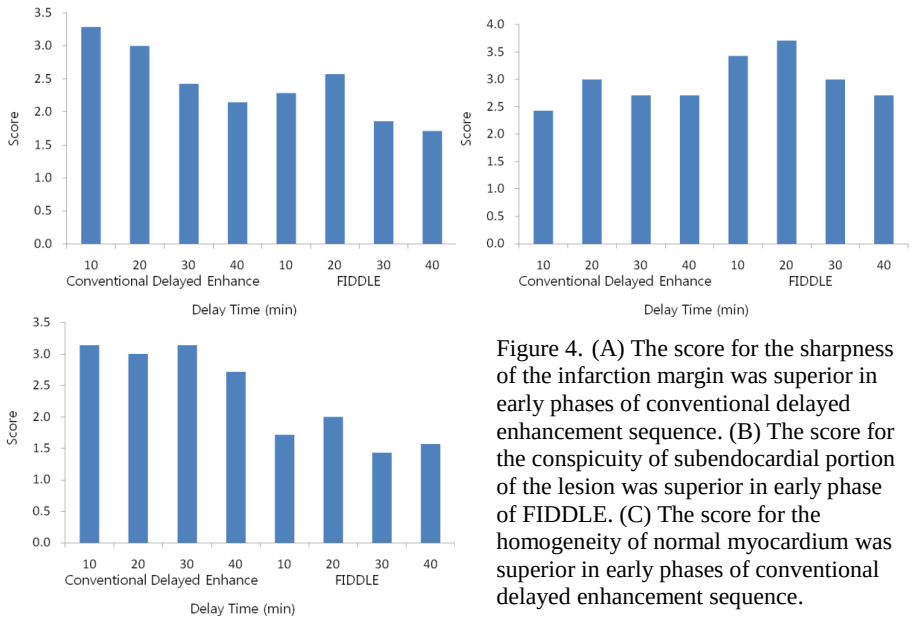

Figure 4. (A) The score for the sharpness of the infarction margin was superior in early phases of conventional delayed enhancement sequence. (B) The score for the conspicuity of subendocardial portion of the lesion was superior in early phase of FIDDLE. (C) The score for the homogeneity of normal myocardium was superior in early phases of conventional delayed enhancement sequence.

Discussion

As we have postulated, FIDDLE technique revealed enhancement in infarcted myocardium correctly and successfully nulled the signal intensity of normal myocardium and blood pool. The mean CNR_{ItoB} was approximately two times higher in FIDDLE sequence than in the

conventional delayed enhancement technique. The difference in CNR_{ItoB} between the two MR techniques was more than 10 times at 10 minutes of delay time in this study. This means that the high signal intensity of infarcted myocardium can stand out over the nulled signal of adjacent blood pool and possibly can result in higher sensitivity in detection of subendocardial infarction, which is sometimes difficult to be detected with the conventional delayed enhancement technique due to the similar signal intensity with the blood in the left ventricle (Figure 2). The transmural extent of myocardial infarction which is known to be able to predict with conventional delayed enhancement MRI according to the previous studies (11-13) is significantly related to the likelyhood of improvement in cardiac function after revascularization . Thus, improved detection of small subendocardial infarction using FIDDLE may identify segments which would benefit from revascularization procedure as well as aid in diagnosis (4).

On the contrary, CNR_{ItoN} of FIDDLE sequence was only approximately half of the conventional delayed enhancement sequence. This result was caused by the lower contrast between the signal intensity of myocardial infarction and normal myocardium in FIDDLE while the noise value was similar in both MR sequences. The reason for lower contrast of FIDDLE might be that TI value has to be determined to null both normal myocardium and blood pool while the conventional delayed enhancement considers nulling of only myocardium (Figure 1).

Although CNR values were not significantly different statistically at various delay times in both MR sequences, this negative result should be interpreted

cautiously considering the small study population of this study. CNR_{ItoN} of FIDDLE sequence tend to be constant along the time course and slightly increased at 40 minutes delay time, while that of the conventional delayed enhancement tends to decrease as the delayed time increases. CNR_{ItoB} showed similar pattern except that of the conventional delayed enhancement was very poor at 10 minute of delay time (Figure 3). This means that lesion conspicuity of FIDDLE sequence might be better in later stage of delay time, while that of the conventional delayed enhancement is best at 20 or 30 minutes of delay time. However, we should be careful when interpret this result as the later stage of FIDDLE sequence is superior to the early stage because of the conflicting result from the qualitative study in which the conspicuity scores for FIDDLE in the early phase were superior to those in the late phase. This discrepancy might have been caused by the deterioration of sharpness of infarction margin and the homogeneity of the normal myocardium in the late phase of FIDDLE, which could not be adequately assessed in the CNR study.

There are several limitations to be warranted. First, the myocardial infarction model was established by the glue embolization of coronary artery, which is not as physiologic as the balloon occlusion or surgical ligation methods with which the reperfusion is possible. The resulting extent of myocardial infarction was transmural in all cases and “no reflow zone”, which stands for the non-enhancing infarcted lesion in delayed enhancedment MRI due to obstruction of microcirculation, was seen frequently. However, this method was safe and easy to perform and enabled more precise location of myocardial infarction. Second, the number of the experiment animal was relatively small

to reveal subtle statistical difference. Third, the TI value for image acquisition was determined subjectively by the MR and there is possibility that the resultant signal intensity can vary greatly.

In conclusion, FIDDLE technique revealed enhancement in infarcted myocardium correctly and successfully nulled the signal intensity of normal myocardium without false positive hyperenhancement. Though the conventional delayed enhancement showed better mean CNR_{ItoN}, the higher CNR_{ItoB} of FIDDLE by nulling signal from blood effectively is expected to enable more sensitive detection of small subendocardial infarction.

References

1. Roger, V.L., et al., *Heart Disease and Stroke Statistics--2012 Update: A Report From the American Heart Association.* Circulation, 2011.
2. Sigurdsson, E., et al., *Unrecognized myocardial infarction: epidemiology, clinical characteristics, and the prognostic role of angina pectoris: the Reykjavik Study.* Annals of internal medicine, 1995. **122**(2): p. 96-102.
3. Simonetti, O.P., et al., *An improved MR imaging technique for the visualization of myocardial infarction.* Radiology, 2001. **218**(1): p. 215-23.
4. Farrelly, C., et al., *Improved detection of subendocardial hyperenhancement in myocardial infarction using dark blood-pool delayed enhancement MRI.* AJR Am J Roentgenol, 2011. **196**(2): p. 339-48.
5. *Siemens applications guide FIDDLE sequence 615-version B (Works-in-Progress): For cardiovascular imaging - implementation of methods for dark blood tissue characterization.* 2011.
6. Amado, L.C., et al., *Accurate and objective infarct sizing by contrast-enhanced magnetic resonance imaging in a canine myocardial infarction model.* J Am Coll Cardiol, 2004. **44**(12): p. 2383-2389.
7. Itskovich, V.V., et al., *Quantification of human atherosclerotic plaques using spatially enhanced cluster analysis of multicontrast-weighted magnetic resonance images.* Magnetic

resonance in medicine, 2004. **52**(3): p. 515-523.

8. Amado, L.C., et al., *Accurate and objective infarct sizing by contrast-enhanced magnetic resonance imaging in a canine myocardial infarction model.* J Am Coll Cardiol, 2004. **44**(12): p. 2383-9.

9. Rochitte, C.E., et al., *Magnitude and time course of microvascular obstruction and tissue injury after acute myocardial infarction.* Circulation, 1998. **98**(10): p. 1006-1014.

10. Hur, S., et al., *80-kVp CT Using Iterative Reconstruction in Image Space Algorithm for the Detection of Hypervascular Hepatocellular Carcinoma: Phantom and Initial Clinical Experience.* Korean Journal of Radiology, 2012. **13**(2): p. 152.

11. Choi, K.M., et al., *Transmural extent of acute myocardial infarction predicts long-term improvement in contractile function.* Circulation, 2001. **104**(10): p. 1101-1107.

12. Selvanayagam, J.B., et al., *Value of delayed-enhancement cardiovascular magnetic resonance imaging in predicting myocardial viability after surgical revascularization.* Circulation, 2004. **110**(12): p. 1535-1541.

13. Vogel-Claussen, J., et al., *Delayed Enhancement MR Imaging: Utility in Myocardial Assessment1.* Radiographics, 2006. **26**(3): p. 795-810.

국문 초록

개의 심근경색 모델을 이용한 Flow Independent Dark Blood Delayed Enhancement 자기공명영상의 특성 평가

서론: 개의 심근경색 모델에서 새로운 지연기 조영증강 자기공명영상 기법인 Flow Independent Dark Blood Delayed Enhancement (FIDDLE)이 체외 고해상도 자기공명영상과 2,3,5-triphenyltetrazolium chloride (TTC)로 염색한 병리검체에서 확인된 심근경색 부위를 잘 보여줄 수 있는지 알아보고자 한다. 또한 기존의 고식적 지연기 조영증강 자기공명영상과 비교하였을 때 신호강도의 특성을 비교 분석하고자 한다.

방법: 혈관내 접착성 영구색전물질 (N-butyl-2-cyanoacrylate)을 이용하여 7 마리 개의 좌측 관상동맥의 분지를 폐쇄하였다. 일 주일이 경과한 후 3-T 자기공명영상촬영기를 이용하여 모든 동물에서 고식적 지연기 조영증강 자기공명영상과 FIDDLE 자기공명영상을 조영제 주입 후 10 분, 20 분, 30 분, 40 분 후에 각각 촬영하였다. 2 마리의 개에서는 추가적으로 사후 체외 고해상도 자기공명영상과 TTC 염색을 시행하였다. 경색 심근, 정상 심근, 좌심실 내 혈액의 신호강도와 영상의 잡음(noise)를 두 기법 모두에서 각각 측정하였다. 이를 이용하여 경색 심근과 정상 심근, 경색 심근과 좌심실내 혈액 사이의 대조도대잡음비(contrast to noise ratio)를 각각 계산하고 서로 비교하였다. 또한 정성적으로 영상을 평가하여 병변 경계의 명확성, 심내막하 경색 부위가 눈에 띄는 정도

(conspicuity), 그리고 정상 심근 신호강도의 균일성에 대해 점수를 부여하고 비교하였다.

결과: 두 기법 모두 7 마리 실험동물 전부에서 심근경색 부위의 지연기 조영증강을 보여주었고 2 마리에서는 자기공명영상에서 나타난 병변이 체외 자기공명영상과 TTC 염색 병리검체에서의 심근경색 병변과 일치함을 확인하였다. 경색 심근과 정상 심근 사이의 대조도대잡음비는 고식적 지연기 조영증강 자기공명영상이 FIDDLE 보다 1.99 배 높았으며 통계적으로 유의했으나(P=.018, 모두), 경색 심근과 좌심실내 혈액 사이의 대조도대잡음비는 FIDDLE 이 2.12 배 높았다. 그러나 통계적 유의성은 10 분 지연기에서만 보였다(P=.028). 정성적 영상평가에서는 눈에 띄는 정도에서 FIDDLE 이 우수하였으나 병변 경계의 명확성과 정상 심근의 균일도는 열등하였다.

결론: 체외 고해상도 자기공명영상과 TTC 염색 병리소견을 이용하여 새로운 FIDDLE 기법이 위양성 조영증강 없이 경색 심근을 정확하게 보여주고 있음을 확인하였다. FIDDLE 기법은 심실 내 혈액의 신호강도를 효과적으로 억제함으로써 경색 심근과 좌심실 내 혈액 사이의 신호강도의 대조도를 높임으로써 심내막하 심근경색을 보다 민감하게 검출할 수 있을 것으로 기대된다.

주요어: 심근경색, 지연기 조영증강, 자기공명영상, 개 심근경색 모델

학 번: 2010-23707