Repolarization heterogeneity of magnetocardiography predicts long-term prognosis in patients with acute myocardial infarction

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Repolarization heterogeneity of magnetocardiography predicts long-term prognosis in patients with acute myocardial infarction

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ABSTRACT

Repolarization Heterogeneity of Magnetocardiography Predicts Long-Term Prognosis in Patients with Acute Myocardial Infarction

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Background: Magnetocardiography (MCG) has been proposed as a noninvasive, diagnostic tool for risk-stratifying patients with acute myocardial infarction (AMI). This study evaluated whether MCG predicts long-term prognosis in AMI.

Methods and Results: In 124 AMI patients (95 males, mean age 60±11 years), including 39 with ST-elevation myocardial infarction (MI), a 64-channel MCG was performed within 2 days after AMI. During a mean follow-up period of 68±37 months, major adverse cardiac events (MACE) were evaluated. MACE occurred in 31 (25%) patients, including 20 revascularizations, 8 deaths, and 3 re-infarctions. Non-dipole patterns were observed at 40 ms before the end of the T wave (Te40) in 89 (72%) patients. Non-dipole patterns were observed at T-peak in 77% (24/31) and 54% (50/93) of patients with and without MACE, respectively (P=0.02). Maximum current, field map angles, and distance dynamics were not different between groups.

In the multivariate analysis, patients with non-dipole patterns at T-peak had increased age- and sex-adjusted hazard ratios for MACE (relative risk 2.95, 95% confidence interval 1.18-7.35) and lower cumulative MACE-free survival than those with dipole patterns (P=0.02).

Conclusions: Non-dipole patterns at T-peak were more frequently observed in patients with MACE and were related to poor long-term prognosis. Thus, repolarization heterogeneity measured by MCG may be a useful predictor for AMI prognosis.

Key words : acute myocardial infarction, long-term, prognosis, magnetocardiography

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I. INTRODUCTION

Research into prognostic factors for acute myocardial infarction (AMI) is informative for optimizing therapeutic strategies. Traditional methods for stratifying risk for acute coronary syndrome are electrocardiography (ECG) and cardiac biomarkers. ECG is the most widely used test for evaluating patients with unstable angina and AMI. In the Thrombolysis in Myocardial Ischemia (TIMI) III Registry, independent predictors of 1-year death or myocardial infarction (MI) were left bundle branch block (LBBB) and new ST segment deviation >0.5 mm [1]. Elevated cardiac biomarkers of myocardial necrosis (creatine kinase-MB [CK-MB], troponin) are associated with a worse long-term prognosis [2]. Furthermore, elevated C-reactive protein (CRP) correlates with an increased risk of mortality [3]. Creatinine is another simple tool for AMI risk stratification. Creatinine or creatinine clearance is associated with increased mortality,

independent of other standard risk factors [4]. Other biomarkers related to increased cardiac risk include natriuretic peptides (brain natriuretic peptide or N-terminal pro-brain natriuretic peptide), white blood cell count, myeloperoxidase, and glucose or hemoglobin A1c. In addition, transthoracic echocardiography (TTE) is a popular method to assess patients with acute coronary syndrome. Left ventricular dysfunction, particularly left ventricular end-systolic volume, is known as a major prognostic factor for AMI [5]. Although the above methods can stratify risk for AMI, several promising new techniques have been studied to determine if they provide better prognostic prediction.

Magnetocardiography (MCG) is a noncontact, noninvasive, and radiation-free method for providing a complete investigation of a given patient's cardiac magnetic field within 10 minutes. Clinical research using MCG has been wide ranging: it has been found to be more accurate than electrocardiogram (ECG) for the evaluation of MI and ventricular repolarization abnormalities [6, 7] and is able to identify patients at risk for ventricular tachycardia [8]. MCG has been proposed as a tool for risk-stratifying patients with AMI and ischemia [9-11]. Increased intra-QRS fragmentation in MCG predicts arrhythmic events, especially ventricular tachycardia and mortality in post-MI patients with left ventricular dysfunction [12, 13]. Moreover, MCG has been reported to show higher non-dipolar structures on cardiac magnetic field maps after ST-elevation and non-ST-elevation

myocardial infarction [11, 14]. Also, temporal and spatial analysis of QT intervals in healthy subjects and in patients with coronary artery disease using MCG have revealed that the spatial distribution of QT intervals in patients differed from those in healthy subjects in three ways: they showed greater dispersion, greater local variability, and a change in overall MCG pattern [15]. However, MCG patterns that link with AMI prognosis remain to be elucidated. Therefore, this study evaluated whether specific MCG findings could predict long-term prognosis in patients with AMI.

II. MATERIALS AND METHODS

The study group

This study was conducted in the Cardiovascular Center of the Yonsei University Severance Hospital (Seoul, Korea) with the approval of the institutional review board. Informed consent was obtained from all patients. MCGs were recorded from 140 consecutive AMI patients aged 20-80 years from March 2005 to July 2014. Among these patients, MCGs from 16 patients were unable to be evaluated due to the following: inverted T-wave (n=8); flat T-wave (n=5); and complete AV block (n=3). Ultimately, 124 patients (95 males, mean age 60±11 years), including 39 with ST-elevation MI, were evaluated. MCGs were not evaluated for any patient who met the following exclusionary criteria: a prior diagnosis of MI, previous defibrillator implantation or coronary bypass surgery, and cancer patients .

MI was diagnosed by one of the following: typical chest pain with new Q wave or significant ST change on a 12-lead ECG; a significant increase in the plasma creatine kinase (CK) cardiac isoenzyme level; or an akinetic or dyskinetic ventricular wall motion abnormality in an area supplied by a stenosed coronary artery. Coronary angiography was performed and left ventricular ejection fraction (LVEF) was obtained in every patient. A significant coronary artery stenosis was defined by greater than 50% luminal narrowing of the vessel diameter. Data were collected and summarized using standardized abstraction forms by an abstractor with 3 years of training blinded to the outcome of interest.

Clinical parameters

Each patient was checked for a history of hypertension and diabetes mellitus. Two-dimensional TTE was performed within 48 hours of AMI to confirm left ventricular ejection fraction (LVEF). Coronary angiographic findings were converted to a coronary artery disease (CAD) severity score, as follows: normal coronary = 0, 1 vessel disease (VD) = 1, 2VD = 2, 3VD = 3. Measured cardiac biomarkers were CK, CK-MB, and troponin-T (TnT).

MCG recording and interpretation

For all patients, 12-lead ECGs and MCGs were recorded within 30 min while the patient was at rest. High-resolution MCG recordings were obtained within 2 days after AMI using a KRISS 64-channel biomagnetometer (Bio-Signal Research Center, KRISS, Daejeon, Korea) in a

magnetically shielded room in a hospital environment. The MCG system employs double relaxation oscillation superconducting quantum interference device (DROS) sensors. The average noise spectral density of the entire system in the magnetically shielded room was 10 fT/Hz at 1 Hz and 5 fT/Hz over 100 Hz. The system is equipped with 64 planar first order superconducting quantum interference device (SQUID) gradiometers, which measure the tangential components of the cardiomagnetic fields. A high-pass filter of 0.5 Hz, a low-pass filter of 1.6 kHz, and a 60-Hz notch filter were used for recording [16, 17]. MCG recordings were carried out while the patient was at rest for 30 seconds, after resting for 2 minutes in a supine position on the bed. After the acquisition, MCG signals were baseline-corrected, digitally filtered, and averaged to increase the signal-to-noise ratio. Data were averaged, centering on the R wave peak [18].

Analysis of MCG

CDV and MF maps

The summation of the raw signals from 64 recording sites was integrated as the MCG time tracing (Figure 1A). The MCG time tracing analyzed the Q, R, and T waves and the QT interval. The end of the T wave (Te) was the visually determined vertex (maximum curvature) of the signal following the inflection point after the peak of the T wave (Tp).

Current density vector (CDV) maps represent electrical activation signals of the heart. The maximum current angle is the angle of maximum

electrical current between magnetic poles in the heart (Figure 1B). Magnetic field (MF) maps express the magnetic field derived from electrical activation signals with color-coded images (Figure 1C). In the MF map, the red and blue poles display outgoing and inward magnetic fields with respect to the plane of the thorax, respectively. The field map angle is the angle of direction from the center of the negative blue pole to the center of the positive red pole. The dynamic distance of poles was evaluated. MF and CDV maps were analyzed from Te back to Tp.

Figure 1

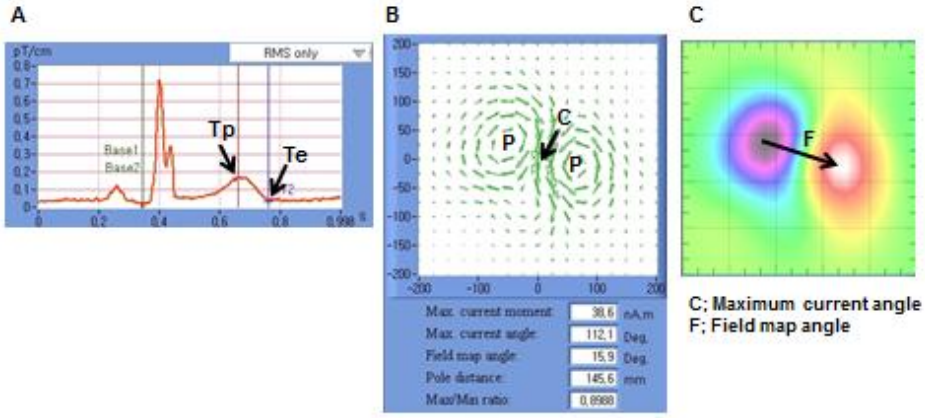

Figure 1. Measurement of MCG. A, MCG tracing. B, Current vector density map. C, Magnetic field map. Maximum current angle (C), Field map angle (F), and the number and distance of poles (P) were measured every 20 ms from T-end (Te) to T-peak (Tp).

Dipole and non-dipole patterns

A dipole pattern was defined as a magnetic field containing two poles. If there were more than 2 poles, it was defined as a non-dipole pattern (Figure 2). Figure 3A is a typical example of normal repolarization showing a dipole pattern; there was a single electrical current from the right inferior direction. Figure 3B shows an abnormal repolarization with a non-dipole pattern; the electrical current was deconcentrated and from the left inferior direction.

Figure 2

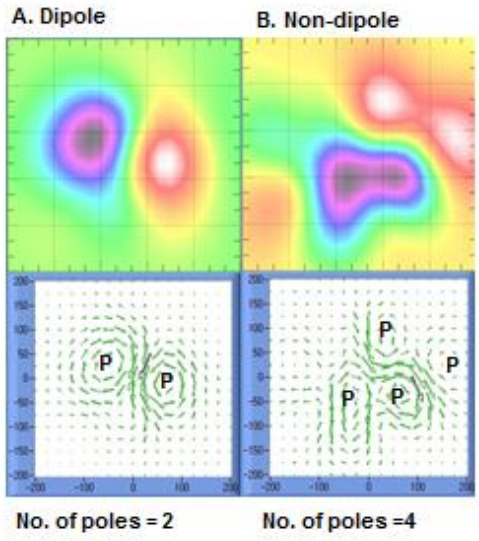

Figure 2. Examples of dipole (A) and non-dipole pattern (B). The number of poles (P) is 2 and 4 in dipole and non-dipole patterns, respectively.

Spatiotemporal activation graph

A spatiotemporal activation graph (STAG) expresses the time-dependent activation of an electromagnetic field from the base to the apex (Figure 3, middle panels). The A and B STAG images represent time-dependent tracing of the magnetic field in a dipole pattern and a non-dipole pattern, respectively.

Figure 3

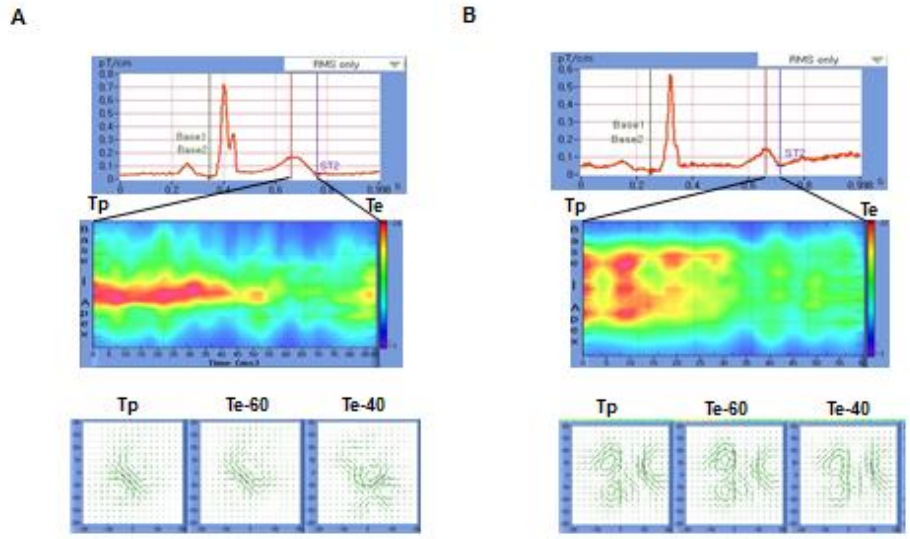

Figure 3. Typical MCG finding from a 79-year-old female patient without MACE (A) and a 66-year-old female patient with MACE (B). MCG tracing (upper panels), spatiotemporal activation graph (STAG, middle panels), and magnetic field and current vector density maps (lower panels). While the

dipole pattern was observed at Tp in the patient without MACE, the non-dipole pattern can be seen in the patient with MACE. Note the continuous change and dispersion of the magnetic field from Tp to Te.

Follow-up

Patients were followed at 1-month, 3-month, and 6-month intervals after discharge from the clinic. The end-point was a major adverse cardiac event (MACE), including composite of death from any cause, reinfarction, and percutaneous coronary intervention (PCI) during the follow-up period. Any patients who had symptoms and signs of angina pectoris or reinfarction during the follow-up period underwent a coronary work-up to confirm coronary lesion and treatment. If a patient had typical chest pain with elevated cardiac enzymes, the patient was categorized as having non-fatal reinfarction.

Statistical analysis

The data were analyzed using SPSS 20.0 for windows (IBM Corp., Armonk, NY, USA). All continuous variables are expressed as means ± standard deviations, and categorical data are reported as an absolute number or percentage. Baseline data were compared using two-sided t-tests for continuous data or Chi-square tests for categorical data. The hazard ratios (HRs) and 95% confidence intervals (CIs) for MACE were calculated with the Cox proportional-hazards model. The multivariate model included age, sex, CK-MB, serum creatinine, and non-dipole pattern at Tp. Kaplan-Meier survival curves were plotted for dipole and non-dipole patterns at Tp and were

compared by means of the log-rank test. Significance was set at P <0.05.

III. RESULTS

Baseline characteristics

During the mean follow-up duration of 68±37 months, MACE occurred in 31 (25%) patients, including 20 PCIs, 8 deaths, and 3 reinfarctions. Clinical characteristics of patients are presented in Table 1. More females than males had a MACE (P=0.01), and patients with MACE had higher levels of serum creatinine (P=0.04) at the time of symptom presentation. Patients managed with PCI had more MACEs (P=0.02) and patients in the coronary artery bypass graft (CABG) group had no MACEs (P=0.02). Other clinical parameters and medication use showed no differences between the 2 groups.

Table 1. Baseline characteristics of study patients

Parameters	Total n=124	MACE (-) n=93	MACE (+) n=31	P-value
Age, years	59.8±11.3	59.0±11.3	62.1±11.4	0.20
Sex (Female), n	29 (23%)	17 (18%)	12 (39%)	0.02
STEMI, n	39 (32%)	27 (29%)	12 (39%)	0.27

Hypertension, n	64 (52%)	49 (53%)	15 (48%)	0.69
Diabetes, n	37 (30%)	31 (33%)	6 (19%)	0.25
Serum creatinine, mg/dL	1.2±1.3	1.1±0.53	1.6±2.4	0.04
CK, IU/L	813.8±1199.7	765.5±1071.6	958.7±1533.4	0.44
CK-MB, ng/mL	206.3±156.1	92.4±117.3	147.9±235.1	0.09
Troponin-T, ng/mL	2.0±3.1	1.8±2.7	2.8±3.9	0.11
LVEF, %	52.1±13.4	52.4±12.8	51.0±15.0	0.59
CAD severity score*	1.9±1.0	1.9±1.0	2.2±0.9	0.13
Management				
PCI, n	90 (73%)	63 (70%)	27 (87%)	0.02
CABG, n	14 (11%)	14 (16%)	0 (0%)	0.02
Medication only, n	20 (16%)	17 (19%)	3 (10%)	0.40
Medication				
Antiplatelet, n	121 (98%)	91 (98%)	30 (97%)	1.00

Beta blocker, n	92 (74%)	79 (85%)	22 (71%)	0.19
ACEI or ARB, n	101 (82%)	72 (77%)	20 (65%)	0.34
Statin, n	110 (89%)	81 (87%)	29 (94%)	0.18

STEMI, ST-elevation myocardial infarction; CK, creatine kinase; CK-MB, creatine kinase MB; CAD, coronary artery disease; LVEF, left ventricular ejection fraction. PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft; ACEI, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor antagonist; *CAD severity score: 1 vessel disease (VD) =1, 2 VD =2, 3 VD =3

Comparison of MCG parameters

Non-dipole patterns were observed at 40 ms before Te (Te40) in 89 (72%) patients. However, non-dipole patterns were observed at T-peak in 77% (24/31) and 54% (50/93) of patients with and without MACE, respectively. Non-dipole patterns at Tp were more frequently observed in patients with than without MACE (P=0.02) (Table 2). There were no differences in the maximum current angles at the Tp (42.5±91.5° vs. 53.4±92.0°, p=0.57), MF map angles (-11.3±83.6° vs. -9.64±94.0°, P=0.93), or pole distance (144.0±24.5 mm vs. 143.7±32.3 mm, P=0.97) between patients with and without MACE.

Table 2. Non-dipole patterns in patients with or without major adverse cardiac events (MACE)

Parameters	Total n=124	No MACE (n=93)	MACE (n=31)	P-value
Non-dipole pattern				
*Te	124 (100%)	93 (100%)	31 (100%)	-
Te-20 ms	115 (93%)	85 (90%)	30 (97%)	0.45
Te-40 ms	89 (72%)	62 (66%)	27 (87%)	0.04
Te-60 ms	78 (63%)	53 (56%)	25 (81%)	0.02
T-peak	74 (60%)	50 (53%)	24 (77%)	0.02
Maximum current angle (°)	45.2±19.4	42.5±91.5	53.4±92.0	0.57
Field map angle (°)	-10.9±85.9	-11.3±83.6	-9.64±94.0	0.93
Pole distance, mm	143.9±26.5	144.0±24.5	143.7±32.3	0.97

Te, end of T-wave

Predictors of MACE

In the univariate analysis, the predictors of MACE were female sex (HR 2.85, 95% CI 1.36-6.00, P=0.01), serum creatinine (HR 1.21, 95% CI 1.02-1.44, P=0.03), CK-MB (HR 1.002, 95% CI 1.001-1.004, P=0.01), and non-dipole pattern at Tp (HR 3.02, 95% CI 1.23-7.42, p=0.02). In the multivariate analysis, the predictors of MACE were female sex (HR 3.07, 95% CI 1.22-7.08, P=0.02), CK-MB (HR 1.002, 95% CI 1.001-1.004, P=0.01), and non-dipole pattern at Tp (HR 2.95, 95% CI 1.18-7.35, P=0.02)

Table 3. Univariate and multivariate analysis

Parameters	Univariate		Multivariate	
	HR (95% CI)	P-value	HR (95% CI)	P-value
Age, years	1.02 (0.98-1.05)	0.364		
Female	2.85 (1.36-6.00)	0.01	3.07 (1.22-.08)	0.02
Hypertension	1.27 (0.62-2.62)	0.51		
Diabetes	1.96 (0.80-4.81)	0.14		
Serum creatinine (per 1 mg/dL increase)	1.21 (1.02-1.44)	0.03	1.15 (0.98-1.36)	0.09
CK-MB (per 1 ng/mL increase)	1.002 (1.001-1.004)	0.01	1.002 (1.001-.004)	0.01
Troponin-T (per 1 ng/mL increase)	1.06 (0.96-1.17)	0.28		
LVEF (per 1% increase)	0.99 (0.96-1.02)	0.33		
CAD severity score*	1.40 (0.93-2.10)	0.10		
Non-dipole pattern	3.02 (1.23-7.42)	0.02	2.95 (1.18-7.35)	0.02

CK-MB, creatine kinase MB; CAD, coronary artery disease; LVEF, Left ventricular ejection fraction.

*CAD severity score: 1 vessel disease (VD) =1, 2 VD =2, 3 VD =3

Figure 4 shows the Kaplan-Meier survival curves for MACE in patients with dipole and non-dipole patterns. Patients with non-dipole patterns

had lower cumulative MACE-free survival than did patients with a dipole pattern (P=0.02).

Figure 4

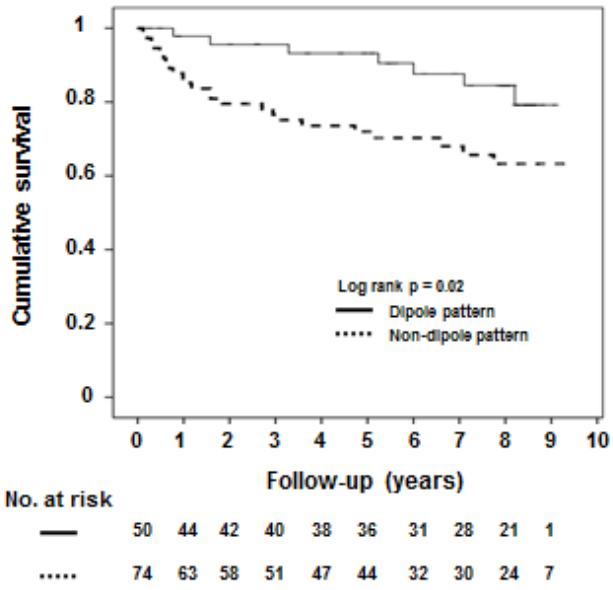

Figure 4. MACE-free survival. Kaplan-Meier survival curves for cardiac events in patients with different repolarization patterns at Tp. Patients with non-dipole patterns at Tp had lower cumulative cardiac event-free survival than did the dipole pattern group (P=0.02).

IV. DISCUSSION

Major findings

The primary finding in this study is that a heterogeneous repolarization pattern was observed in post-MI patients. Interestingly, a non-dipole pattern at T-peak was more frequently observed in patients with MACE and was associated with poor long-term prognosis. This finding suggests that a repolarization heterogeneity measured by MCG might be used to predict the prognosis of AMI.

MCG patterns in post-MI patients

ECG is the most popular non-invasive diagnostic tool for diagnosing AMI, and it can also reflect disease severity and prognosis. MCG, another non-invasive diagnostic modality, may provide a more precise approach to ischemic heart disease than does ECG [6, 7]. In the present study, MCG facilitated the detection of non-dipoles because of its superior spatial resolution and because it shows the differences in physical properties between magnetic and electrical fields. It is therefore useful for detecting cardiac changes at early stages that are currently undetectable by ECG [19].

Previous studies classified abnormal magnetic field map patterns as compressed, stretched, broken, or rotated poles [10]. However, all of these patterns commonly appeared in ischemic heart disease patients, and there were no different clinical findings according to these four patterns. Therefore, in the present study, we categorized all types of abnormal magnetic field map

patterns as having a non-dipole pattern. Through analysis of MCG findings from AMI patients, we confirmed these two types of magnetic field map patterns (dipole and non-dipole) in the repolarization phase. Moreover, in the current density map, healthy people showed dipole patterns. But, non-dipole patterns were found in post-MI patients [19]. These finding support the idea that abnormal cardiac conductivity is caused by ischemia [20]. In this study, most patients showed a non-dipole pattern at Te and 60 ms prior to Te. However, only 60% of patients showed non-dipole patterns at Tp. This magnetic dispersion at the T wave suggests a heterogeneous repolarization abnormality due to ischemia [21].

Heterogeneous repolarization in MCG patterns and long-term prognosis

MCG is a novel method for studying AMI, and more studies are needed to confirm the clinical importance of variable MCG findings. Previous studies have confirmed specific MCG findings in ischemic heart disease patients, and these investigations focused on the diagnostic value of MCG modality [9-11]. However, whether specific MCG findings could predict prognosis had not been elucidated. Typical parameters useful for diagnosis of ischemic heart disease were maximum current angle, field map angle, pole distance, and abnormal repolarization patterns in the magnetic field map. In this study, a non-dipole pattern at the Tp had significant prognostic value in post-MI patients. However, other parameters, including maximum current angle, field map angle, and pole distance, had no prognostic value in post-MI

patients. A previous study suggested that the T peak-end interval positively correlated to the prognosis of MI [22]. Consistent with that, our study supported the idea that repolarization heterogeneity has a significant correlation with poor prognosis in AMI patients.

LVEF is one of the most important prognostic factors for total mortality, sudden cardiac death, and heart failure in post-MI patients. However, LVEF was not different between the patients with MACE or without MACE in our study. This discrepancy might be explained by the fact that many patients in our study had relatively preserved LVEF. Moreover, LVEF could be influenced by myocardial stunning and segmental hyperkinesia outside the infarction area at an early stage of MI [23].

Limitations

This study has severe limitations. Ten percent of our post-MI patients had T-wave inversion or non-specific ST segment change on ECG. Because it was difficult to select the T-peak, those patients were excluded. Display characteristics, added noise, and different analysts may have affected manual repolarization interval measurements in MCG [24]. Undefined or unclear clinical meaning and pathophysiologic backgrounds of MCG findings are major limitations of this study.

V. CONCLUSION

Although the magnetic dispersion was commonly observed from Te to 20 ms before Te, it was persistently observed in 60% of AMI patients. Importantly, most of the AMI patients with MACE showed magnetic dispersion at the T-peak. This finding suggests that MCG might be used to diagnose the repolarization dispersion produced by ischemia and thus predict the prognosis for AMI.

REFERENCES

1. Cannon, C.P., et al., The electrocardiogram predicts one-year outcome of patients with unstable angina and non-Q wave myocardial infarction: results of the TIMI III Registry ECG Ancillary Study. Thrombolysis in Myocardial Ischemia. J Am Coll Cardiol, 1997. **30**(1): p. 133-40.
2. Kleiman, N.S., et al., Prospective analysis of creatine kinase muscle-brain fraction and comparison with troponin T to predict cardiac risk and benefit of an invasive strategy in patients with non-ST-elevation acute coronary syndromes. J Am Coll Cardiol, 2002. **40**(6): p. 1044-50.
3. Morrow, D.A., et al., C-reactive protein is a potent predictor of mortality independently of and in combination with troponin T in acute coronary syndromes: a TIMI 11A substudy. Thrombolysis in Myocardial Infarction. J Am Coll Cardiol, 1998. **31**(7): p. 1460-5.
4. Gibson, C.M., et al., Association of creatinine and creatinine clearance on presentation in acute myocardial infarction with subsequent mortality. J Am Coll Cardiol, 2003. **42**(9): p. 1535-43.
5. Breithardt, G., et al., Prognosis and risk stratification after myocardial infarction. Eur Heart J, 1995. **16 Suppl G**: p. 10-9.
6. Fenici, R., D. Brisinda, and A.M. Meloni, Clinical application of magnetocardiography. Expert Rev Mol Diagn, 2005. **5**(3): p. 291-313.
7. Kwong, J.S., et al., Diagnostic value of magnetocardiography in coronary artery disease and cardiac arrhythmias: a review of clinical data. Int J Cardiol, 2013. **167**(5): p. 1835-42.
8. Endt, P., et al., Identification of post-myocardial infarction patients with ventricular tachycardia by time-domain intra-QRS analysis of signal-averaged electrocardiogram and magnetocardiogram. Med Biol Eng Comput, 2000. **38**(6): p. 659-65.
9. Lim, H.K., et al., Can magnetocardiography detect patients with non-ST-segment elevation myocardial infarction? Ann Med, 2007. **39**(8): p. 617-27.
10. Lim, H.K., et al., Usefulness of magnetocardiogram to detect unstable angina pectoris and non-ST elevation myocardial

infarction. Am J Cardiol, 2009. **103**(4): p. 448-54.
11. Van Leeuwen, P., et al., Changes in dipolar structure of cardiac magnetic field maps after ST elevation myocardial infarction. Ann Noninvasive Electrocardiol, 2011. **16**(4): p. 379-87.
12. Korhonen, P., et al., Increased intra-QRS fragmentation in magnetocardiography as a predictor of arrhythmic events and mortality in patients with cardiac dysfunction after myocardial infarction. J Cardiovasc Electrophysiol, 2006. **17**(4): p. 396-401.
13. Korhonen, P., et al., Relation of magnetocardiographic arrhythmia risk parameters to delayed ventricular conduction in postinfarction ventricular tachycardia. Pacing Clin Electrophysiol, 2002. **25**(9): p. 1339-45.
14. Kyoon Lim, H., et al., Detection of non-ST-elevation myocardial infarction using magnetocardiogram: new information from spatiotemporal electrical activation map. Ann Med, 2009. **41**(7): p. 533-46.
15. Van Leeuwen, P., et al., Spatial distribution of repolarization times in patients with coronary artery disease. Pacing Clin Electrophysiol, 2003. **26**(8): p. 1706-14.
16. Lee YH, et al., 64-channel magetocariogram system based on double relaxation oscillation SQUID planar gradiometers. Supercond Sci Technol, 2006. **19**: p. S284–S288.
17. Kim K, et al., Clinical parameter assessment in magnetocardiography by using the support vector machine. Int J Bioelectromagnetism., 2005. **7**: p. 224–7.
18. Kim, K., et al., Optimal sensor distribution for measuring the tangential field components in MCG. Neurol Clin Neurophysiol, 2004. **2004**: p. 60.
19. Ikefuji, H., et al., Visualization of cardiac dipole using a current density map: detection of cardiac current undetectable by electrocardiography using magnetocardiography. J Med Invest, 2007. **54**(1-2): p. 116-23.
20. Stinstra, J.G., et al., Modelling passive cardiac conductivity during ischaemia. Med Biol Eng Comput, 2005. **43**(6): p. 776-82.
21. Takala, P., et al., Heart rate adjustment of magnetic field map rotation in detection of myocardial ischemia in exercise magnetocardiography. Basic Res Cardiol, 2002. **97**(1): p. 88-96.
22. Lin, X.M., et al., [Clinical assessment of Tpeak-end interval for

prediction of myocardial infarction.]. Nan Fang Yi Ke Da Xue Xue Bao, 2010. **30**(9): p. 2169-70.
23. Wita, K., et al., Prediction of long-term outcome after primary percutaneous coronary intervention for acute anterior myocardial infarction. Kardiol Pol, 2010. **68**(4): p. 393-400.
24. Smith, F.E., et al., Errors in repolarization measurement using magnetocardiography. Pacing Clin Electrophysiol, 2002. **25**(8): p. 1223-9.

ABSTRACT(IN KOREAN)

급성 심근경색 환자에서 Magnetocardiography에 나타난 이완기 불균질성의 장기정 예후 예측

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서론

Magnetocardiography (MCG) 는 급성 심근경색 및 허혈성 심질환 환자들의 위험도를 예측하는 비침습적 진단도구로 제시되어 왔다. 이 연구는 MCG가 급성 심근경색의 장기적 예후를 예측할 수 있는 지를 알아보는 것이다.

방법과 결과

85명의 non-ST elevation MI 와 39명의 ST elevation MI를 포함해 총 124명의 급성 심근경색 환자가 등록되었다 (여성 29명, 평균나이 60 ± 11.세). MCG 기록들은 급성 심근경색 발생 후 2일 이내에 자기적으로 보호된 방에서 64-channel MCG system을 통해 얻어졌다. 평균 68±37개월의 관찰기간 동안 MACE는 31 (25%)의 환자에서 발생하였으며 각각 20명의 재관류, 8명의 사망, 그리고 3명의 심근경색 재발이 있었다. T파의 끝으로 부터의 40ms전에서 non-dipole pattern은 89명(72%)의 환자에서 보였다. 하지만 T-peak에서 non-dipole pattern은 MACE가 있던 환자군 에서는 77% (24/31), 없던 환자군 에서는 54% (50/93)로 관찰되었다 (P=0.02). Maximum current, field map angles, 그리고 distance dynamics는 양 그룹간에 차이를 보이지 않았다. 다변수 분석에서 T-peak에서 non-dipole pattern을 보이는 환자군은 dipole patterns 을 보이는 환자군에 비하여 증가한 연령과 성별을 보정한 MACE의 상대위험도 (hazard ratios 2.95, 95% confidence interval 1.18-7.35) 를 가졌고, 감소한 cumulative MACE-free survival을 보였다 (P=0.02).

결론

T-peak 에서 Non-dipole pattern은 MACE가 있는 환자군에서 보다 더 종종 관찰되었고 좋지 않은 장기적 예후와 연관되어 있었다. 따라서 MCG에서 재분극기의 비균질성은 급성심근경색 환자의 예후를 예측하는데 유용하게 사용될 수 있다.

핵심되는 말 : 급성심근경색, 장기적 예후, magnetocardiography