Heart and Vessels (2019) 34:971–975
https://doi.org/10.1007/s00380-018-01330-9

ORIGINAL ARTICLE

Myocardial perfusion defect assessed by single-photon emission computed tomography and frontal QRS-T angle in patients with prior anterior myocardial infarction

Satoshi Kurisu[1] · Kazuhiro Nitta[1] · Yoji Sumimoto[1] · Hiroki Ikenaga[1] · Ken Ishibashi[1] · Yukihiro Fukuda[1] · Yasuki Kihara[1]

Received: 11 October 2018 / Accepted: 21 December 2018 / Published online: 2 January 2019

Abstract

The frontal QRS-T angle is one of the markers of ventricular repolarization. We sought to assess the effects of myocardial perfusion defect on QRS-T angle in patients with prior anterior myocardial infarction (MI). Seventy-one patients with prior anterior MI and 71 age- and sex-matched control subjects having no myocardial perfusion defect were selected. Frontal QRS-T angle was defined as the absolute value of the difference between the frontal plane QRS axis and T-wave axis. The extent of myocardial perfusion defect was determined using myocardial perfusion single-photon emission computed tomography (SPECT). The extent of myocardial perfusion defect of patients with prior anterior MI was $21.8 \pm 13.7\%$. Frontal QRS-T angle was significantly larger in patients with prior anterior MI than control subjects ($82° \pm 49°$ vs $30° \pm 26°$, $p < 0.001$). Prevalence of abnormal frontal QRS-T angle defined as more than 90° was significantly higher in patients with prior anterior MI than control subjects (42% vs 4%, $p < 0.001$). Multivariate linear regression analysis showed that age (β=0.18, $p = 0.02$) and myocardial perfusion defect ($\beta = 0.46$, $p = 0.02$) were independent determinants of frontal QRS-T angle. Our results suggest that the extent of myocardial perfusion defect is an independent determinant of frontal QRS-T angle in patients with prior anterior MI.

Keywords Electrocardiogram · Myocardial infarction · Ventricular repolarization

Introduction

The frontal QRS-T angle defined as the absolute value of the difference between QRS axis and T-wave axis on 12-lead electrocardiogram (ECG) is one of markers of ventricular repolarization [1-5]. Abnormalities in QRS-T angle may reflect electrical instability, placing patients at high risk for ventricular arrhythmias and sudden cardiac death. Although myocardial infarction (MI) is a major structural heart disease altering ventricular repolarization, the association between the extent of myocardial perfusion defect and QRS-T angle remains to be investigated.

ECG-gated myocardial perfusion single-photon emission computed tomography (SPECT) is a unique modality which enables us to evaluate myocardial perfusion and left ventricular function simultaneously [6-8]. In the present study, we sought to assess the effects of myocardial perfusion defect on QRS-T angle in patients with prior anterior MI using myocardial perfusion SPECT.

Methods

Patients

Between November 2014 and October 2016, 983 patients underwent ECG and myocardial perfusion SPECT for evaluating coronary artery disease. Of these, 88 patients with anterior MI beyond at least more than 12 months after the onset were retrospectively selected. Patients with bundle branch block and those undergoing hemodialysis or cardiac surgery were excluded. Finally, 71 patients with prior

✉ Satoshi Kurisu
skurisu@nifty.com

1 Department of Cardiovascular Medicine, Hiroshima University Graduate School of Biomedical and Health Sciences, 1-2-3, Kasumi-cho, Minami-ku, Hiroshima 734-8551, Japan

anterior MI were enrolled in this study. For controls, 71 age- and sex-matched subjects having no myocardial perfusion defect were selected. Informed consent was obtained from all patients.

ECG

A standard 12-lead ECG was recorded at a paper speed of 25 mm/s and an amplification of 10 mm/mV at the time of MPS. QRS axis and T-wave axis were automatically measured. According to previous reports [1-5], frontal QRS-T angle was defined as the absolute value of the difference between the frontal plane QRS axis and T-wave axis. When QRS-T angle was more than 180°, it was adjusted to the minimal angle using (360° − angle). QRS-T angle more than 90° was considered abnormal based on previous studies [9].

Myocardial perfusion SPECT

All patients fasted overnight, and underwent myocardial perfusion SPECT synchronized with the electrocardiogram [7, 8]. Adnosine was infused over 6 min (120 µg/kg/min), and Tl-201 (111 MBq [3.0 mCi]) was injected 3 min after the initiation of adenosine infusion. The stress-Tl-201 SPECT acquisition was started 5 min after the stress test. Four hours later, redistribution Tl-201 SPECT images were obtained. SPECT images were acquired with a dual-detector 90°γ-camera (Brightview X; Philips). Images were acquired with the following parameters: 36 total projections; 180° from right anterior oblique to left posterior oblique and a noncircular orbit; 64 × 64 matrix; 6.4 mm pixel size; 16 frames per cardiac cycle with retrospective electrocardiogram gating; low-energy, high-resolution collimation; and 40 s per stop. Images were reconstructed using ordered-subset expectation maximization (iteration, 2; subset, 9) with a Butterworth filter (order, 8; cutoff frequency, 0.50 cycles/pixel for stress image and 0.45 cycles/pixel for redistribution image).

Analysis of myocardial perfusion SPECT

Semiquantitative visual interpretation of SPECT images was performed with the short and vertical long axes divided into 17 segments. Each segment was scored using a 5-point scoring system (0, normal uptake; 1, mildly reduced uptake; 2, moderately reduced uptake; 3, severely reduced uptake; and 4, absence of detectable radiotracer in a segment) [10, 11]. The extent of myocardial perfusion defect was determined by the summed redistribution score (SRS) using the following formula: myocardial perfusion defect (%) = SRS × 100/68. Left ventricular end-diastolic volume (LVEDV), end-systolic volume (LVESV) and ejection fraction (LVEF) were obtained from redistribution images using Quantitative gated SPECT (QGS) (Cedars-Sinai Medical Center, USA) [6].

Statistical analysis

Continuous variables are shown as mean ± SD, and categorical variables are shown as frequencies and percentages. Continuous variables were compared by Wilcoxon test. Categorical variables were compared by Chi-square test or

Table 1 Patient characteristics

Variable	Patients with prior anterior MI (*n* = 71)	Control subjects (*n* = 71)	*P* value
Age (years)	71 ± 8	71 ± 8	0.94
Male gender	21 (30%)	21 (30%)	1.00
BMI (kg/m^2)	24 ± 4	24 ± 4	0.97
Hypertension	65 (92%)	44 (62%)	< 0.001
Diabetes	35 (49%)	18 (25%)	0.003
Atrial fibrillation	7 (10%)	1 (1%)	0.02
Serum creatinine (mg/dl)	1.0 ± 0.4	1.0 ± 0.4	0.28
Myocardial perfusion SPECT			
SSS	19.0 ± 9.4	1.1 ± 1.6	< 0.001
SRS	14.8 ± 9.3	0	< 0.001
Myocardial perfusion defect (%)	21.8 ± 13.7	0	< 0.001
LVEDV (ml)	104 ± 61	59 ± 16	< 0.001
LVESV (ml)	63 ± 53	22 ± 10	< 0.001
LVEF (%)	44 ± 13	65 ± 10	< 0.001

MI myocardial infarction, *BMI* body mass index, *SPECT* single-photon emission computed tomography, *SSS* summed stress score, *SRS* summed rest score, *SDS* summed difference score, *LVEDV* left ventricular end-diastolic volume, *LVESV* left ventricular end-systolic volume, *VEF* left ventricular ejection fraction

Fisher's exact test. Correlations between QRS-T angle and clinical variables such as myocardial perfusion defect were assessed by Pearson's correlation test. Multivariate linear regression analysis was performed to determine variables associated with QRS-T angle. Differences were considered significant if the p value was < 0.05. Statistical analysis was conducted using JMP 11 software (SAS Institute, Tokyo, Japan).

Results

Patient characteristics

Patient characteristics are shown in Table 1. Patients with prior anterior MI had hypertension, diabetes and atrial fibrillation more frequently than control subjects. The extent of myocardial perfusion defect of patients with prior anterior MI was 21.8 ± 13.7%. LVEDV (104 ± 61 ml vs 59 ± 16 ml, $p < 0.001$) was significantly larger, and LVEF (44 ± 13% vs 65 ± 10%, $p < 0.001$) was significantly lower in patients with prior anterior MI compared with control subjects.

Effects of myocardial perfusion defect on frontal QRS-T angle

QRS axis, T-wave axis and frontal QRS-T angle of patients with prior anterior MI and control subjects are shown in Fig. 1. Patients with prior anterior MI had smaller QRS axis and larger T-wave axis compared with control subjects. Consequently, frontal QRS-T angle was significantly larger in patients with prior anterior MI than control subjects (82° ± 49° vs 30° ± 26°, $p < 0.001$). Prevalence of abnormal frontal QRS-T angle was significantly higher in patients with prior anterior MI than control subjects (42% vs 4%, $p < 0.001$). There was a significant correlation between the extent of myocardial perfusion defect and frontal QRS-T angle ($r = 0.62$, $p < 0.001$) (Fig. 2). Age ($r = 0.18$, $p = 0.03$), LVEDV ($r = 0.38$, $p < 0.001$), LVESV ($r = 0.40$, $p < 0.001$), and LVEF ($r = -0.51$, $p < 0.001$) were also significantly associated with frontal QRS-T angle (Table 2).

Determinants of frontal QRS-T angle

Multivariate linear regression analysis was performed to determine factors associated with frontal QRS-T angle. Age ($\beta = 0.18$, $p = 0.02$) and myocardial perfusion defect ($\beta = 0.46$, $p = 0.02$) were independent determinants of frontal QRS-T angle (Table 3, model 3).

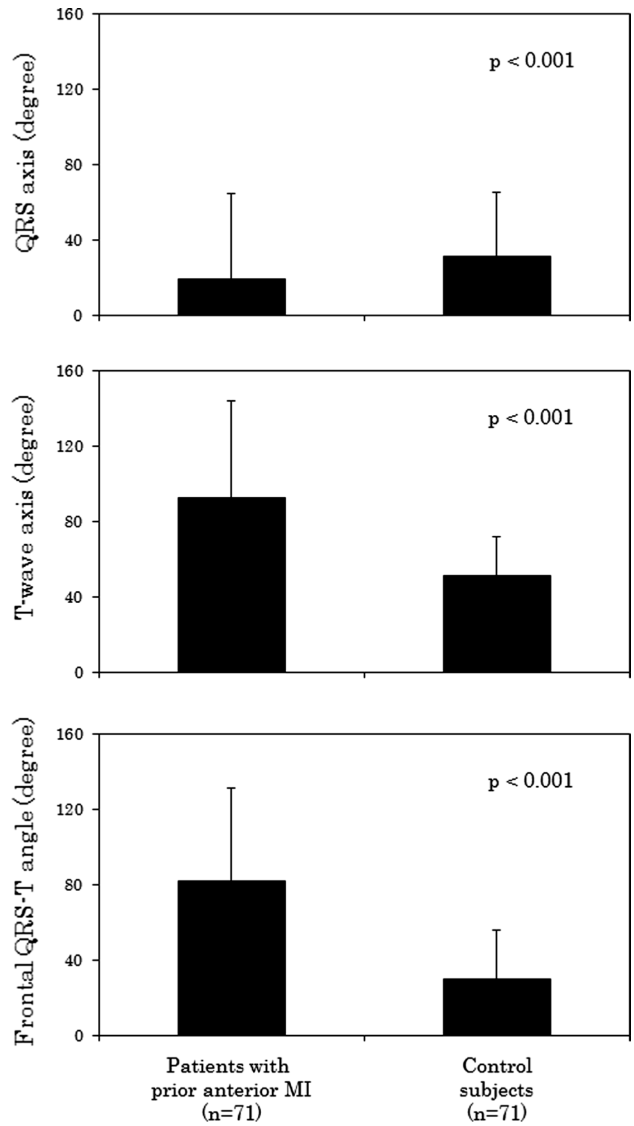

Fig. 1 Comparisons of QRS axis, T-wave axis and frontal QRS-T angle between patients with prior anterior myocardial infarction and control subjects

Discussion

In the present study, we demonstrated the following: (1) patients with prior anterior MI had larger QRS-T angle compared with control subjects; and (2) the extent of myocardial perfusion defect was an independent determinant of frontal QRS-T angle.

When there is an imbalance of electrical activation and recovery of the ventricles, QRS axis and T-wave axis are no longer aligned, the QRS-T angle widens. Frontal QRS-T

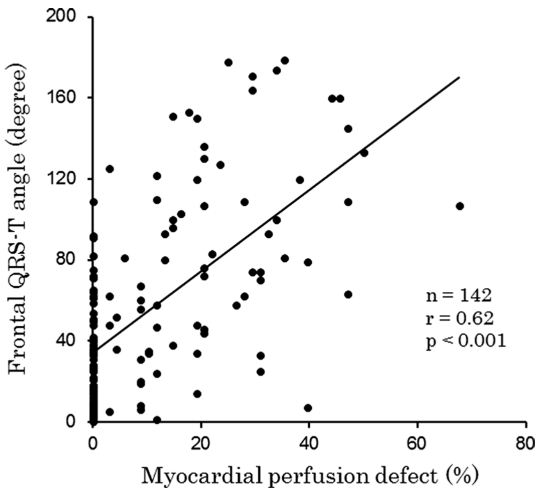

Fig. 2 Correlation between the extent of myocardial perfusion defect and frontal QRS-T angle ($r = 0.62$, $p < 0.001$)

Table 2 Correlations between frontal QRS-T angle and clinical variables

Variable	*r*	*P* value
Age	0.18	0.03
BMI	− 0.01	0.90
Serum creatinine	0.12	0.19
Myocardial perfusion defect	0.62	< 0.001
LVEDV	0.38	< 0.001
LVESV	0.40	< 0.001
LVEF	− 0.51	< 0.001

LVEDV left ventricular end-diastolic volume, *LVESV* left ventricular end-systolic volume, *LVEF* left ventricular ejection fraction, *BMI* body mass index

angle can be easily calculated from a 12-lead ECG as the absolute value of the difference between the frontal QRS axis and T-wave axis. Frontal QRS-T angle plays a role in quantifying the extent of abnormal repolarization before overt ECG changes appear [1-5], and has been shown to predict total mortality in the general population [2], in diabetes mellitus [3], in congestive heart failure [4] or in acute coronary syndrome [5].

Abnormalities in QRS-T angle are possibly related to underlying structural heart diseases. A recent study has shown that patients with abnormal QRS-T angle have prior MI more frequently than those with normal QRS-T angle in the diabetic population [3]. In the present study, we showed that patients with prior anterior MI had larger QRS-T angle, and higher prevalence of abnormal QRS-T angle compared with control subjects. We further demonstrated that the extent of myocardial perfusion defect was associated with frontal QRS-T angle in patients with prior anterior MI using myocardial perfusion SPECT.

Sudden cardiac death is mainly caused by ventricular arrhythmias, accounting for approximately 50% of all cardiac mortality [12]. Several studies using cardiac magnetic resonance imaging have assessed the association between myocardial scar size and ventricular arrhythmias [13, 14]. Zeidan-Shwiri et al. examined patients with prior MI who received an implantable cardioverter defibrillator (ICD), and showed that infarct gray zone and MI core were predictors of appropriate ICD therapies [13]. Scott et al. also reported that the extent of LV scar was associated with the occurrence of ventricular arrhythmias in a cohort of ICD recipients [14]. Their results may be explained by the widening of QRS-T angle in proportion to the extent of myocardial perfusion defect as shown in the present study. Considering these studies and our results, frontal QRS-T angle may be useful in predicting the occurrence of ventricular arrhythmias in patients with prior anterior MI. Further studies are necessary to clarify the linkage of frontal QRS-T angle with the extent of myocardial perfusion defect and the occurrence of ventricular arrhythmias. In addition, frontal QRS-T angle is a simple ECG marker, and its follow-up may contribute to estimate the risk at that time in each case.

Table 3 Multivariate linear regression analysis to determine factors associated with frontal QRS-T angle

Variable	Model 1		Model 2		Model 3	
	β	*P* value	*β*	*P* value	*β*	*P* value
Age	0.16	0.02	0.17	0.02	0.18	0.02
Male	0.002	0.97	− 0.007	0.92	− 0.04	0.59
BMI	0.03	0.65	0.03	0.64	0.04	0.54
Hypertension	0.046	0.53	0.05	0.50	0.03	0.71
Diabetes	0.13	0.06	0.13	0.08	0.13	0.07
Atrial fibrillation	− 0.05	0.50	− 0.05	0.52	− 0.07	0.31
Myocardial perfusion defect	0.57	< 0.001	0.55	< 0.001	0.46	< 0.001
LVEDV			0.04	0.64	− 0.01	0.91
LVEF					− 0.18	0.15

LVEDV left ventricular end-diastolic volume, *LVEF* left ventricular ejection fraction, *BMI* body mass index

There were several limitations in this study. First, we included only patients with prior anterior MI. It remains unclear whether our findings can be applied to patients with prior inferior MI. Further studies should be performed to clarify the association between frontal QRS-T angle and MI location. Second, generally, women have a smaller QRS-T angle than men [1]. We could not evaluate QRS-T angle separately by gender because of small sample size. Finally, redistribution images were obtained 4 h after the stress test. Twenty-four hour late images enhance the detection myocardial viability after MI [9].

In conclusion, our results suggest that the extent of myocardial perfusion defect is an independent determinant of frontal QRS-T angle in patients with prior anterior MI.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Oehler A, Feldman T, Henrikson CA, Tereshchenko LG (2014) QRS-T angle: a review. Ann Noninvasive Electrocardiol 19:534–542
2. Aro AL, Huikuri HV, Tikkanen JT, Junttila MJ, Rissanen HA, Reunanen A, Anttonen O (2012) QRS-T angle as a predictor of sudden cardiac death in a middle-aged general population. Europace 14:872–876
3. May O, Graversen CB, Johansen MØ, Arildsen H (2017) A large frontal QRS-T angle is a strong predictor of the long-term risk of myocardial infarction and all-cause mortality in the diabetic population. J Diabetes Complicat 31:551–555
4. Gotsman I, Keren A, Hellman Y, Banker J, Lotan C, Zwas DR (2013) Usefulness of electrocardiographic frontal QRS-T angle to predict increased morbidity and mortality in patients with chronic heart failure. Am J Cardiol 111:1452–1459
5. Lown MT, Munyombwe T, Harrison W, West RM, Hall CA, Morrell C, Jackson BM, Sapsford RJ, Kilcullen N, Pepper CB, Batin PD, Hall AS, Gale CP, Evaluation of Methods and Management of Acute Coronary Events (EMMACE) Investigators (2012) Association of frontal QRS-T angle-age risk score on admission electrocardiogram with mortality in patients admitted with an acute coronary syndrome. Am J Cardiol 109:307–313
6. Germano G, Kavanagh PB, Slomka PJ, Van Kriekinge SD, Pollard G, Berman DS (2007) Quantitation in gated perfusion SPECT imaging: the Cedars-Sinai approach. J Nucl Cardiol 14:433–454
7. Kurisu S, Shimonaga T, Ikenaga H, Watanabe N, Higaki T, Ishibashi K, Dohi Y, Fukuda Y, Kihara Y (2017) Selvester QRS score and total perfusion deficit calculated by quantitative gated single-photon emission computed tomography in patients with prior anterior myocardial infarction in the coronary intervention era. Heart Vessels 32:369–375
8. Kurisu S, Nitta K, Sumimoto Y, Ikenaga H, Ishibashi K, Fukuda Y, Kihara Y (2018) Effects of aortic tortuosity on left ventricular diastolic parameters derived from gated myocardial perfusion single photon emission computed tomography in patients with normal myocardial perfusion. Heart Vessels 33:651–656
9. Pavri BB, Hillis MB, Subacius H, Brumberg GE, Schaechter A, Levine JH, Kadish A, Defibrillators in Nonischemic Cardiomyopathy Treatment Evaluation (DEFINITE) Investigators (2008) Prognostic value and temporal behavior of the planar QRS-T angle in patients with nonischemic cardiomyopathy. Circulation 117:3181–3186
10. Padala SK, Ghatak A, Padala S, Katten DM, Polk DM, Heller GV (2014) Cardiovascular risk stratification in diabetic patients following stress single-photon emission-computed tomography myocardial perfusion imaging: the impact of achieved exercise level. J Nucl Cardiol 21:1132–1143
11. Kasama S, Toyama T, Sato M, Sano H, Ueda T, Sasaki T, Nakahara T, Higuchi T, Tsushima Y, Kurabayashi M (2016) Prognostic value of myocardial perfusion single photon emission computed tomography for major adverse cardiac cerebrovascular and renal events in patients with chronic kidney disease: results from first year of follow-up of the Gunma-CKD SPECT multicenter study. Eur J Nucl Med Mol Imaging 43:302–311
12. Huikuri HV, Castellanos A, Myerburg RJ (2001) Sudden death due to cardiac arrhythmias. N Engl J Med 345:1473–1482
13. Zeidan-Shwiri T, Yang Y, Lashevsky I, Kadmon E, Kagal D, Dick A, Laish Farkash A, Paul G, Gao D, Shurrab M, Newman D, Wright G, Crystal E (2015) Magnetic resonance estimates of the extent and heterogeneity of scar tissue in ICD patients with ischemic cardiomyopathy predict ventricular arrhythmia. Heart Rhythm 12:802–808
14. Scott PA, Rosengarten JA, Murday DC, Peebles CR, Harden SP, Curzen NP, Morgan JM (2013) Left ventricular scar burden specifies the potential for ventricular arrhythmogenesis: an LGE-CMR study. J Cardiovasc Electrophysiol 24:430–436
15. He YM, Yang XJ, Wu YW, Zhang B (2009) Twenty-four-hour thallium-201 imaging enhances the detection of myocardial ischemia and viability after myocardial infarction: a comparison study with echocardiography follow-up. Clin Nucl Med 34:65–69