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ORIGINAL ARTICLE

Effects of deep inspiration on QRS axis, T-wave axis and frontal QRS-T angle in the routine electrocardiogram

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Abstract
The frontal QRS-T angle on the electrocardiogram has been described as a variable of ventricular repolarization. We evaluated how deep inspiration affected QRS axis, T-wave axis and frontal QRS-T angle. We also assessed the effects on left ventricular volume on the association using myocardial perfusion SPECT. Fifty patients undergoing ECGs both in resting state and in deep inspiration and subsequent SPECT were enrolled. Frontal QRS-T angle was defined as the absolute value of the difference between the frontal QRS axis and T-wave axis. Change in frontal QRS-T angle was calculated using (QRS-T angle in deep inspiration−QRS-T angle in resting state). In resting state, QRS axis and T-wave axis were 20.9° ± 30.0° and 40.9° ± 36.1°, respectively. Frontal QRS-T angle was 35.9° ± 36.1°. Deep inspiration caused rightward shifts of QRS axis (42.3° ± 29.5°, $p < 0.001$) and T-wave axis (49.5° ± 39.7°, $p < 0.001$). However, deep inspiration did not affect frontal QRS-T angle (33.9° ± 35.8°, $p = 0.44$). Frontal QRS-T angle in deep inspiration had good correlation ($r = 0.87$, $p < 0.001$) and agreement with that in resting state. Left ventricular (LV) end-diastolic volume had a significant association with change in frontal QRS-T angle ($r = 0.29$, $p = 0.04$). Our data suggest that frontal QRS-T angle in deep inspiration has a good correlation with that in resting state, and the agreement is acceptable. In patients with dilated LV, QRS-T angle in deep inspiration may be susceptible to the overestimation.

Keywords Electrocardiogram · Breathing · Ventricular repolarization

Introduction

The frontal QRS axis and T-wave axis are routinely reported on most current electrocardiogram (ECG) machines. The frontal QRS-T angle, defined as the absolute value of the difference between QRS axis and T-wave axis, has been described as a variable of ventricular repolarization [1–7]. Many studies have shown the usefulness of frontal QRS-T angle in predicting mortality [1–6] or ventricular arrhythmias [7].

When ECG is recorded in daily practice, patients are usually instructed to breathe normally or to hold their breath for a moment. A few reports have suggested the potential effects of breathing on ECG findings such as QRS amplitude or QRS axis [8, 9], but this issue is commonly neglected in daily practice. Because applications of frontal QRS-T angle are recently discussed [1–7], it is clinically important to clarify the effects of breathing on frontal QRS-T angle. In the present study, we evaluated how deep inspiration affected QRS axis, T-wave axis and frontal QRS-T angle in the routine ECG. We also assessed the effects on left ventricular (LV) volume on the association using myocardial perfusion single-photon emission computed tomography (SPECT) [10, 11].

Methods

Patients

Between July 2018 and September 2018, 86 patients underwent ECG and subsequent myocardial perfusion SPECT for evaluating myocardial ischemia. Patients with atrial

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fibrillation, bundle branch block or ventricular pacing were excluded. Finally, 50 patients undergoing ECGs both in resting state and in deep inspiration were enrolled in this study. This study was approved by the Ethical Committee of Faculty of Medicine, Hiroshima University, and conducted in compliance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all patients included in the study.

QRS axis, T-wave axis and QRS-T angle

A standard 12-lead ECG was recorded at a paper speed of 25 mm/s and an amplification of 10 mm/mV in a supine position. QRS axis and T-wave axis were automatically measured. According to previous reports [1–7, 12], frontal QRS-T angle was defined as the absolute value of the difference between the frontal QRS axis and T-wave axis. When frontal QRS-T angle was more than 180°, it was adjusted to the minimal angle using (360°−angle).

Breathing during ECGs

In each patient, two ECGs were obtained: (1) resting state, in which the patient was instructed to exhale normally and hold his breath for 5 s; (2) deep inspiration, in which the patient was instructed to take a deep breath and hold for 5 s. In each ECG, frontal QRS-T angle was measured. Change in frontal QRS-T angle was calculated using (QRS-T angle in deep inspiration−QRS-T angle in resting state).

Myocardial perfusion SPECT

All patients fasted overnight and underwent myocardial perfusion SPECT synchronized with ECG [10, 11]. Adenosine 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 Healthcare, Milpitas, CA, USA). 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

LV end-diastolic volume (LVEDV) and ejection fraction (LVEF) were obtained from redistribution images using quantitative gated SPECT (QGS) (Cedars-Sinai Medical Center, USA) [10, 11, 13].

Statistical analysis

Continuous variables are shown as mean ± SD, and categorical variables are shown as frequencies and percentages. Continuous variables in resting state and deep inspiration were compared by Wilcoxon test. Correlations between frontal QRS-T angle and clinical variables were assessed by Pearson's correlation test. The agreement between resting state and deep inspiration was assessed by Bland–Altman plot showing the difference and the limits of agreement. 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. There were 37 male and 13 female patients with a mean age of 68 years. Six patients (12%) had previous myocardial infarction, and two patients had been undergoing hemodialysis. LVEDV was 68 ± 19 ml and LVEF was 61 ± 10%.

Effects of deep inspiration on frontal QRS-T angle

QRS axis, T-wave axis and frontal QRS-T angle are shown in Fig. 1. In resting state, QRS axis and T-wave axis were 20.9° ± 30.0° and 40.9° ± 36.1°, respectively. Consequently, frontal QRS-T angle was 35.9° ± 36.1°.

Table 1 Patient characteristics

Number of patients	50
Age (years)	68 ± 10
Female	13 (26%)
Body mass index (kg/m^2)	25 ± 3
Hypertension	18 (36%)
Diabetes	9 (18%)
Previous myocardial infarction	6 (12%)
Hemodialysis	2 (4%)
Left ventricular end-diastolic volume (ml)	68 ± 19
Left ventricular ejection fraction (%)	61 ± 10

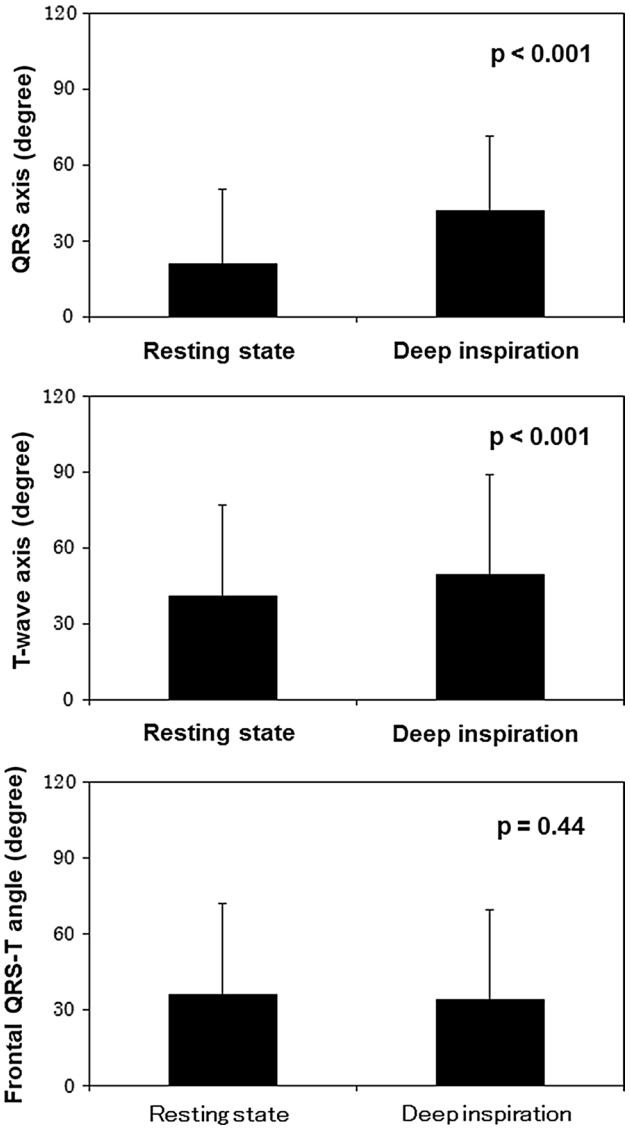

Fig. 1 QRS axis (upper panel), T-wave axis (middle panel) and frontal QRS-T angle (lower panel) in resting state and deep inspiration

Deep inspiration caused rightward shifts of QRS axis (42.3° ± 29.5°, $p < 0.001$) and T-wave axis (49.5° ± 39.7°, $p < 0.001$). However, deep inspiration did not affect frontal QRS-T angle (33.9° ± 35.8°, $p = 0.44$).

Frontal QRS-T angle in deep inspiration was correlated well with that in resting state ($r = 0.87$, $p < 0.001$) (Fig. 2, left panel). Bland–Altman plot showed a good agreement between the two states (Fig. 2, right panel).

LVEDV ($r = 0.29$, $p = 0.04$) had a significant association with change in frontal QRS-T angle, but age ($r = -0.19$, $p = 0.19$), body mass index ($r = 0.16$, $p = 0.27$) or LVEF ($r = -0.07$, $p = 0.61$) did not (Table 2).

Discussion

In the present study, we showed the following: (1) Deep inspiration caused rightward shifts of QRS axis and T-wave axis, but did not affect frontal QRS-T angle; (2) frontal QRS-T angle in deep inspiration had good correlation and agreement with that in resting state; and (3) LVEDV had a significant association with change in frontal QRS-T angle.

ECG is still a routine cardiac examination in clinical practice because of its established value, broad availability and low cost. Frontal QRS-T angle is a simple variable derived from QRS axis and T-wave axis [1–7, 12], and it becomes wide based on an imbalance of electrical activation and recovery of the ventricles. Many studies have reported the usefulness of QRS-T angle in predicting total mortality [1–6] or ventricular arrhythmias [7]. However, the potential effects of breathing on QRS-T angle have received little attention.

Breathing has some possible effects on ECG findings through change in anatomical orientation of the heart, displacement of the precordial electrodes relative to the heart, and change in electrical conductance properties of the thorax [8, 9]. Changes in frontal ECG axes are primarily attributable to change in anatomical orientation of the heart. Indeed, Foster et al. previously showed no significant change in LV long-axis orientation due to breathing using cardiac magnetic resonance imaging, suggesting that change in position occurred predominantly rather than change in orientation of the heart [14]. However, their patients were never instructed to take deep inspiration. Deep inspiration should cause changes in both position and orientation of the heart through a downward shift of the diaphragm. These anatomical changes can contribute to the changes in frontal ECG axes. In the present study, we found that deep inspiration caused a rightward shift of QRS axis, which was consistent with the results of a previous study [9]. We further found that deep inspiration caused a rightward shift of T-wave axis and QRS-T angle was comparable between resting state and deep inspiration. Frontal QRS-T angle in deep inspiration had a good correlation with that in resting state, and the agreement was acceptable. Our results suggested that breathing did not really matter when assessing frontal QRS-T angle in the routine ECG.

In the present study, we found that LVEDV was a variable having a positive association with change in frontal QRS-T angle between resting state and deep inspiration. This indicates that, especially in patients with dilated LV, QRS-T angle in deep inspiration is susceptible to the overestimation. To clarify its mechanism, it should be further evaluated whether the change in orientation of the heart associated with deep inspiration is larger in patients with dilated LV using cardiac magnetic resonance imaging.

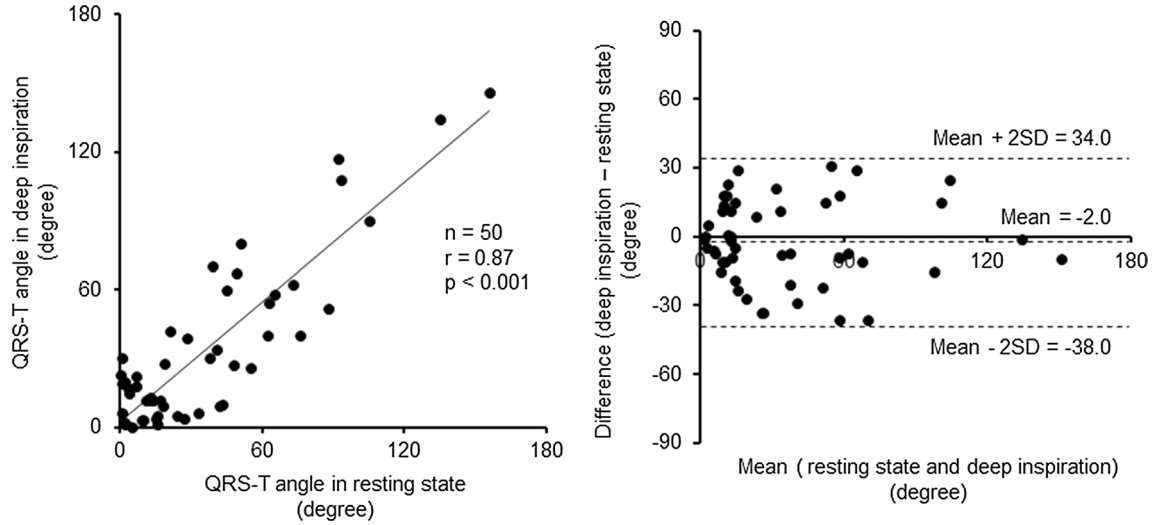

Fig. 2 Correlation and agreement of QRS-T angles obtained in resting state and deep inspiration

Table 2 Factors associated with change in frontal QRS-T angle

Variables	Univariate		Multivariate	
	β	*p* value	*β*	*p* value
Age	−0.19	0.19	−0.08	0.59
Female	−0.08	0.57		
Body mass index	0.16	0.27	0.10	0.47
Previous myocardial infarction	−0.29	0.04	−0.35	0.01
Hypertension	0.11	0.44		
Diabetes mellitus	−0.16	0.27		
Frontal QRS angle in resting state	−0.27	0.06	−0.19	0.16
Left ventricular end-diastolic volume	0.29	0.04	0.32	0.03
Left ventricular ejection fraction	0.07	0.61		

There were several limitations in this study. First, routine echocardiography was not performed in this population. We could not evaluate the effects of LV hypertrophy on change in frontal QRS-T angle between resting state and deep inspiration. Second, we did not assess changes in position and orientation of the heart induced by deep inspiration. It remains unclear how changes in frontal ECG axes are associated with change in anatomical orientation of the heart. Finally, small sample size was a major limitation of this study.

In conclusion, our data suggest that frontal QRS-T angle in deep inspiration has a good correlation with that in resting state, and the agreement is acceptable. In patients with dilated LV, QRS-T angle in deep inspiration may be susceptible to the overestimation.

Compliance with ethical standards

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

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