The relationship between J wave and ventricular tachycardia during Takotsubo cardiomyopathy

Seong Huan Choi†, Oh-Hyun Lee†, Gwang-Seok Yoon, Sung Woo Kwon, Sung-Hee Shin, Sang-Don Park, Seong-Ill Woo, Jun Kwan, Dae-Hyeok Kim*† and Yong-Soo Baek*†

Abstract

Background and objectives: Takotsubo cardiomyopathy (TTC) occasionally causes life-threatening ventricular arrhythmia. J wave on surface electrocardiography (sECG) has also been associated with idiopathic ventricular fibrillation and cardiac events; therefore, we investigated whether the presence of J wave on sECG is a potential risk factor for ventricular arrhythmia in patients with TTC.

Subjects and methods: We performed a retrospective study in 79 patients who were diagnosed with TTC from 2010 to 2014. Among them, 20 (25.3%) were diagnosed with ventricular tachycardia (VT). The J wave on the sECG was defined as J point elevation manifested through QRS notching or slurring at least 1 mm above the baseline in at least two leads.

Results: A higher prevalence of ventricular tachycardia was observed in patients with J wave. The corrected QT interval (QTc) was significantly longer in the VT group than in the non-VT group. In a multivariate analysis, the presence of J wave appeared to be the only independent predictors of VT [Hazard Ratio (HR) 3.5, \( p = 0.019 \)].

Conclusion: Our results suggest that the presence of J wave on the sECG is significantly associated with VT, and appear to indicate that the presence of J wave is a strong and independent predictor of VT in patients with TTC.

Keywords: J wave, Ventricular tachycardia, Takotsubo cardiomyopathy

Introduction

Takotsubo cardiomyopathy (TTC) or apical ballooning syndrome is a form of reversible cardiomyopathy mimicking the symptomatology and electrocardiographic findings of acute myocardial infarction (AMI) without significant coronary artery disease on angiography [1]. Furthermore, life-threatening ventricular tachyarrhythmias caused by repolarization abnormalities and QTc prolongation, including torsades de pointes (TdP), may be seen in up to 8% of TTC patients [2]. The J point and ST-segment elevation which sometimes manifests as a notch or slur of the QRS (J wave) is the characteristic ECG pattern of early repolarization (ER). Moreover, recent studies have demonstrated that J wave on the sECG is associated with ventricular tachycardia (VT) and fibrillation (VF) in an experimental model consisting of canine ventricular wedge preparations [3]. This concept has now expanded to include other structural heart diseases such as AMI, variant angina, and even some forms of cardiomyopathy [4]. In spite of the increasing importance of J wave, its significance in TTC patients with ventricular arrhythmia is...
unknown. In this study, we aimed to investigate whether
the presence of J wave on the sECG is a potential risk fac-
tor for ventricular arrhythmia in patients with TTC.

Subjects and methods
Patient selection and data collection
We performed a retrospective single-center study which
included 79 patients (mean age = 66.4 ± 15.3 years,
38 males) who were diagnosed with TTC from 2010
to 2014. We collected data from consecutive patients
who were classified into two groups based on the pre-
ence or absence of ventricular tachycardia (VT group:
n = 20 [25.3%], non-VT group: n = 59 [74.6%]). VT group
patients were admitted to intensive care unit (ICU);
therefore, continuous ECG monitoring was used to
detect any arrhythmia. The diagnosis of TTC was made
according to the Mayo Clinic criteria [5]. Clinical and
echocardiographic parameters; precipitating factors and
subtypes of TTC; peak cardiac enzyme and electrolyte
levels were examined. The inclusion criteria for TTC in
our study were (1) transthoracic echocardiogram con-
sistent with ABS/TTC (transient hypokinesis, akinesis
or dyskinesis of the left ventricular mid-segments with
or without apical involvement; the regional wall motion
abnormality extend beyond a single epicardial vascular
distribution), and (2) new ECG abnormality (either ST-
segment elevation and/or T-wave inversion) or modest
elevation in cardiac troponin. Exclusion criteria were (1)
transechocardiogram consistent with ischemic cardio-
myopathy or dilated cardiomyopathy and (2) presence
of obstructive coronary disease or angiographic evidence
of acute coronary syndrome [5]. This study was approved
by the Institutional Review Board at Inha University Hos-
pany, which waived the requirement of obtaining written
informed consent from patients.

ECG analysis
All ECGs obtained during hospitalization were reviewed
and analyzed by three independent investigators, who
had expertise in cardiology, to confirm the correct J wave
pattern. Presence of J wave was confirmed only if the
three reviewer’s observations were coherent. Twelve-lead
ECGs were downloaded from the GE Marquette MUSE
system (GE Medical Systems, Milwaukee, WI, USA) and
analyzed digitally (Adobe Acrobat X professional; Adobe
systems Incorporated, San Jose, CA, USA). J wave was
defined as an elevation of QRS-ST junction (J point) in
at least two leads on a resting 12-lead ECG, as described
previously [6]. The amplitude of J point elevation had to
be at least 1 mm (0.1 mV) above the isoelectric line, either
as QRS slurring (smooth transition from the QRS seg-
ment to the ST segment), or notching (positive J deflec-
tion inscribed on the S wave) in at least two consecutive
inferior leads (II, III, and aVF), lateral leads (I, aVL, and
V4–V6), or both. We included patients with Brugada pat-
ttern showing J wave in the anterior precordial leads (V1–
V3) on the ECG, and measured the amplitude of J wave
at the peak of the positive deflection, and at the QRS-ST
junction in cases in which notched and slurred ECG pat-
tern was observed, respectively.

Statistical analysis
Statistical analyses were performed using the SPSS statis-
tical software (SPSS version 21.0 for Windows, SPSS Inc.,
Chicago, IL, USA). Continuous variables were expressed
as mean ± SD and compared using the Student t test or
Mann–Whitney U test, as appropriate. Categorical vari-
ables were expressed as percentages and compared using
Chi-square or Fisher’s exact tests, as appropriate. Uni-
variate and multivariate Cox regression analyses were
performed to identify a subset of predictor variables for
VT. Results showing a p value < 0.05 (2-tailed) were con-
sidered statistically significant.

Results
Baseline characteristics
Table 1 shows the baseline characteristics of the study
population. Among the 20 patients in the VT group,
13 and 7 were male and female, respectively. The mean
age in the VT group was 69 ± 13.8 years. The non-VT
group consisted of 59 patients and included 24 males
and 35 females. The mean age of the non-VT group was
66 ± 15.8 years and was not statistically different from
that of the VT group (p = 0.55).

With the exception of cardiogenic shock, two groups
did not statistically differ in terms of clinical presenta-
tion. Cardiogenic shock was significantly more common
in the VT group (n = 9, 45%) than in the non-VT group
(n = 12, 20%) (p = 0.028). VT group had higher mortal-
ity rate compared to non-VT group (40.2% vs. 13.3%, HR
3.7, 95% CI, 1.4–9.9, p = 0.009). No statistical differences
were observed between the two groups in terms of risk
factors for cardiac disease, including diabetes mellitus,
hypertension, smoking, and low-density lipoprotein cho-
lesterol (LDL-C) level; or in terms of precipitating factors
of TTC, including emotional triggers and physical trig-
gers such as asthma attack, ischemic stroke, bleeding,
sepsis, surgical procedures, malignancy, and acute kidney
injury [7].

Laboratory, ECG, and echocardiographic findings
Table 2 shows ECG and laboratory findings in the study
population. The QTc interval was significantly longer in
the VT group (577.0 ± 58.5 ms) than in the non-VT group
(534.2 ± 61.1 ms) (p = 0.01). No statistical difference in
electrolyte levels; cardiac enzymes; and prevalence of atrial
arrhythmia, bradycardia, and other electrocardiographic changes; including ST-segment elevation, T wave inversion, and q wave, were observed between two groups. Similarly, echocardiographic findings and phenotypes between the VT and non-VT group were not significantly different between the groups (Table 3).

Patients with J wave had a significantly higher prevalence of ventricular tachycardia (53% vs. 8%, p < 0.001) and polymorphic VT or TdP (n = 11, 36%) than those without J wave (n = 3, 6%) (p = 0.001). However, the prevalence of monomorphic VT did not statistically differ between the groups (p = 0.19).

### Table 1 Baseline characteristics of patients in the VT group and Non-VT group

|                         | Total (n = 79) | VT group (n = 20) | Non-VT group (n = 59) | P value |
|-------------------------|---------------|------------------|----------------------|---------|
| Age, years              | 66.4 ± 15.3   | 68.6 ± 13.8      | 65.6 ± 15.7          | 0.55    |
| Male gender, n (%)      | 37 (47)       | 13 (65)          | 24 (41)              | 0.07    |
| Body surface area, m²   | 1.5 ± 0.1     | 1.6 ± 0.1        | 1.5 ± 0.1            | 0.58    |
| **Cardiac risk factor** |               |                  |                      |         |
| Diabetes, n (%)         | 19 (25)       | 5 (25)           | 14 (25)              | 1.00    |
| Hypertension, n (%)     | 40 (50)       | 8 (40)           | 32 (53)              | 0.30    |
| Smoker, n (%)           | 20 (25)       | 5 (25)           | 15 (25)              | 1.00    |
| LDL-C, mg/dL            | 83.2 ± 41.9   | 86.0 ± 43.7      | 75.7 ± 37.8          | 0.42    |
| **Trigger**             |               |                  |                      |         |
| Physical triggers       |               |                  |                      |         |
| Asthma attack, n (%)    | 3 (4)         | 1 (5)            | 2 (3)                | 0.73    |
| Ischemic stroke, n (%)  | 3 (4)         | 0 (0)            | 3 (5)                | 0.31    |
| Bleeding, n (%)         | 4 (5)         | 2 (10)           | 2 (3)                | 0.24    |
| Sepsis, n (%)           | 50 (64)       | 13 (65)          | 37 (63)              | 0.89    |
| Surgical procedures, n (%) | 3 (4) | 2 (10)          | 1 (2)                | 0.09    |
| Malignancy, n (%)       | 2 (3)         | 1 (5)            | 1 (2)                | 0.41    |
| AKI, n (%)              | 6 (8)         | 0 (0)            | 6 (10)               | 0.14    |
| Emotional triggers      |               |                  |                      |         |
| Depression, n (%)       | 1 (1)         | 0 (0)            | 1 (2)                | 0.56    |
| Anxiety, n (%)          | 2 (3)         | 0 (0)            | 2 (3)                | 0.41    |
| Suicide attempt, n (%)  | 1 (1)         | 1 (5)            | 0 (0)                | 0.08    |
| Idiopathic, n (%)       | 4 (5)         | 0 (0)            | 4 (7)                | 0.24    |
| **Clinical presentation** |            |                  |                      |         |
| Chest pain, n (%)       | 22 (27)       | 4 (20)           | 18 (30)              | 0.76    |
| Dyspnea, n (%)          | 34 (42)       | 6 (30)           | 28 (46)              | 0.57    |
| Nausea/vomiting, n (%)  | 4 (5)         | 1 (5)            | 3 (5)                | 1.00    |
| Palpitations, n (%)     | 5 (6)         | 2 (10)           | 3 (5)                | 0.27    |
| Loss of consciousness, n (%) | 5 (6) | 4 (20)          | 1 (1)                | 0.06    |
| Cardiogenic shock, n (%) | 21 (26) | 9 (45)         | 12 (20)              | 0.028   |
| Pulmonary edema, n (%)  | 52 (65)       | 15 (75)          | 37 (61)              | 0.59    |

Values are mean ± SD or number (%); VT ventricular tachycardia; CRF chronic renal failure; LDL-C low-density lipoprotein cholesterol; others idiopathic; P value by Student t-Test and Mann–Whitney U test

### Detailed characteristics of the J wave for the prediction of VT

Figure 1 shows baseline ECGs of patients with TTC. Figures 1a, 2a show a notched J wave (arrows) in inferior leads (II, III, aVF) in patients who had an event of monomorphic (Fig. 1b) or polymorphic VT (Fig. 2b). Table 4 shows that the prevalence of J wave was significantly higher in the VT group (n = 15, 75%) than in the non-VT group (n = 14, 25%) (p = 0.001). Moreover, the prevalence of J wave with a notched pattern was significantly higher in the VT group than in the non-VT (n = 13, 65% vs. n = 13, 21%; p = 0.001). In addition, a J
wave in the inferior leads or a J point elevation ≥ 0.2 mV were significantly more common in the VT group (n = 9, 45% vs. n = 12, 20%; p = 0.04, n = 9, 45% vs. n = 2, 3%; p = 0.001, respectively). Similarly, J wave in the inferolateral leads with a J point elevation ≥ 0.2 mV was also significantly higher in the VT group (n = 8, 40% vs. n = 2, 3%; p < 0.001). Likewise, the prevalence of horizontal/descending ST segment after the J point was significantly higher in the VT group (n = 13, 65% vs. n = 11, 18%). However, no significant difference in the prevalence of ascending ST segment after the J wave was observed between the two groups.

Univariate Cox regression analysis demonstrated that QTc duration and presence of J wave were significantly associated with the occurrence of VT (HR 1.0; p = 0.002, HR 5.2; p = 0.002, respectively). Multivariate Cox regression analysis showed that the presence of J

Table 2 ECG and laboratory findings in the VT and Non-VT group

| Electrocardiographic changes                  | Total (n = 79) | VT group (n = 20) | Non-VT group (n = 59) | P value |
|-----------------------------------------------|----------------|-------------------|-----------------------|---------|
| Atrial arrhythmia, n (%)                      | 26 (33)        | 12 (60)           | 14 (25)               | 0.003   |
| AV block, n (%)                               | 2 (2)          | 0 (0)             | 2 (3)                 | 1.000   |
| ST-segment elevation, n (%)                   | 36 (45)        | 9 (45)            | 27 (45)               | 1.000   |
| T-wave inversion, n (%)                       | 55 (68)        | 16 (80)           | 39 (65)               | 0.27    |
| Q wave, n (%)                                 | 18 (22)        | 4 (20)            | 14 (23)               | 0.51    |
| QTc interval, ms                              | 545.2 ± 63.6   | 577.0 ± 58.5      | 534.2 ± 61.1          | 0.01    |

| Laboratory findings                           |                |                   |                       |         |
| Sodium, mmol/L                                | 139.1 ± 4.9    | 139.6 ± 5.9       | 138.9 ± 4.6           | 0.59    |
| Potassium, mmol/L                             | 4.1 ± 0.7      | 3.9 ± 0.8         | 4.1 ± 0.7             | 0.64    |
| Ionized calcium, mg/dL                        | 0.96 ± 0.1     | 0.95 ± 0.1        | 0.97 ± 0.1            | 0.51    |
| Magnesium, mg/dL                              | 2.1 ± 0.4      | 2.1 ± 0.4         | 2.2 ± 0.4             | 0.16    |

| Cardiac enzymes                               |                |                   |                       |         |
| Peak CK, ng/mL                                | 827.2 ± 1409.9 | 1008.5 ± 1634.4   | 766.7 ± 1336.7        | 0.51    |
| Peak CK-MB, ng/mL                             | 30.7 ± 46.9    | 49.1 ± 69.7       | 24.7 ± 35.1           | 0.15    |
| Peak troponin-I, ng/mL                        | 9.8 ± 20.6     | 16.5 ± 34.1       | 7.7 ± 13.3            | 0.28    |
| NT-proBNP, pg/mL                              | 12900.2 ± 13370.2 | 14179.8 ± 13207.2 | 12293.6 ± 13499.0    | 0.28    |

| Table 3 TTE findings in the VT group and Non-VT group |

| Phenotype                                      | Total (n = 79) | VT group (n = 20) | Non-VT group (n = 59) | P value |
|------------------------------------------------|----------------|-------------------|-----------------------|---------|
| Classic TTC pattern, n (%)                     | 45 (56)        | 12 (60)           | 33 (55)               | 0.81    |
| Apical sparing TTC pattern, n (%)              | 12 (16)        | 5 (25)            | 7 (13)                | 0.29    |
| Isolated basal LV dysfunction, n (%)           | 0 (0)          | 0 (0)             | 0 (0)                 | 0.01    |
| Global LV hypokinesis                          | 8 (10)         | 0 (0)             | 8 (13)                | 0.19    |
| Others                                         | 14 (17)        | 3 (15)            | 11 (18)               | 0.73    |

| Echocardiographic parameters                   |                |                   |                       |         |
| LVEF (%)                                       | 35.0 ± 7.6     | 35.7 ± 10.3       | 34.8 ± 6.6            | 0.67    |
| LVDD (mm)                                      | 48.9 ± 5.4     | 47.1 ± 6.4        | 49.5 ± 5.1            | 0.13    |
| LVESD (mm)                                     | 37.6 ± 7.4     | 35.4 ± 6.9        | 38.3 ± 7.5            | 0.17    |
| LAD (mm)                                       | 41.7 ± 7.3     | 41.1 ± 6.9        | 41.9 ± 7.5            | 0.72    |
| E/E'                                           | 14.2 ± 7.5     | 12.3 ± 3.3        | 14.6 ± 8.1            | 0.31    |

Values are mean ± SD or number (%); VT ventricular tachycardia; Atrial arrhythmia: PSVT, atrial tachycardia, atrial fibrillation; CK creatine kinase; CK-MB creatine kinase-myocardial band; NT-proBNP N-terminal pro-brain natriuretic peptide

Values are mean ± SD or number (%); TTE transthoracic echocardiography; VT ventricular tachycardia; TTC Takotsubo cardiomyopathy; LVEF left ventricular ejection fraction; LVDD left ventricular end-diastolic diameter; LVESD left ventricular end-systolic diameter; LAD left atrial diameter; E/E' early diastolic mitral inflow velocity/early diastolic tissue Doppler velocity
wave was significantly associated with the occurrence of VT (HR 3.5; \( p = 0.019 \)) (Table 5).

**Discussion**

The existence of J wave on sECG is considered a benign finding observed in approximately 2–10% of the general population [8]. However, following the findings reported by Haissaguerre et al. [9] and Nam et al. [10] the J wave syndrome has emerged as a significant cause of idiopathic ventricular fibrillation. The concept has now expanded to include other structural heart disease such as acute myocardial infarction, variant angina and even some forms of cardiomyopathy, such as arrhythmogenic right ventricular dysplasia/cardiomyopathy and noncompaction cardiomyopathy. In addition, two important J wave syndromes, the ER and Brugada syndromes (BS) are also considered to be of clinical importance.

J wave on the sECG is believed to originate from the generation of a transmural voltage gradient between the endocardium and epicardium during repolarization or depolarization, due to decreased inward sodium or calcium channel currents, or an increase in outward potassium currents mediated through the \( I_{\text{to}} \), \( I_{\text{K-ATP}} \), and \( I_{\text{K-Ach}} \) channels. These outward current shifts and heterogeneous loss of the action potential (AP) dome result in a marked dispersion of repolarization, which is followed by phase 2 reentry and gives rise to polymorphic VT or VF. Transient ischemia, caused by multivessel coronary spasm or neurological stress, [11] has been suggested as an additional mechanism triggering J wave and VT.

Masato et al. [12], reported a prevalence of J wave of approximately 30% (9 of 30 patients), and of VT/VF in the J wave and non-J wave group of approximately 22% (2 of 9 patients) and 9% (2 of 22 patents), respectively, in patients with TTC. Similarly, in our study, we found...
J wave prevalence of 37.5% (30 of 80 patients), and VT prevalence of 53% (15 of 30 patients) and 8% (5 of 50 patients) in the J wave and non-J wave group, respectively.

Samuelov-Kinori et al. [13] reported longer QTc intervals in patients with TTC who developed TdP. The mechanisms of QT prolongation in TTC appear to be similar to those of AMI resulting from autonomic dysregulation [14], and the intracardial gradient (apicobasal) of myocardial edema leads to transient inhomogeneity and gives rise to regional dispersion of AP duration [15]. These mechanisms may explain the prolonged QT interval in TTC, and the even longer QT interval seen in the VT and J wave groups, compared with that in the non-VT and non-J wave groups. Results from univariate and multivariate logistic analyses also showed that a prolonged QT interval appears to be an independent risk factor for VT. Multivariate logistic analyses also indicated that male sex is a risk factor for VT, in agreement with previous studies suggesting that male sex is strongly associated with the ER pattern observed on the ECG [16].

A relationship between the magnitude of the J point elevation and a higher occurrence of VF episodes has been previously reported [9]. Antzelevitch et al. [17] classified the ER pattern into three subtypes to estimate the risk for the development of malignant arrhythmia, according to the ECG leads in which the ER pattern appears. An ER pattern in the lateral leads; inferior or inferolateral leads; and globally, in the inferior, lateral and right precordial leads, is associated with a low, moderate, and high risk, respectively. However, Tikkanen et al. [18] proposed another classification based on the shape of the ST segment after the J wave, with a rapidly ascending ST, and a horizontal or descending ST segment being considered benign and malignant forms. Likewise, we found that the prevalence of J wave with an amplitude $\geq 0.2$ mV, seen in the inferior leads, or in the inferolateral leads with a J point elevation $\geq 0.2$ mV as well as horizontal/ descending ST segments seen after the J point, was significantly higher in the VT group than in the non-VT group.

Our results suggest that the presence of a J wave on the sECG is significantly associated with the occurrence

### Table 4 QTc interval and characteristics of the J wave between VT and Non-VT group

| Presence of J wave, No (%) | Total (n = 79) | VT group (n = 20) | Non-VT group (n = 59) | P value |
|----------------------------|---------------|------------------|----------------------|---------|
| Slur-Notch, No (%)         | 30 (37)       | 15 (75)          | 15 (25)              | 0.001   |
| Slur                       | 4 (5)         | 2 (10)           | 2 (3)                | 0.57    |
| Notch                      | 26 (32)       | 13 (65)          | 13 (21)              | 0.001   |
| Inferior                   | 21 (26)       | 9 (45)           | 12 (20)              | 0.04    |
| Inferolateral (both)*      | 3 (3)         | 2 (10)           | 1 (1)                | 0.15    |
| Magnitude of J wave, No (%)| 11 (13)       | 9 (45)           | 2 (3)                | 0.001   |
| J point elevation ≥ 0.2 mV & inferolateral leads location† | 10 (12) | 8 (40) | 2 (3) | <0.001 |
| J point with ST segment, No (%) | 6 (7) | 2 (10) | 4 (6) | 0.64 |
| Ascending                  | 24 (30)       | 13 (65)          | 11 (18)              | <0.001  |

Values are mean ± SD or number (%); VT ventricular tachycardia; Inferolateral* J wave in at least two inferior leads and in two lateral leads; Inferolateral location† J wave in at least two inferior leads or in two lateral leads, or both.

### Table 5 Multivariate cox analysis of known risk factors for ventricular tachycardia

| Variables                  | HR   | 95% CI    | P value |
|----------------------------|------|-----------|---------|
| Univariate regression analysis |     |           |         |
| Age                        | 1.02 | 0.99~1.05 | 0.21    |
| Male sex                   | 1.84 | 0.73~4.63 | 0.19    |
| Hypertension               | 0.70 | 0.28~1.72 | 0.44    |
| Diabetes Mellitus          | 0.89 | 0.33~2.63 | 0.89    |
| Smoking                    | 1.20 | 0.43~3.33 | 0.72    |
| QTc duration               | 1.01 | 1.00~1.02 | 0.002   |
| Peak CK level              | 1.00 | 1.00~1.00 | 0.26    |
| LVEF                       | 0.99 | 0.94~1.06 | 0.90    |
| ST-segment elevation       | 1.06 | 0.44~2.56 | 0.99    |
| Presence of J wave         | 5.16 | 1.87~14.27| 0.002   |
| Multivariate regression analysis | |          |         |
| QTc duration               | 1.01 | 1.00~1.01 | 0.06    |
| Presence of J wave         | 3.53 | 1.23~10.17| 0.019   |

HR hazard ratio; CI confidence interval; LVEF left ventricular ejection fraction; CK creatine kinase
of polymorphic VT or TdP during TTC. Therefore, the identification of a J wave on sECG during TTC may help to distinguish patients who are susceptible to developing VT, especially in men with a prolonged QT interval, in whom close monitoring and primary prevention of VT should be considered. Additionally, evidence on the genetic basis for ER is currently limited, but recent reports suggest that mutations in candidate genes such as KCNJ8 which encode a pore-forming subunit of the ATP-sensitive potassium channel, as well as CACNA1C, CACNR2, and CACNA2D1 which encode a L-type calcium channel, and SCN5A related to I Na, may be implicated in ER pathophysiology [19–21]. Hence, further studies are needed to clarify the relationship between genetic susceptibility and VT in TTC patients with J wave on sECG.

Our study had several limitations. Firstly, this was a retrospective study, with a small sample size, and limited to a single center. Secondly, since we could not perform stress tests or cardiac magnetic resonance imaging to verify the presence of myocardial scar, which is known to have arrhythmogenic potential, it could not be objectively ruled out. Thirdly, although we monitored cardiac rhythm thoroughly in patients hospitalized in the intensive care unit, this level of monitoring could not be achieved in the general ward. Nevertheless, our results provide valuable evidence of clinical implications of J wave in predicting the development of lethal arrhythmia during TTC. Further multi-center, prospective studies in larger groups of patients, are necessary to confirm the predictive value of J wave.

Conclusion
In conclusion, our findings suggest that the presence of J wave on the sECG is significantly associated with ventricular arrhythmia during TTC, and appear to indicate that the presence of J wave is a strong and independent predictor of VT in patients with TTC.

Abbreviations
TCC: Takotsubo Cardiomyopathy; sECG: Surface Electrocardiography; VT: Ventricular Tachycardia; AMI: Acute Myocardial Infarction; TdP: Torsades de Pointes; ER: Early Repolarization; VF: Ventricular Fibrillation; BS: Brugada Syndromes; AP: Action Potential.

Acknowledgements
None.

Authors’ contributions
Choi SH, Lee OH and Baek YS involved in writing draft and analyzing data. Kim DH and Baek YS were involved in writing draft and creating concept of study. KSW, YGS, SSH, PSD, WI and KJ involved in data review and writing draft. All authors read and approved the final manuscript.

Funding
This study was supported by Korean Heart Rhythm Society (KHRS 2017-4); and the INHA UNIVERSITY Research Grant; and the INHA UNIVERSITY HOSPITAL Research Grant; and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MISP) under NRF-2014R1A5A2009392.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate
This study was approved by the Institutional Review Board at Inha University Hospital, which waived the requirement of obtaining written informed consent from patients.

Consent for publication
Not applicable.

Competing interests
The authors have declared no competing interests.

Received: 13 October 2019   Accepted: 21 May 2020
Published online: 08 June 2020

References
1. Hurst RT, Prasad A, Askew JV 3rd, Sengupta PP, Tajik AJ. Takotsubo cardiomyopathy: a unique cardiomyopathy with variable ventricular morphology. JACC Cardiovas Imaging. 2010;3:641–9.
2. Madias C, Fitzgibbons TP, Alsheikh-Ali AA, Bouchard JL, Kalsmith B, Garlitski AC, et al. Acquired long QT syndrome from stress cardiomyopathy is associated with ventricular arrhythmias and torsades de pointes. Heart Rhythm. 2011;8:555–61.
3. Koncz I, Gurabi Z, Patocsikai B, Panamak BK, Szel T, Hu D, et al. Mechanisms underlying the development of the electrocardiographic and arrhythmic manifestations of early repolarization syndrome. J Mol Cell Cardiol. 2014;68:20–8.
4. Nam GB. Idiopathic ventricular fibrillation, early repolarization and other J wave-related ventricular fibrillation syndromes: from an electrocardiographic enigma to an electrophysiological dogma. Circ J. 2012;76:2723–31.
5. Prasad A, Lerman A, Rihal CS. Apical ballooning syndrome (tako-tsubo or stress cardiomyopathy): a mimic of acute myocardial infarction. Am Heart J. 2008;155:408–17.
6. Wang J, Tang M, Mao KX, Chu JM, Hua W, Jia YH, et al. Idiopathic ventricular fibrillation with fragmented QRS-complex and J wave in resting electrocardiogram. J Gen Intern Med. 2012;27:143–7.
7. Ghadir RJ, Wittstein IS, Prasad A, et al. International expert consensus document on Takotsubo syndrome (Part I): clinical characteristics, diagnostic criteria, and pathophysiology. Eur Heart J. 2018;39(22):2032–46.
8. Sethi KK, Sethi K, Chutani SK. Early repolarisation and J wave syndromes. Indian Heart J. 2014;66:443–52.
9. Haisaguerre M, Derval N, Sacher F, Jesel L, Deisenhofer I, Roy L, et al. Sudden cardiac arrest associated with early repolarization. N Engl J Med. 2008;358:2016–23.
10. Nam GB, Kim YH, Antzelevitch C. Augmentation of J waves and electrical storms in patients with early repolarization. N Engl J Med. 2008;358:2078–9.
11. Kukla P, Jastrzebski M, Praefort W. J-wave-associated ventricular fibrillation in a patient with a subarachnoid haemorrhage. Europace. 2012;14:1063–4.
12. Shimizu M, Nishizaki M, Yamawake N, Fuji H, Sakurada H, Isobe M, et al. J wave and fragmented QRS formation during the hyperacute phase in takotsubo cardiomyopathy. Circ J. 2014;78:943–9.
13. Samuelov-Kinori L, Kinori M, Kogan Y, Swartson M, Shalev H, Guy D, et al. Takotsubo cardiomyopathy and QT interval prolongation: who are the patients at risk for torsades de pointes? J Electrocardiol. 2009;42(4):353–7.
14. Ogura R, Hiasa Y, Takahashi T, Yamaguchi K, Fujikawa K, Ohara Y, et al. Specific findings of the standard 12-lead ECG in patients with ‘takotsubo’ cardiomyopathy: comparison with the findings of acute anterior myocardial infarction. Circ J. 2003;67:687–90.
15. Peruzzolo Marra M, Zorzi A, Corbetti F, De Lazzeri M, Migliore F, Tona F, et al. Apico basal gradient of left ventricular myocardial edema underlies...
Transient T-wave inversion and QT interval prolongation (wellens' ECG pattern) in tako-tsubo cardiomyopathy. Heart Rhythm. 2013;10:70–7.

16. Junttila MJ, Sager SJ, Tikkanen JT, Anttonen O, Huikuri HV, Myerburg RJ. Clinical significance of variants of J-points and J-waves: early repolarization patterns and risk. Eur Heart J. 2012;33:2639–43.

17. Antzelevitch C, Yan GX. J wave syndromes. Heart Rhythm. 2010;7:549–58.

18. Tikkanen JT, Junttila MJ, Anttonen O, Aro AL, Luttinen S, Kerola T, et al. Early repolarization: electrocardiographic phenotypes associated with favorable long-term outcome. Circulation. 2011;123:2666–73.

19. Haissaguerre M, Chatel S, Sacher F, Weerasooriya R, Probst V, Loussouarn G, et al. Ventricular fibrillation with prominent early repolarization associated with a rare variant of KCNJ8/KATP channel. J Cardiovasc Electrophysiol. 2009;20:93–8.

20. Medeiros-Domingo A, Tan BH, Crotti L, Tester DJ, Eckhardt L, Cuoretti A, et al. Gain-of-function mutation S422L in the KCNJ8-encoded cardiac K(ATP) channel Kir6.1 as a pathogenic substrate for J-wave syndromes. Heart Rhythm. 2010;7:1466–71.

21. Burashnikov E, Pfeiffer R, Barajas-Martinez H, Delpon E, Hu D, Desai M, et al. Mutations in the cardiac L-type calcium channel associated with inherited J-wave syndromes and sudden cardiac death. Heart Rhythm. 2010;7:1872–82.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.