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Predicting the outcome of acute pulmonary embolism by dynamic changes of the QRS complex in lead V1

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ABSTRACT

Electrocardiography can provide useful prognostic information in acute pulmonary embolism (APE). Several abnormal QRS changes in lead V1, including notched or fragmented QRS, incomplete or complete right bundle branch block (IRBBB or CRBBB) and the QR sign, which are associated with APE, are of prognostic significance. To illustrate this, we describe lead V1 QRS changes in combination with the clinical state of six APE patients. The dynamic ECG changes suggest that a change from a diminution of the S wave amplitude to notched S wave, next to RBBB and then to the QR sign indicate worsening of the patients' condition, and vice versa. Also, a diminution of the S wave amplitude in lead V1 associated with a final R' wave in the right precordial accessory leads indicates the possibility of hidden RBBB. Understanding dynamic QRS changes in APE may aid in risk stratification.

Introduction

Electrocardiography (ECG) can provide useful prognostic information in patients with acute pulmonary embolism (APE) [1,2]. Based on our observations, the ECG changes in APE may be very dynamic, and they seem to correlate with the progression or regression of the disease severity, especially in high or intermediate-risk APE patients. QRS complex changes in lead V1 that are associated with outcome in APE include notched [3,4] or fragmented QRS [5], incomplete or complete right bundle branch block [2] (IRBBB or CRBBB) and the QR sign [6,7]. We also found that a diminution of the S-wave amplitude in lead V1 associated with a final R' wave in the right precordial accessory leads suggests the possibility of hidden RBBB. When [3] comparing the morphological QRS changes in lead V1 during baseline and hemodynamic instability in 20 patients, we found that the following features had prognostic impact: new appearance of the QR sign in seven, new appearance of RBBB in five, new appearance of notched S wave in three, change from notched S wave to RBBB in one, change from notched S wave to the QR sign in one and change from RBBB to the QR sign in one patient. Thus, we hypothesize that a change from a notched S wave to RBBB and then to the QR sign in lead V1 reflects the progression of the disease severity. We also believe that the clinical situation is improving if the ECG changes in the opposite direction. Here we describe the morphological changes of the QRS complex in lead V1 along with the progression or regression of the disease severity in six illustrative patient cases.

Case reports

Patient #1 was a 48-year-old female with chest discomfort and palpitations for three days. She had a recent history of a tibial fracture but no history of cardiopulmonary disease. The blood pressure was 130/85 mmHg. The ECG (Fig. 1A) at admission showed sinus tachycardia, S1Q3T3, negative T-waves (NTW) in leads V1-V3, notching of the descending branch of the S wave in lead V1. The second ECG (Fig. 1B) after syncope (BP 100/55 mmHg) showed prominent notching in the descending branch of the S wave in lead V1, deeper S-wave in lead I, and new ST elevation (STE) in leads V1 and aVR, ST depression (STD) in leads I and V4-V6. APE was confirmed by CT pulmonary artery angiography (CTPA) revealing bilateral pulmonary arterial thrombus. The patient's condition rapidly deteriorated into cardiogenic shock. However, the patient's family declined thrombolytic therapy for various reasons. Although a variety of vasopressor drugs were given, her BP continued to decline and she died on the second day. The third ECG (Fig. 1C) during hypotension (BP 85/55 mmHg) showed notching in the nadir of the S wave in lead V1. The fourth ECG (Fig. 1D) during cardiogenic shock (BP 70/50 mmHg) showed notching in the ascending branch of the S wave in lead V1. The fifth ECG (Fig. 1E) during cardiogenic shock (BP 60/30 mmHg) showed typical IRBBB and CRBBB. The

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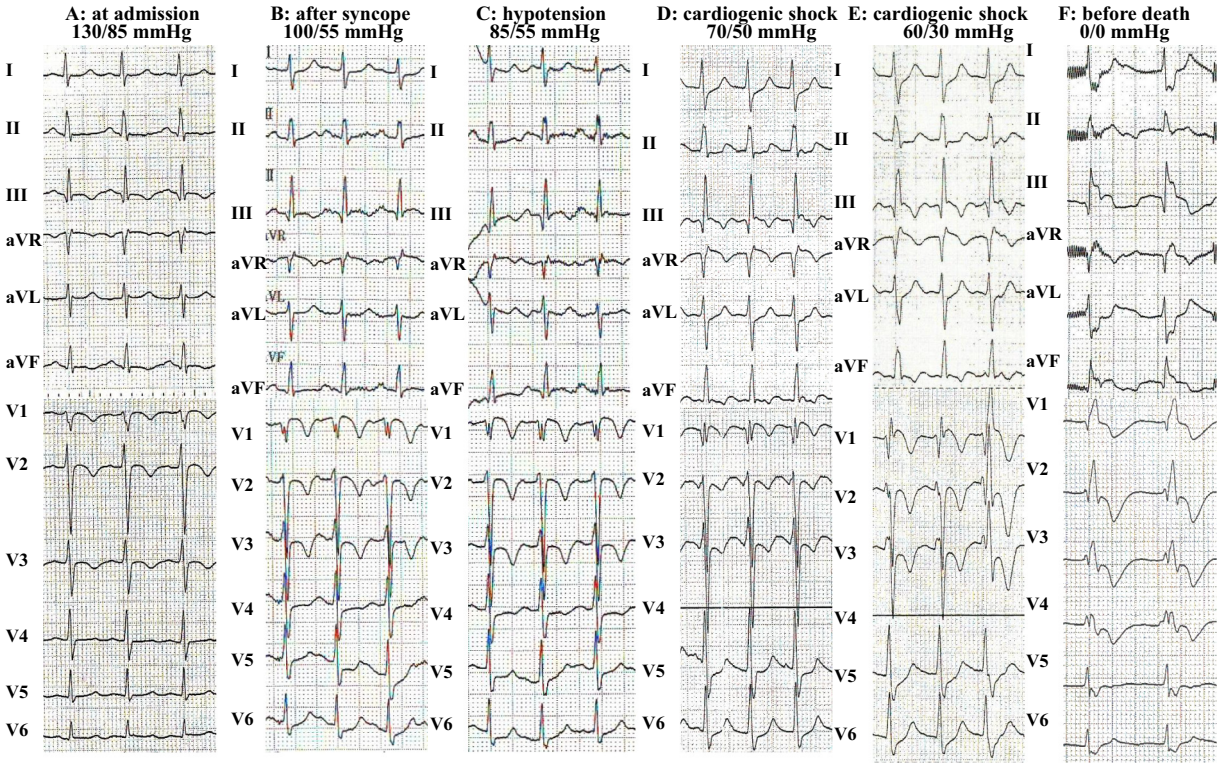

Fig. 1. (A) The ECG at admission showed sinus tachycardia, S1Q3T3, negative T-waves in leads V1-V3, notching of the descending branch of the S wave in lead V1. (B) The second ECG after syncope showed prominent notching in the descending branch of the S wave in lead V1, deeper S-wave in lead I, and new ST elevation in leads V1 and aVR, ST depression in leads I and V4-V6. (C) The ECG during hypotension showed notching in the nadir of the S wave in lead V1. (D) The ECG during cardiogenic shock showed notching in the ascending branch of the S wave in lead V1. (E) The ECG during cardiogenic shock showed typical incomplete and complete right bundle branch block. (F) The ECG before death showed the QR sign in lead V1, and rSR' configuration in lead V2 suggestive of CRBBB.

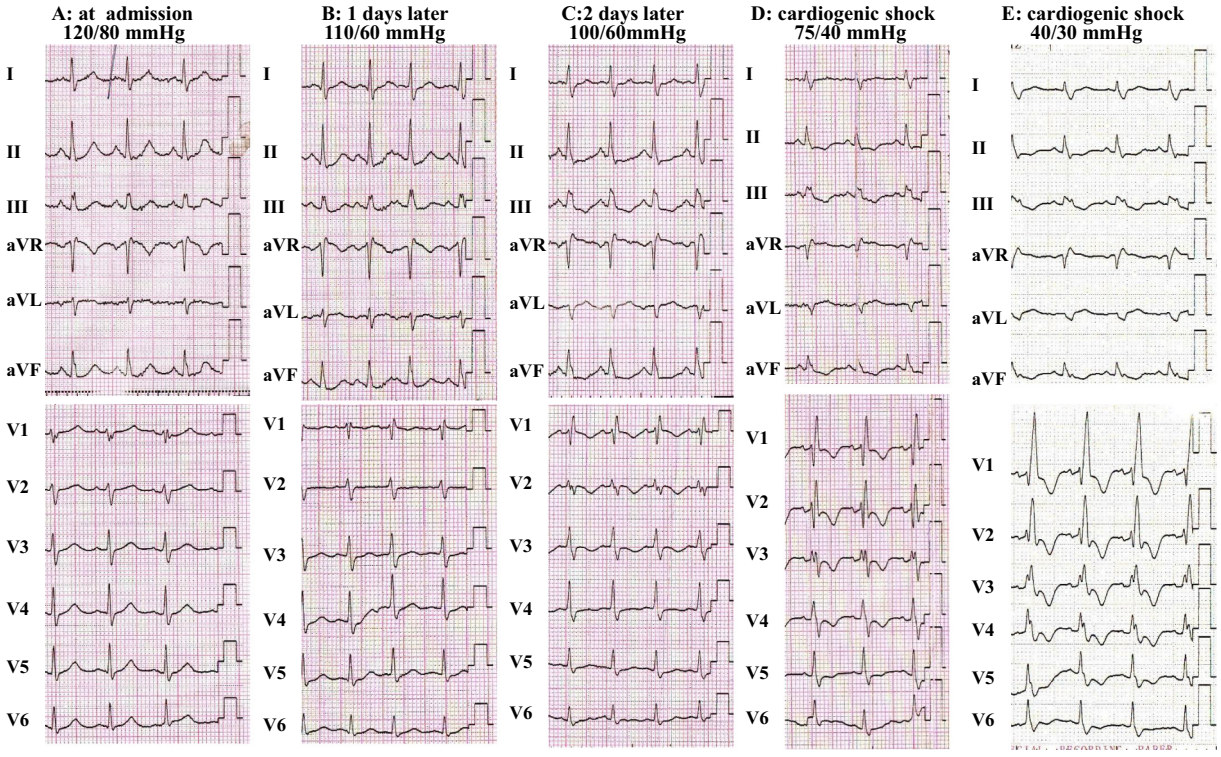

Fig. 2. (A) The ECG on admission showed sinus tachycardia, notching of the terminal portion of the S wave in lead V1 in the first and the second QRS complexes and incomplete right bundle branch block in the third QRS complex. (B) The ECG one day later showed incomplete right bundle branch block. (C) The ECG two days later showed incomplete right bundle branch block with higher R' wave than in the ECG one day later. (D) The ECG during cardiogenic shock showed incomplete right bundle branch block with higher R' wave than the ECG two days later. (E) The ECG during cardiogenic shock showed complete right bundle branch block with higher R' wave than in the previous ECGs.

sixth ECG (Fig. 1F) before death (BP not measurable) showed the QR sign in lead V1, and rSR' configuration in lead V2 suggestive of CRBBB.

Patient #2 was a 76-year-old female with cough and syncope for four days. The ECG (Fig. 2A) on admission (BP 120/80 mmHg) showed sinus tachycardia, notching of the terminal portion of the S wave in lead V1 in the first and the second QRS complexes and IRBBB in the third QRS complex. The second ECG (Fig. 2B) one day later (BP 110/60 mmHg) showed IRBBB. The third ECG (Fig. 2C) two days later (BP 100/60 mmHg) showed IRBBB with higher R' wave than in the second ECG. APE was diagnosed by CTPA revealing bilateral pulmonary arterial thrombus. She deteriorated into hemodynamic instability, but her family declined thrombolytic therapy. Although vasopressor drugs were given, her BP continued to decline and she died on the third day. The fourth ECG (Fig. 1D) during cardiogenic shock (BP 75/40 mmHg) showed IRBBB with higher R' wave than in the third ECG. The fifth ECG (Fig. 1E) during cardiogenic shock (BP 40/30 mmHg) showed complete RBBB with higher R' wave than in the previous ECGs.

Patient #3 was a 63-year old female with progressive dyspnea, chest discomfort and repetitive syncope for five days. ECG at admission showed the SI-SII-SIII pattern, notching of the ascending limb of the very shallow S wave in lead V1, clockwise rotation in the precordial leads, STE in leads aVR and V1 to V3, and NTWs in leads III and V1 to V4 (Fig. 3A). The BP at admission was 80/50 mmHg. Echocardiography showed right ventricular (RV) enlargement, free wall hypokinesia, flattening of the interventricular septum and severe tricuspid regurgitation. APE was confirmed by CTPA revealing bilateral pulmonary arterial thrombus. The patient rapidly deteriorated into unconsciousness and the BP dropped to 30/20 mmHg. The second ECG shows notching in the terminal portion of the very shallow S wave in lead V1, STE in leads III, aVR, V1 to V3, and STD in leads I, II, aVL and V5 to V6 (Fig. 3B). The patient received vasopressor drugs, tissue plasminogen activator (tPA) and cardiopulmonary resuscitation. She was hemodynamically stable 1 h after the tPA infusion. The ECG (Fig. 3C) 2 h after thrombolytic therapy (BP 100/70 mmHg) showed notching in the nadir of the S wave in lead V1 with deeper S-wave amplitude compared to the first and second ECGs, NTW in V1 to V5. The patient recovered well. Four days later, the ECG (Fig. 3D) showed further S-wave amplitude deepening and disappearance of notching of the S wave in lead V1. A repeat echocardiogram showed normalization of RV morphology and function.

Patient #4 was a 56-year old male with palpitations, dyspnea on exertion and repetitive syncope for two days. ECG at admission showed sinus tachycardia 127 bpm, S1Q3T3, NTW in the inferior leads, V1 and V3R-V5R, the depth of the S wave in V1 was 1.34 cm, there was a notched S wave in V4R, and a final R' wave in V5R (Fig. 4A). APE was confirmed by CTPA revealing right pulmonary arterial thrombus. He remained hemodynamically stable during the hospitalization but he had RV enlargement and moderate tricuspid regurgitation on echocardiography, positive Troponin I (153 ng/ml, normal value <50 ng/ml) and elevated NT-proBNP (1865 pg/ml, normal value <300 pg/ml). Based on the presence of RV dysfunction and positive Troponin level, we decided to give thrombolytic therapy. And he had symptom relief after the thrombolytic therapy. The second ECG 1 h after thrombolytic therapy showed sinus tachycardia 108 bpm, S1Q3T3, NTW in the inferior leads, V1-V5 and V3R-V5R, the depth of the S-wave in V1 was 1.68 cm, the S wave was notched in V3R-V4R, and V5R had a final R' wave (Fig. 4B). The ECG (Fig. 4C) two days later showed sinus tachycardia 100 bpm, diminution of the S wave in lead I, NTW in the inferior leads, V1-V3 and V3R-V5R, the depth of the S wave in V1 was 1.99 cm, notched S wave in V5R, and disappearance of a final R' in the right precordial accessory leads (Fig. 4C). Three days later, the ECG (Fig. 4D) showed sinus rhythm 88 bpm, NTWs in the inferior leads, V1-V3 and

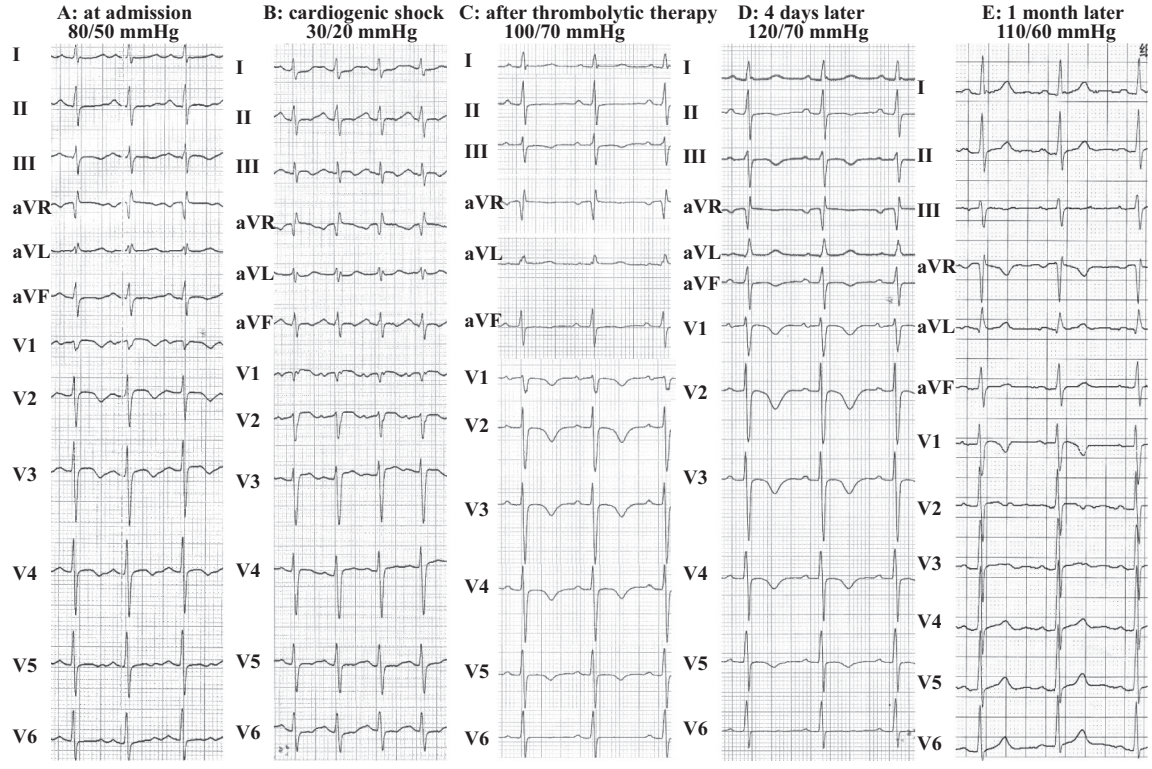

Fig. 3. (A) ECG at admission showed the SI-SII-SIII pattern, notching of the ascending limb of the very shallow S wave in lead V1, clockwise rotation in the precordial leads, ST elevation in leads aVR and V1 to V3, and negative T waves in leads III and V1 to V4. (B) The ECG during cardiogenic shock shows notching in the terminal portion of the very shallow S wave in lead V1, ST elevation in leads III, aVR, V1 to V3, and ST depression in leads I, II, aVL and V5 to V6. (C) The ECG 2 h after thrombolytic therapy showed notching in the nadir of the S wave in lead V1 with deeper S-wave amplitude compared to the previous ECGs, negative T waves in V1 to V5. (D) the ECG four days later showed further S-wave amplitude deepening and disappearance of notching of the S wave in lead V1.

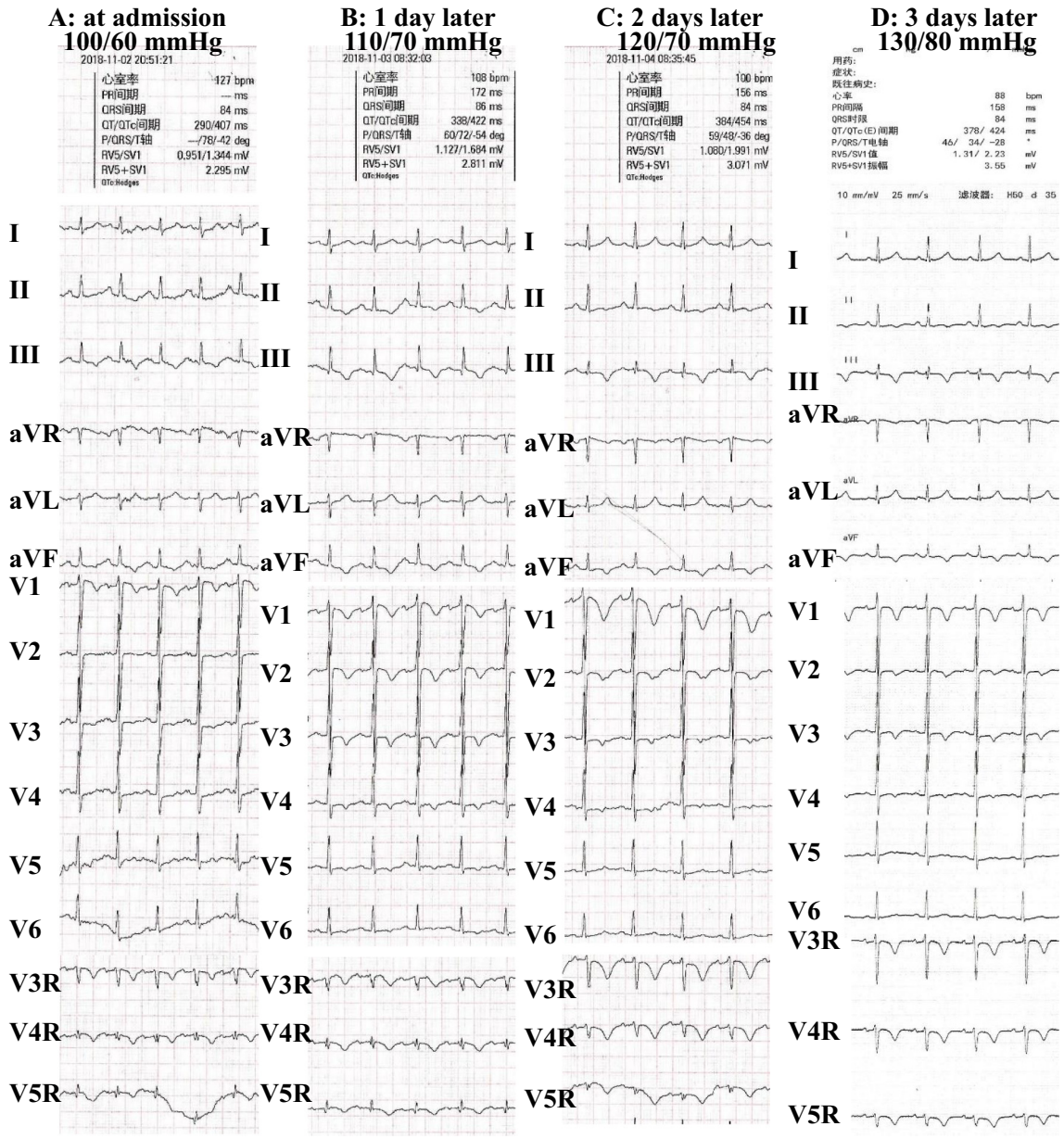

Fig. 4. (A) ECG at admission showed sinus tachycardia 127 bpm, S1Q3T3, negative T waves in the inferior leads, V1 and V3R-V5R, the depth of the S wave in V1 was 1.34 cm, there was a notched S wave in V4R, and a final R' wave in V5R. (B) The ECG 1 h after thrombolytic therapy showed sinus tachycardia 108 bpm, S1Q3T3, negative T waves in the inferior leads, V1-V5 and V3R-V5R, the depth of the S-wave in V1 was 1.68 cm, the S wave was notched in V3R-V4R, and V5R had a final R' wave. (C) The ECG two days later showed sinus tachycardia 100 bpm, diminution of the S wave in lead I, negative T waves in the inferior leads, V1-V3 and V3R-V5R, the depth of the S wave in V1 was 1.99 cm, notched S wave in V5R, and disappearance of a final R' in the right precordial accessory leads. (D) the ECG three days later showed sinus rhythm 88 bpm, negative T waves in the inferior leads, V1-V3 and V3R-V5R, the depth of the S wave in V1 was 2.23 cm, disappearance of the final R' wave and notched S wave in the right precordial accessory leads.

V3R-V5R, the depth of the S wave in V1 was 2.23 cm, disappearance of the final R' wave and notched S wave in the right precordial accessory leads. A repeat echocardiogram revealed normalization of RV diameter and function. A repeat CTPA demonstrated resolution of the right pulmonary arterial thrombus.

Patient #5 was a 65-year old male with dyspnea, chest pain, and repetitive syncope for 15 days. ECG at admission showed right axis deviation, S1Q3T3, NTWs in the inferior leads and V1-V6, clockwise rotation in the precordial leads, STE in leads V1-V2, QR sign in leads V4R—V1, rSR' configuration in lead V5R suggestive of CRBBB, notched S wave in V2 (Fig. 5A). APE was confirmed by CTPA revealing bilateral pulmonary arterial thrombus. He remained hemodynamically stable but he had RV enlargement, free wall hypokinesia, elevated estimated pulmonary artery systolic pressure (ePASP, 81 mmHg) and severe tricuspid regurgitation on echocardiography, arterial hypoxemia (PaO2 58 mmHg), elevated Troponin I (203 ng/ml, normal value <50 ng/ml) and elevated NT-proBNP (2563 pg/ml, normal value <300 pg/ml). Based on the presence of RV dysfunction, hypoxemia and positive Troponin level, we decided to give thrombolytic therapy. The patient had symptom relief after thrombolytic therapy. The second ECG after thrombolytic therapy showed S1Q3T3, NTWs in the inferior leads and V1-V6, clockwise rotation in the precordial leads, QR sign in lead V1 with lower R-wave amplitude than at admission, disappearance of notched S wave in V2 (Fig. 5B). The ECG (Fig. 5C) one day later showed S1Q3T3, NTWs in the inferior leads and V1-V5, clockwise rotation to lead V5, new emerging IRBBB in lead V1. Ten days later, the ECG (Fig. 5D) showed disappearance of S1Q3T3 and NTWs in the inferior leads, persistent NTWs in leads V1-V3, disappearance of IRBBB, the S

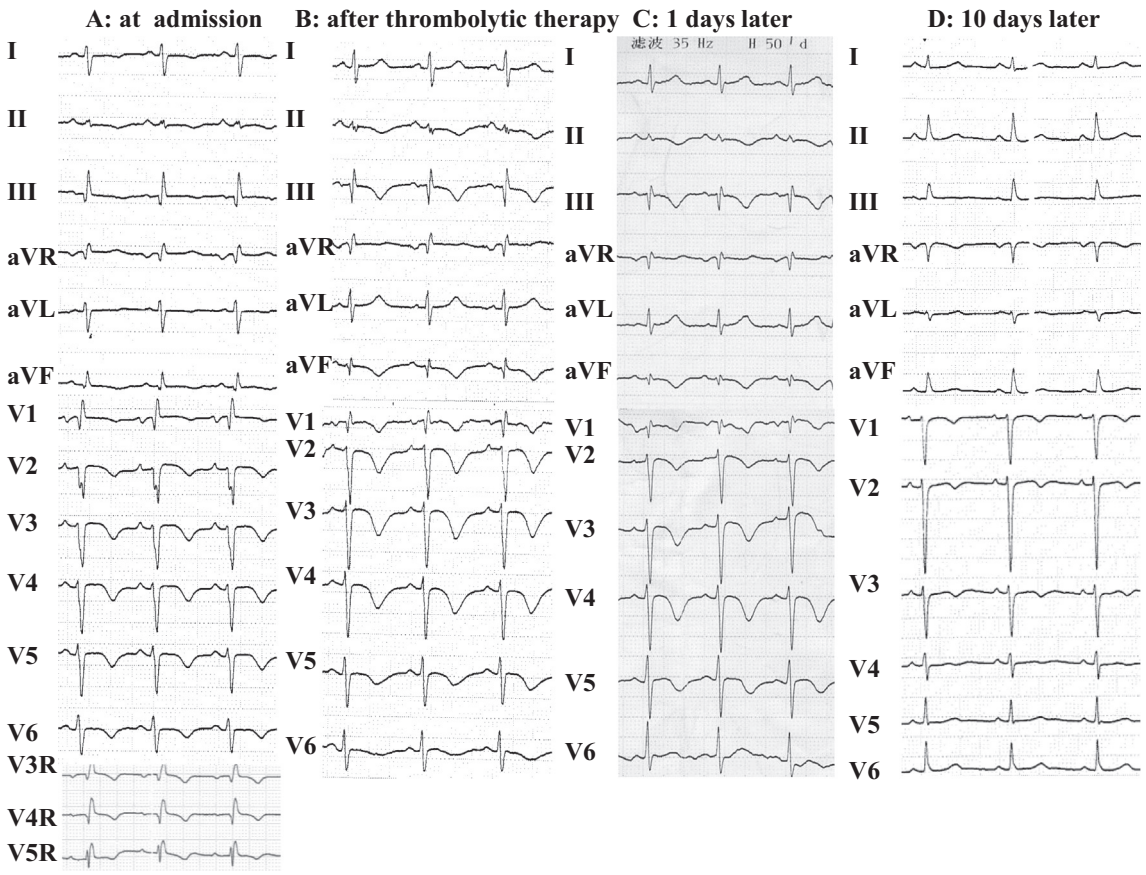

Fig. 5. (A) ECG at admission showed right axis deviation, S1Q3T3, negative T waves in the inferior leads and V1-V6, clockwise rotation in the precordial leads, ST elevation in leads V1-V2, QR sign in leads V4R—V1, rSR' configuration in lead V5R suggestive of CRBBB, notched S wave in V2. (B) The second ECG after thrombolytic therapy showed S1Q3T3, negative T waves in the inferior leads and V1-V6, clockwise rotation in the precordial leads, QR sign in lead V1 with lower R-wave amplitude than at admission, disappearance of notched S wave in V2. (C) The ECG one day later showed S1Q3T3, negative T waves in the inferior leads and V1-V5, clockwise rotation to lead V5, new emerging incomplete right bundle branch block in lead V1. (D) the ECG ten days later showed disappearance of S1Q3T3 and negative T waves in the inferior leads, persistent negative T waves in leads V1-V3, disappearance of incomplete right bundle branch block, the S wave in V1 was much deeper than in the previous ECGs.

wave in V1 was much deeper than in the previous ECGs. A repeat echocardiography showed mild RV enlargement, mild tricuspid regurgitation and elevated ePSAP (35 mmHg).

Patient #6 was a 62-year old male with palpitations and chest discomfort on exertion for three days. ECG at admission (2013-12-24) showed sinus tachycardia 120 bpm, notched S wave in lead V1, and 0.55 cm of the depth of the S wave in V1 (Fig. 6A). He had RV enlargement, mild tricuspid regurgitation, and elevated ePSAP (51 mmHg), and normal left ventricular end-diastolic diameter on echocardiography, positive Troponin I (312 ng/ml, normal value <50 ng/ml) and elevated NT-proBNP (5379 pg/ml, normal value <300 pg/ml). He was diagnosed as non-ST-elevation myocardial infarction but that confirmatory testing was lacking and in retrospect, APE should have been considered. He was treated with aspirin, clopidogrel, atorvastatin, low molecular weight heparin and diuretics. He refused to receive coronary angiography. His symptoms were gradually relieved, and he was discharged from hospital four days later. The ECG three days later (2013-12-26) showed sinus tachycardia 100 bpm, disappearance of the notched S wave in lead V1 and a 0.7 cm deep S wave in V1 (Fig. 6B). The echocardiography before discharge revealed RV dilatation, mild tricuspid regurgitation, elevated ePSAP (41 mmHg), and normal LV end-diastolic diameter. Three months later, he was readmitted due to palpitation, dyspnea and edema of lower limbs. The ECG (2014-03-31) showed sinus tachycardia 110 bpm, notched S wave in lead V1, and a 0.55 cm deep S wave in V1 (Fig. 6C). Transthoracic echocardiography revealed RV dilatation, mild tricuspid regurgitation, ePSAP 50 mmHg, and a normal-sized LV. Chronic or acute on chronic PE was confirmed by CTPA revealing bilateral pulmonary arterial thrombus. Coronary angiography showed only minor atherosclerosis in the left anterior descending coronary artery. Thus, he received standardized anticoagulation therapy and Fasudil (a rho-kinase inhibitor, for prolonged pulmonary preferential vasodilation in pulmonary arterial hypertension [8]), and his symptoms were gradually relieved. The ECG after two weeks' anticoagulation therapy (2014-04-15) showed disappearance of the notched S wave in lead V1 and a deeper S wave (0.9 cm) in V1 than before (Fig. 6D). Echocardiography (2014-04-15) revealed normal RV diameter and function, and a normal-sized LV. Although he received continuous standardized anticoagulation therapy, he had the symptoms of dyspnea on exertion and edema of lower limbs. The ECGs during the follow-up showed normalization of the T waves in leads V1-V3, and the S-wave in lead V1 had lower amplitude (0.55 cm in Fig. 6E and 0.3 cm in Fig. 6F). Transthoracic echocardiography (2014-06-30) revealed RV dilatation, mild tricuspid regurgitation, ePSAP 45 mmHg, and normal LV.

Discussion

These six patient cases with APE are rather unique as ECGs were recorded with the progression or regression of the disease severity, also during severe cardiogenic shock, which enabled us to draw conclusions about possible associations between the dynamic ECG changes and the clinical situation. Especially the QRS complex in lead V1 seemed to undergo many changes with the progression or regression of the disease severity. Serial morphological QRS changes in the six cases are presented in Fig. 7. We think that the ECG manifestations represent a

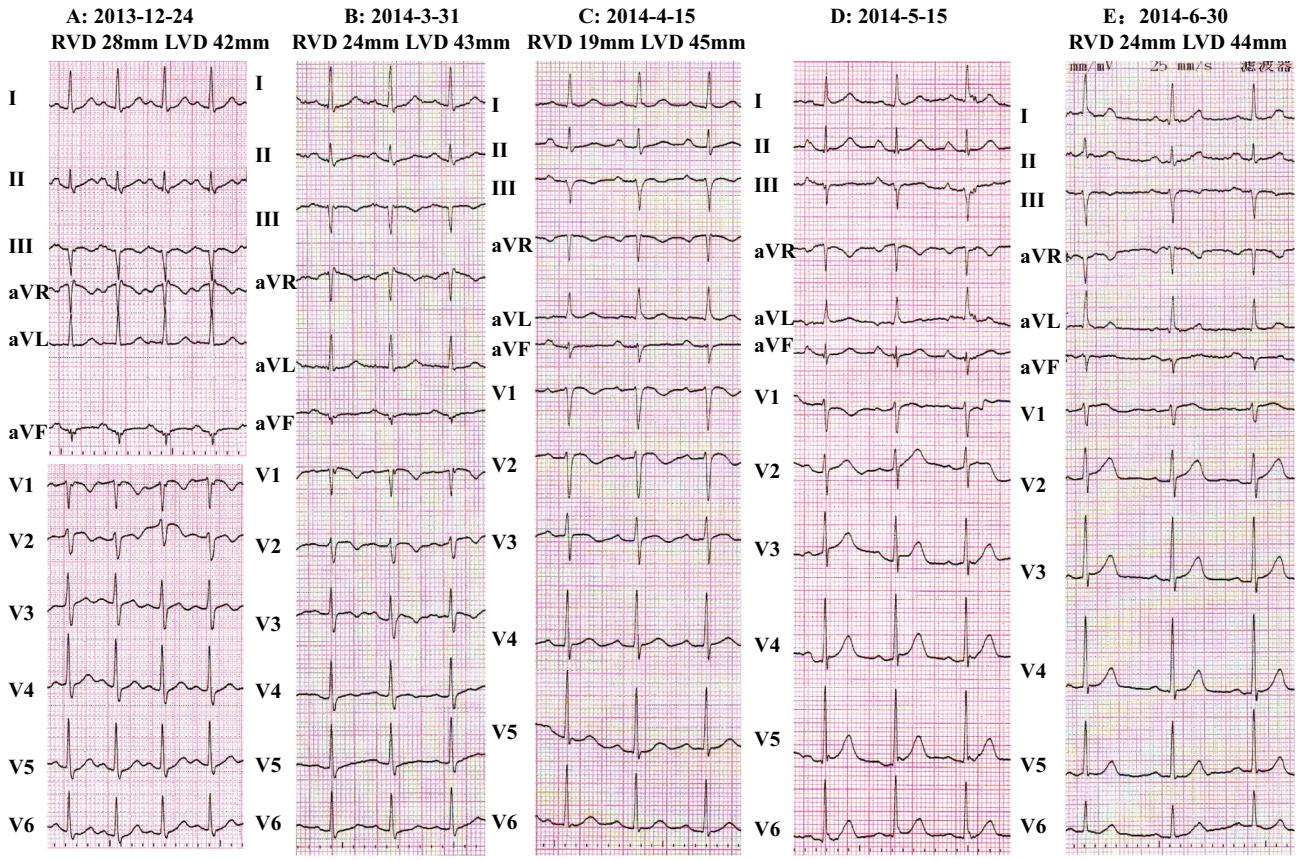

Fig. 6. (A) ECG at admission (2013-12-24) showed sinus tachycardia 120 bpm, notched S wave in lead V1, and S-wave depth of 0.55 cm in V1. (B) The ECG three days later (2013-12-26) showed sinus tachycardia 100 bpm, disappearance of the notched S wave in lead V1, S-wave depth of 0.7 cm in V1. (C) The ECG (2014-03-31) showed sinus tachycardia 110 bpm, notched S wave in lead V1, and S-wave depth of 0.55 cm in V1. (D) The ECG after two weeks' anticoagulation therapy (2014-04-15) showed disappearance of the notched S wave in lead V1, and deeper S wave in V1 (0.9 cm). (E) The ECG (2014-05-15) showed S-wave depth of 0.55 cm in lead V1 during the follow-up. (F) The ECG (2014-06-30) showed S-wave depth of 0.3 cm in lead V1 during the follow-up.

certain pattern, which mirrors the progression or regression of the disease severity during the acute disease process. We found that the progression of the disease severity was paralleled by changes of the QRS complex in lead V1: a continuous diminution of the S-wave amplitude, followed by notching of the S wave from the descending branch next to the nadir and then to the ascending branch, then RBBB and finally the QR sign. The gradual increase of the amplitude of the R' waves in RBBB and the R wave in QR sign was evident with the progression of the disease severity. The changes seemed to go in the opposite direction when the disease severity improved. The ECG features observed in case 4 suggests that a diminution of the S-wave amplitude in lead V1 associated with a final R' wave in the right precordial accessory leads could represent masquerading RBBB.

In patient #6, despite the last echocardiography findings suggestive of chronic thromboembolic pulmonary hypertension, we observed that with clinical improvement, along with the decrease in RV diameter and pulmonary artery pressure, the notching of the S wave in V1 disappeared. Also, the S wave became deeper in that lead. The changes seemed to go in the opposite direction with clinical deterioration, along with increase in RV diameter and pulmonary artery pressure. This is to our knowledge the first article, which in detail describes progression and regression of QRS changes in lead V1 parallel to changes in the hemodynamic state of the patients.

Lead V1 is adjacent to the right ventricular outflow tract. The QRS-complex configuration in V1 may be affected by changes in the position of the ventricular septum, and also by volume and pressure overload of the ventricles. Also the position of the recording electrode, the insertion point of the conduction system, the degree and the site of RBBB and other factors may influence the QRS morphology in V1 [4]. Even acute changes in the relative size of the ventricles (LV/RV ratio) significantly influence the S-wave amplitude in lead V1. With the increase of RV size, prolongation of the RV conduction time and abnormal conduction in the right bundle branch secondary to pulmonary artery obstruction in APE, the continuous increase of RV depolarization vector could offset the dominant left ventricular depolarization vector. In that case, the S-wave amplitude in lead V1 would gradually decrease and the R' wave in RBBB or the R wave in QR sign would gradually increase. Schamroth et al. [9] reported that a diminution of the S-wave amplitude in lead V2 indicates an early stage of RBBB. Further progression results in a slurred or notched wave in the ascending branch of the S wave in lead V2, followed by the emerging of an R' wave. With further progression, the R' wave becomes increasingly higher until CRBBB develops. In another report by Smith and Ray [10], progression in the severity of pulmonary arterial obstruction in APE was significantly associated with the appearance of a notched S wave and R/S ratio regression, followed by the RSR' pattern and, finally, by CRBBB in the right precordial leads. Watanabe et al. [11] reported a new, notched S-wave in lead V1 during recurrent pulmonary artery thrombus. Our cases indicate that the progression of the disease severity is initially expressed by a diminution of the S-wave amplitude in lead V1. Further progression develops notching of the S wave from the descending branch to the nadir and then to the ascending branch in lead V1. This is followed by a gradual increase of the R'-wave amplitude and thus development of IRBBB and CRBBB. With the progression in the severity of pulmonary arterial obstruction, significant RV dilatation and IVS flattening rotate the initial depolarization vector from V1 resulting in an appearance of q/Q wave

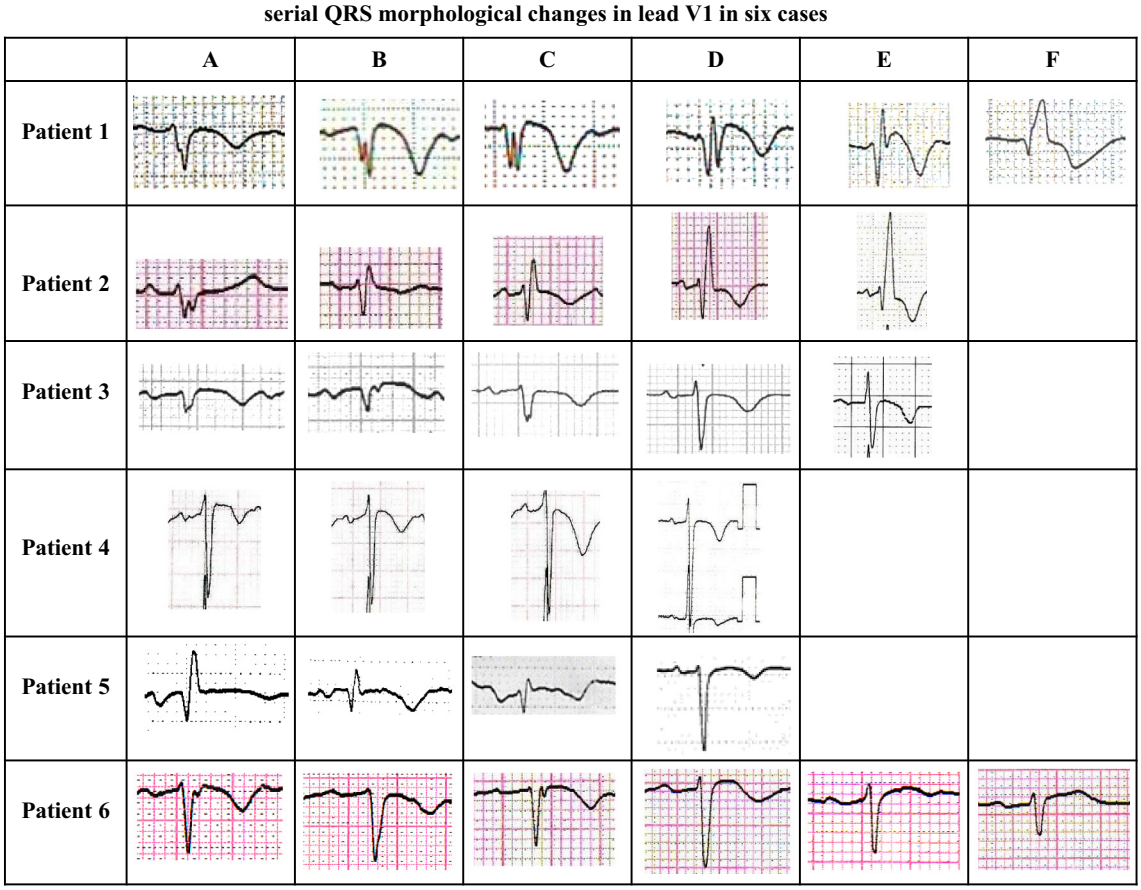

Fig. 7. Serial morphological QRS changes in lead V1 of the six cases.

in V1, thus resulting in the QR sign [7]. In patient #1, simultaneous QR sign in lead V1 and rSR' configuration in lead V2 was suggestive of CRBBB (see Fig. 1F). Patient #5 showed simultaneous QR sign in leads V4R-V1 and rSR' configuration in lead V5R suggestive of CRBBB (see Fig. 5A). These facts indicate that the QR sign in lead V1 is essentially a combination of RBBB and RV deformation secondary to pulmonary arterial obstruction.

Our group has demonstrated that a notched S wave in lead V1 associated with a final R' wave in the right precordial accessory leads suggests the possibility of hidden or masquerading RBBB [4]. Case 4 suggest that a diminution of the S-wave amplitude in lead V1 associated with a final R' wave in the right precordial accessory leads indicates the possibility of this ECG phenomenon.

We also observed that with clinical improvement after thrombolysis, there was a decrease of the amplitude of the R wave in the QR sign (case 5) and gradual deepening of the S wave in lead V1 (case 3 and 4).

All these facts seem to suggest that a diminution of the S-wave amplitude, notching of the S wave, RBBB and the QR sign in lead V1 in APE represent a conduction disorder in the RV but reflecting different levels of severity.

This descriptive case report series illustrates the significance of morphological QRS changes along with the progression or regression of the disease severity in APE. However, there are obvious limitations with our report. The small number of patients is a limitation, but on the other hand, ECG recording was performed repeatedly in all patients, even during severe cardiogenic shock. Assessment of the patients' condition depended solely on clinical symptoms and hemodynamic status. Lack of simultaneous pulmonary artery pressure and echocardiographic data corresponding to the ECG is a main limitation.

In conclusion, morphological changes of the QRS complex in lead V1 can provide useful prognostic information in APE patients. Clinicians need to be familiar with different features of the ECG during the acute stage of the disease.

Declaration of Competing Interest

None.

References

[1] Digby GC, Kukla P, Zhan ZQ, et al. The value of electrocardiographic abnormalities in the prognosis of pulmonary embolism: a consensus paper. Ann Noninvasive Electrocardiol 2015;20(3):207–23.
[2] Qaddoura A, Digby GC, Kabali C, Kukla P, Zhan ZQ, Baranchuk AM. The value of electrocardiography in prognosticating clinical deterioration and mortality in acute pulmonary embolism: a systematic review and meta-analysis. Clin Cardiol 2017;40(10):814–24.
[3] Zhan ZQ, Wang CQ, Nikus KC, et al. Electrocardiogram patterns during hemodynamic instability in patients with acute pulmonary embolism. Ann Noninvasive Electrocardiol 2014;19(6):543–51.
[4] Zhong-qun Z, Nikus KC, Perez-Riera AR, Chong-quan W. Electrocardiographic findings in accessory right precordial leads in adults and seniors with notched S waves in lead V1-a preliminary study. Ann Noninvasive Electrocardiol 2014;19(3):234–40.
[5] Cetin MS, Ozcan Cetin EH, Arisoy F, et al. Fragmented QRS complex predicts in-hospital adverse events and long-term mortality in patients with acute pulmonary embolism. Ann Noninvasive Electrocardiol 2016;21(5):470–8.
[6] Kucher N, Walpoth N, Wustmann K, Noveanu M, Gertsch M. QR in V1–an ECG sign associated with right ventricular strain and adverse clinical outcome in pulmonary embolism. Eur Heart J 2003;24(12):1113–9.
[7] Waligóra M, Kopeć G, Jonas K, et al. Mechanism and prognostic role of qR in V1 in patients with pulmonary arterial hypertension. J Electrocardiol 2017;50(4):476–83.

[8] Gupta V, Gupta N, Shaik IH, et al. Liposomal fasudil, a rho-kinase inhibitor, for prolonged pulmonary preferential vasodilation in pulmonary arterial hypertension. J Control Release 2013;167(2):189–99.
[9] Schamroth L, Myburgh DP, Schamroth CL. The early signs of right bundle branch block. Chest 1985;87(2):180–5.
[10] Smith M, Ray CT. Electrocardiographic signs of early right ventricular enlargement in acute pulmonary embolism. Chest 1970;58:205–12.
[11] Watanabe T, Kikushima S, Tanno K, et al. Uncommon electrocardiographic changes corresponding to symptoms during recurrent pulmonary embolism as documented by computed tomography scans. Clin Cardiol 1998;21(11):858–61.