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Effects of balloon pulmonary angioplasty procedure on electrocardiographic parameters in patients with chronic thromboembolic pulmonary hypertension

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ABSTRACT

Aim: The aim of the present study was to evaluate the value of electrocardiography (ECG) in predicting postoperative hemodynamic improvement in patients with chronic thromboembolic pulmonary hypertension (CTEPH) undergoing balloon pulmonary angioplasty (BPA).

Material and methods: A total of 32 patients were included in the study. During ECG analysis, parameters that have been suggested to be related to right ventricular hypertrophy and/or dilatation were evaluated. The significance of the change in each parameter obtained at the pre-BPA visit and at the scheduled control visit 6 months after BPA was tested. In addition to ECG analysis, data related to right heart catheterization (RHC) and echocardiography, B-type natriuretic peptide (BNP) levels and World Health Organization (WHO) functional classifications of all patients were also recorded. The relationship between the amount of possible change in ECG parameters and the amount of possible change in hemodynamic parameters was investigated.

Results: The Daniel score, which has been suggested to have prognostic value in acute pulmonary embolism, decreased from 8.22 ± 5.68 to 6.56 ± 5.55 after the BPA procedure (p: 0.035). Among all parameters studied, only T wave height (V_2 t) in V_2 derivation changed significantly from -0.77 ± 2.39 to 1.27 ± 2.58 mm (p: 0.036). The amount of change in V_2 T was found to significantly correlate with the amount of change in systolic right ventricular pressure, mean pulmonary artery pressure, pulmonary vascular resistance, and systemic vascular resistance.

Conclusion: Postprocedural T wave changes in lead V2 might serve as a marker of hemodynamic improvement in patients with CTEPH who undergo BPA.

Introduction

Chronic thromboembolic pulmonary hypertension (CTEPH) is a disease of obstructive pulmonary artery remodeling following pulmonary thromboembolism. The cumulative incidence has been reported to range from 0.1 to 9.1% within the first 2 years after a symptomatic pulmonary embolism event [1]. Pulmonary endarterectomy (PEA) is the treatment of choice for patients with accessible pulmonary artery lesions [2]. Most patients' symptoms and hemodynamics improve to near normal levels after surgery [3–6].

Balloon pulmonary angioplasty (BPA) is the treatment of choice when pulmonary endarterectomy (PEA) cannot be performed in patients with CTEPH. Previous studies have reported significant improvement in mortality and morbidity after BPA [7–9]. A recent European Society of Cardiology (ESC) guideline for the diagnosis and treatment of pulmonary hypertension [10] has recommended BPA for patients who are technically inoperable or have residual pulmonary hypertension after PEA and distal obstructions amenable to BPA with class 1 indication.

Clinical follow-up of patients after BPA is performed by assessing the functional status (classified functionally according to the WHO/NYHA functional class and assessed with the 6-min walk test) and NT-proBNP levels and by performing transthoracic echocardiography and right heart catheterization in our center. Right heart catheterization (RHC) is performed routinely during follow-up to evaluate the hemodynamic response after BPA.

Twelve-lead electrocardiography (12-lead ECG) has been suggested to play a role in the risk stratification of patients with pulmonary hypertension [11]. Electrocardiographic alterations after the BPA

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procedure were evaluated in several previous studies [12–14]. Alterations in various ECG markers have been suggested to be related to a more favorable hemodynamic and/or functional improvement.

The aim of the present study was to investigate alterations in ECG parameters after the BPA procedure in patients with CTEPH. We also aimed to evaluate the association between possible electrocardiographic alterations and improvements in hemodynamics, symptomatic functional status and right ventricular function after the procedure.

Material and methods

Our study, which was designed as a descriptive study, was carried out by the Marmara University Medical Faculty Hospital Department of Cardiology. All BPA cases performed in our hospital between 01.10.2017 and 31.12.2020 were included in our study.

ECGs obtained before the BPA procedure and ECGs obtained at the scheduled 6-month follow-up visit were analyzed. The intention was to evaluate the significance of alterations in each ECG parameter following the BPA procedure. In addition, the significance of alterations in echocardiographic parameters, RHC data and clinical parameters obtained before and 6 months after the procedure were also evaluated. We also intended to investigate the possible significant correlations between the magnitude of change in ECG parameters and magnitude of change in hemodynamical parameters obtained from echocardiography, RHC and clinical status. The study was evaluated by the Marmara University Faculty of Medicine Clinical Research Ethics Committee on 03.01.2020 and approved in line with the protocol code decision of 09.2019.949. Written informed consent forms were obtained from all patients participating in the study.

Electrocardiogram

All 12-lead ECGs were collected by creating separate files for each patient. Attention was given to the fact that all ECGs were taken at 10 mm/V and 25 mm/s. ECGs were converted to digital media with the CamScanner application. They were analyzed digitally with the EP Calipers program. In the EP Calipers program, each ECG was examined in detail using a 3-4× zoom. The 4 large squares were calibrated to 20 mm. T-P was taken as the isoelectric line.

All ECGs were evaluated by a single cardiologist, avoiding interindividual differences between measurements. A total of 20 randomly selected ECGs were reexamined by the same cardiologist who was blinded to the classification of the patients during the examination for the calculations of intraobserver variability.

Height or depth of d_1R, d_1S, d_2p, d_3R, d_3 S, aVR R, V_1R, V_1S, V_5R, V_5S, V_6R, V_6S, V_1T, V_2 T, V_3T and QRS axis were measured in all ECGs. In addition, the presence of the $S_1Q_3T_3$ pattern used in the calculation of the Daniel score (Table 1) was sought in all examined ECGs. The presence of one of the following conditions was accepted as the pathological Q wave definition: 1- > 40 ms (1 mm) width, 2- > 2 mm deep, and 3- >25% of the QRS complex.

The criteria associated with right ventricular hypertrophy were measured according to the American Heart Association (AHA) recommendations of the electrocardiogram: tall R in V1 > 6 mm; increased R:S ratio in V1 > 1.0; deep S in V_5 > 10 mm; deep S in V_6 > 3 mm; tall R in aVR > 4 mm; small S in V1 < 2 mm; small R in $V_{5,6}$ < 3 mm; reduced R/S ratio V_5 < 0,75; reduced R/S ratio V_6 < 0,4; reduced R/S V_5 to R/S V_1; (R1 + SIII) – (SI + RIII) <15 mm, max $R_{v1,v2}$ + max $S_{dI,aVL}$–S V_1 > 6 mm; R in V1 + S in $V_{5,6}$ > 10.5 mm; R peak in V1 > 0.035 s; and presence of QR in V1 [15]. The number of positive criteria before and after the procedure was noted in the patients.

While calculating the height of the T waves in V1, V2 and V3, the waves above the T-p isoelectric line were considered positive, and the waves below the isoelectric line were considered negative. The sum of the two T wave components was recorded as the height of the T wave in the presence of biphasic T waves.

Table 1
Daniel scoring system recommended for use to predict cardiac stress associated with acute pulmonary embolism [18].

		point
Tachycardia(>100/min)		2
Incomplete right bundle branch block		2
Complete right bundle branch block		3
T wave negativity between V_1-V_4		4
T wave negativity in V_1	<1 mm	0
	1–2	1
	>2 mm	2
T wave negativity in V_2	<1 mm	1
	1–2	2
	>2 mm	3
T wave negativity in V_3	<1 mm	1
	1–2	2
	>2 mm	3
S wave in D_1		0
Q wave in D_3		1
T negativity in D_3		1
T negativity in D3		2

During QRS axis analysis, the value measured by the ECG device was accepted, and the accuracy of the axis was checked based on the R and S waves of leads I and III. The device measurements were found to be correct, except for a few ECGs with marked artifacts. The QRS axis values were calculated manually in these ECGs with artifacts. The site 'https://en.my-ekg.com/calculation-ekg/heart-axis-calculator.php' was used for the measurement.

Transthoracic echocardiography

All echocardiographic examinations were performed by the same operator who was blinded to the clinical data using a cardiac ultrasound machine (IE33; Philips Medical Systems, Andover, MA) with digital storage software for offline analysis. Transthoracic echocardiography was performed for each patient before the BPA procedure and at the scheduled 6-month follow-up visit, and echocardiographic images were recorded for detailed analysis.

Two-dimensional echocardiography, pulsed and continuous wave Doppler, and color flow Doppler studies were performed using standard techniques on each patient. The right ventricular basal diameter, right atrium (RA) end-systolic diameter, tricuspid annular plane systolic excursion (TAPSE), tricuspid annular systolic velocity (RVS), left ventricular end-diastolic diameter, left ventricular end-systolic diameter, septum and posterior wall thickness were recorded. All patients were in sinus rhythm at the time of examination, and all measurements were calculated from three consecutive cycles. The average of the three measurements was recorded.

Right heart catheterization

RHC was performed on all patients during the BPA procedure. Right heart catheterization was performed by a Swan Ganz catheter using femoral or jugular venous access with hemodynamic and fluoroscopic guidance. Measurements were obtained at end-expiration and averaged over three to five beats. RA, right ventricular pulmonary artery pressure and pulmonary capillary end pressure were measured during RHC. Mean PAP and PVR ([mean PAP—mean pulmonary capillary wedge pressure]/cardiac index) were calculated. CO was measured by the Fick equation.

Statistical analysis

'Statistical Package for the Social Science (SPSS) 22.0 for Windows, Chicago, IL, USA' software was used for statistical analysis. The distributions of the variables were evaluated by using the 'Kolmogorov–Smirnov' test. Normally distributed continuous variables are expressed as the mean ± standard deviation (SD); continuous variables that are not normally distributed are expressed as the median ('interquartile range'). Categorical variables were expressed as numbers and percentages. The significance of the change in each of the parameters obtained before BPA and during the follow-up was determined by using the 'paired samples Student's *t*-test' for normally distributed data and the 'Wilcoxon signed ranks test' for data with a nonnormal distribution. Two-way correlation analysis was analyzed using the 'Pearson' test for normally distributed data and the 'Spearman' test for nonnormally distributed data. Statistical significance was set at a p value below 0.05.

Results

A total of 32 patients were included in the study, and the general demographic information of the study population is summarized in Table 2. There was some variation regarding the time elapsed from baseline to the scheduled 6-month visit due to restrictions imposed by the COVID pandemic. The median time interval between baseline and the control visit was 5.5 (IQR 6) months. A total of 15 patients (46.9%) had a history of PEA, and the mean time interval from surgery to BPA was 4.2 ± 2.5 (minimum 1, maximum 9) years.

Transthoracic echocardiographic findings and clinical and RHC data of patients obtained before the procedure and during the follow-up are displayed in Table 3. Systolic and mean pulmonary artery pressures, PVR, SVR, and WHO classification scores were observed to decrease significantly after the procedure (Table 3). Among transthoracic echocardiography findings, only the RA area decreased significantly. There were no significant changes in echocardiographic parameters that are assumed to reflect right ventricular functions, such as RVS and TAPSE (Table 3). There was also no significant difference in serum BNP levels between baseline and postprocedural state (Table 3).

Baseline and postprocedural ECG data of patients are displayed in Table 4. Among the ECG data, only the T wave amplitude on derivation V2 was observed to increase significantly after the procedure (Fig. 1). There were no significant alterations in any of the other individual ECG parameters; however, the Daniel score decreased significantly after the BPA procedure (Table 4). There was no significant difference between the baseline and postop states regarding the number of ECG parameters that are supposed to be suggestive of RVH according to AHA recommendations [14] (Table 4).

Bivariate correlation analysis was performed between the amount of change in the echocardiographic and RHC parameters and the amount of change in the Daniel score and V2 T negativity (Table 5, Table 6). There was no significant correlation between the magnitude of change in any parameter and the magnitude of change observed in the Daniel score (Table 5). However, there were significant correlations between the magnitude of changes observed in systolic right ventricular pressure, mean pulmonary artery pressure, pulmonary vascular resistance, systemic vascular resistance, and magnitude of change in T wave amplitude on derivation V2 (Table 6).

Table 2
Demographic characteristics of the patients included in the study.

Age (years)		51.7 ± 14.3
Gender	Male, n (%)	14 (% 43.8)
	Female, n (%)	18 (% 56.2)
BMI (kg/m^2)		27.6 ± 6.6
Anticoagulation, n (%)		25 (% 78.1)
VKA, n (%)		14 (% 43.8)
NOAC, n (%)		11 (% 34.4)
Pulmonary endarterectomy, n (%)		15 (% 46.9)
DM, n (%)		2 (% 6.3)
HT, n (%)		3 (% 9.4)

BMI: Body mass index, VKA: Vitamin K antagonists, NOAC: New generation oral anticoagulants.
DM: Diabetes mellitus HT: Hypertension.

Table 3
Transthoracic echocardiographic findings and clinical and RHC data of patients obtained before – and scheduled 6th month visit after the procedure.

	Baseline	Scheduled 6th month visit	Magnitude of change	%95 Change İnterval	p
Systolic RVP (mmHg)	82.0 ± 18.6	65.6 ± 17.0	16.4 ± 19.1	8.3 / 24.4	<0.001
RA pressure (mmHg)	10.1 ± 5.1	9.3 ± 2.8	1.3 ± 5.0	−1.5 / 3.3	0.45
Mean PAP (mmHg)	50.3 ± 12.9	41.3 ± 9.5	9.1 ± 11.4	4.7/13.5	<0.001
PAWP (mmHg)	10.1 ± 2.3	10.3 ± 1.6	−1.1 ± 2.0	−0.9/0.7	0.78
CO (L/dk.)	4.4 ± 1.3	4.8 ± 0.9	−4.4 ± 1.6	−1.1/0.2	0.16
CI (L/dk./m^2)	2.4 ± 0.6	2.7 ± 0.6	−0.3 ± 0.9	−0.7/0.05	0.09
PVR (woods)	10.7 ± 5.2	7.4 ± 3.4	3.3 ± 4.9	1.4/5.2	0.001
SVR (woods)	19.3 ± 4.9	15.9 ± 4.0	3.4 ± 6.8	0.6/6.3	0.021
WHO	2.9 ± 0.6	2.4 ± 0.8	0.4 ± 0.7	0.2/0.7	0.003
BNP (pg/ml)	2251 ± 4190	1407 ± 3420	844 ± 4262	−720/2407	0.27
RV bazal diameter (mm)	46.7 ± 7.6	45.2 ± 7.1	1.5 ± 4.8	−0.4/3.3	0,11
RA area (cm^2)	24.7 ± 8.6	21.6 ± 7.8	3.1 ± 6.7	0.6/5.6	0.02
TAPSE (mm)	14.6 ± 4.3	15.0 ± 4.7	−0.4 ± 2.8	−1.5/0.6	0.41
RVS (cm/sn)	9.9 ± 2.6	10.6 ± 3.4	0.7 ± 2.5	−1.6/0.3	0.15
Peak TR jet (m/s)	4.1 ± 0.7	3.9 ± 0.8	0.3 ± 0.6	0.05/0.5	0.018
EF (%)	60.6 ± 8.5	60.3 ± 8.2	0.3 ± 10.7	−3.5/4.1	0.87
LVEDD (mm)	43.3 ± 6.8	43.3 ± 5.8	0.03 ± 3.7	−1.4/1.4	0.96
LVESD (mm)	27.5 ± 5.6	27.6 ± 5.1	−0.1 ± 4.4	−1.7/1.5	0.90
Septum (mm)	9.8 ± 1.4	9.9 ± 1.8	−0.1 ± 1.3	−0.6/0.4	0.70
Post. wall (mm)	9.4 ± 1.1	9.4 ± 1.4	0.03 ± 1.4	−0.5/0.6	0.90

BNP: Brain natriuretic peptide, CI: Cardiac index, CO: Cardiac output, EF: Ejection fraction, LVEDD: left ventricle end-diastolic diameter, LVESD: Left ventricle end-systolic diameter, PAP: Pulmonary artery pressure, PAWP: Pulmonary artery wedge pressure, PVR: Pulmonary vascular resistance, RA: Right atrium, RV: Right ventricle, RVP: Right ventricular pressure, RVS: Tricuspid annular systolic velocity, SVR: Systemic vascular resistance, TAPSE: Tricuspid annular plane systolic excursion, TR: Tricuspid regurgitation, WHO: World health organization.

The intraobserver intraclass correlation coefficients (ICCs) for V1R, V5S, and the V2 T wave amplitude were 0.82, 0.80, and 0.78, respectively.

Discussion

We observed that negative T waves on derivation V2 at baseline tended to become positive after the BPA procedure in our study. The magnitude of alteration in T waves on V2 was correlated with the magnitude of change in systolic right ventricular pressure, mean pulmonary artery pressure, pulmonary vascular resistance, and systemic vascular resistance. In addition, a significant decrease was observed in the Daniel score after the procedure.

Although ECG scores have been proposed in the literature that predict severity and prognosis in acute pulmonary embolism, there are not enough data on ECG changes that might be associated with severity and

Table 4
Electrocardiographic parameters obtained at baseline and scheduled 6th month visit after the procedure.

	Baseline	Scheduled 6th month visit	Magnitude of change	%95 CI	p
IR (mm)	4.5 ± 2.1	4.6 ± 2.2	−0.8 ± 1.7	−0.7/ 0.6	0.81
IS (mm)	3.9 ± 3.0	4.0 ± 2.9	−0.5 ± 1.9	−0.8/ 0.6	0.88
IIp (mm)	1.3 ± 0.5	1.4 ± 0.5	−0.1 ± 0.5	−0.3/ 0.08	0.24
IIIR (mm)	6.4 ± 6.0	6.4 ± 4.9	0.03 ± 3.9	−1.4/ 1.5	0.96
IIIS (mm)	2.2 ± 1.8	2.1 ± 1.9	0.05 ± 2.0	−0.7/ 0.8	0.88
avR R (mm)	2.8 ± 1.8	2.6 ± 1.6	0.2 ± 1.3	−0.3/ 0.6	0.50
V_1R (mm)	5.3 ± 4.5	5.8 ± 7.0	−0.5 ± 6.6	−2.8/ 1.9	0.70
V_1S (mm)	3.1 ± 2.7	3.7 ± 3.1	−0.6 ± 2.2	−1.4/ 0.2	0.14
V_5R (mm)	10.5 ± 6.9	5.1 ± 3.2	0.9 ± 5.7	−1.2/ 2.9	0.39
V_5S (mm)	5.7 ± 4.5	5.1 ± 3.2	0.6 ± 4.4	−1.0/ 2.2	0.46
V_6R (mm)	8.2 ± 4.3	8.5 ± 4.0	−0.4 ± 4.6	−2.0/ 1.3	0.67
V_6S (mm)	3.8 ± 2.5	3.8 ± 2.5	0.08 ± 2.7	−0.9/ 1.0	0.86
V_1 T (mm)	−1.4 ± 1.2	−1.2 ± 1.1	−0.30 ± 1.0	−0.7/ 0.07	0.11
V_2 T (mm)	−0.8 ± 2.4	1.3 ± 2.6	−0.9 ± 2.3	−1.7/ −0.06	0.036
V_3 T (mm)	−1.1 ± 3.5	−0.4 ± 3.0	−0.7 ± 2.5	−1.6/ 0.2	0.12
QRS axis	63.0 ± 60.0	74.0 ± 50.0	−11.7 ± 43.4	−27.3/ 4.0	0.14
Heart rate (beats/min)	81.4 ± 13.6	85.3 ± 15.3	−3.9 ± 1 7.0	−10.1/ 2.2	0.20
V_1R + V_5S	11.1 ± 7.5	10.9 ± 8.3	0.1 ± 6.8	−2.3/ 2.6	0.92
V_1R/V_1S	2.2 ± 2.6	2.9 ± 4.8	−0.7 ± 3.7	−2.2/ 0.8	0.33
V_5R/V_5S	2.9 ± 3.3	2.5 ± 2.2	0.4 ± 3.1	−0.8/ 1.5	0.51
V_6R/V_6S	2.8 ± 2.2	2.8 ± 2.5	−0.06 ± 2.5	−1.0/ 0.9	0.9
Daniel Score	8.2 ± 5.7	6.6 ± 5.6	1.7 ± 4.2	0.1/3.2	0.035
Number of ECG parameters suggestive of RVH	6.3 ± 3.5	5.8 ± 3.4	0.6 ± 2.5	0.3/1.5	0.19

RVH: Right ventricular hypertrophy.

prognosis in chronic pulmonary hypertension. Acute alterations in hemodynamics achieved by the BPA procedure gave us the opportunity to evaluate the effect of hemodynamic alterations on ECG in a population of patients with chronic pulmonary hypertension.

In previous studies, it has been shown that V_1 – V_3 T wave negativity is successful in demonstrating right ventricular strain in patients with acute pulmonary embolism [16]. In our study, we observed that V_2 T negativity decreased and that the values tended to be positive in many patients, indicating that right ventricular strain is reduced in patients who underwent balloon pulmonary angioplasty. Although V_1 and V_3 T waves were also observed to decrease, the difference between the baseline and postprocedural state failed to reach statistical significance. Significant alteration of T waves specific to lead V_2 might indicate the regional variability of right ventricular strain. The fact that the change in V_1 and V_3 did not reach statistical significance may be related to the low number of patients. It is possible that the changes in V_1 and V_3 will reach a significant level with the increase in the number of patients.

It has been suggested in previous studies that V_1-V_3 T negativity and ST depression, which indicate RV strain, rather than electrocardiographic right ventricular hypertrophy criteria, might be more sensitive in predicting the severity of pulmonary hypertension in patients with pulmonary hypertension [17]. Our observation of a significant change in V2 t, which is assumed to be a marker of right ventricular strain, without a significant change in right ventricular hypertrophy criteria is in agreement with these studies. The significant correlation of the magnitude of change in the T waves on lead V2 with the magnitude of change in the mean pulmonary artery pressure, systolic pulmonary artery pressure, and pulmonary vascular resistance might be indicative of the mechanistic association between right ventricular strain and T waves on V2. There were no significant alterations after BPA in ECG parameters that are suggestive of electrocardiographic right ventricular hypertrophy in our study. The lack of a significant decrease in right ventricular hypertrophy in the presence of decreased RV strain might be related to the fact that not enough time had passed for the regression of the hypertrophic changes. The mean pulmonary artery pressure after the procedure was 41.3 ± 9.47, which is above the upper limit (25 mmHg). The persistence of pulmonary hypertension after BPA in most of the patients might also have contributed to the persistence of structural changes in the right ventricle.

Approximately half of the patients included in our study had undergone PEA surgery for chronic thromboembolic pulmonary hypertension. Changes made by open heart surgery on the myocardium (such as cannulation and incision scars) might have decreased the sensitivity of post-BPA electrocardiography in detecting postprocedural alterations in right ventricular hypertrophy and strain in those patients. Heterogeneity related to the time interval from surgery to BPA might also complicate the interpretation of electrocardiographic alterations.

A scoring system predicting increased pulmonary artery pressure in pulmonary embolism was developed in 2001 by Daniel et al. [18]. The Daniel score was found to correspond to the degree of perfusion defect on the ventilation-perfusion lung scan, and a score of >8 predicted the worsening of clinical outcomes, including death, shock, or respiratory failure [19]. The Daniel score was observed to decrease significantly in CTEPH patients after BPA in our study. The lack of a significant association between the magnitude of change in the Daniel score and the magnitude of change in the clinical parameters and parameters obtained from echocardiography and/or RHC suggests that the main reason for the decrease in the Daniel score was the decrease in right ventricular strain (V_2 t).

Nishiyama et al. [12] investigated ECG changes in 60 patients after balloon pulmonary angioplasty. The authors reported that a change in the sum of the V_1 R and V5 S waves of >10 mm indicated a better functional status [15]. A change in the sum of the V_1 R and V_5 S of >10 mm was observed in only 2 patients in our study, and a statistical analysis could not be performed.

Waligóra et al. [13] examined the effect of medical treatment on ECGs in a study population of 80 patients with PAH and 11 patients with inoperable CTEPH. In this study, reductions in RV_1, $maxRV_{1,2} + maxS_1$ aVL – SV_1, and PII were found to be proportional to hemodynamic improvement after medical therapy for pulmonary hypertension. The majority of patients evaluated in that study were PAH patients. We did not observe significant alterations in these parameters after BPA. The difference in patient population might be related to this discrepancy, as our study population consisted of only CTEPH patients undergoing the BPA procedure.

Piłka et al. [14] studied ECG alterations in 29 CTEPH patients undergoing BPA along with 7 patients with PAH. The authors reported significant changes in the T wave axis, QRS axis, P wave amplitude and duration in II, R wave amplitude in V_1, R:S ratio in V_1, S wave amplitude in V_5, R wave amplitude in V_5, R:S ratio in V5, S wave amplitude in V_6, R wave amplitude in V_6, and R wave amplitude in aVR. We enrolled all consecutive patients with CTEPH who had undergone BPA in our study; however, patients with CTEPH had to be 'responders' to BPA to be enrolled in the study of Piłka et al. We did not observe significant

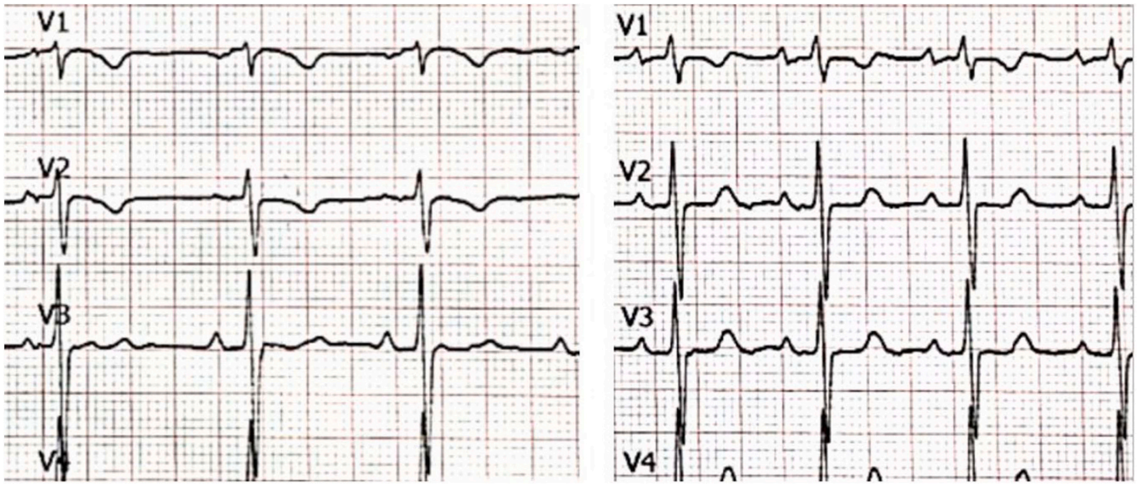

Fig. 1. Schematic example of T wave alterations in V_1, V_2 and V_3 after the BPA procedure.

Table 5
Correlation between the magnitude of change in Daniel score with magnitude of change in echocardiography and RHC parameters.

	R	p
Δ Systolic RVP	0.31	0.15
Δ Mean PAP	0.16	0.43
Δ PVR	0.29	0.13
Δ RA area	−0.14	0.48
Δ WHO	0.30	0.10
Δ SVR	0.30	0.15

PAP: Pulmonary arterial pressure, PVR: Pulmonary vascular resistance, RA: Right atrium, RVP: Right ventricular pressure, SVR: Systemic vascular resistance, WHO: World health organization.

Table 6
Correlation between the magnitude of change in T wave amplitude on derivation V2 with magnitude of change in echocardiography and RHC parameters.

	R	p
Δ Systolic RVP	−0.51	0.01
Δ Mean PAP	−0.40	0.036
Δ PVR	−0.49	0.009
Δ RA area	−0.34	0.068
Δ WHO	−0.25	0.18
Δ SVR	−0.51	0.011

PAP: Pulmonary arterial pressure, PVR: Pulmonary vascular resistance, RA: Right atrium, RVP: Right ventricular pressure, SVR: Systemic vascular resistance, WHO: World health organization.

alterations in the abovementioned ECG parameters. Piłka et al. accepted patients as 'responders' if the mean pulmonary artery pressure was reduced by at least 10 mmHg. In our study, there were only 14 patients who met this criterion, and we believe that the data of the non-responders enrolled in our study might have diminished the observed global effect of BPA on electrocardiography.

Limitations

The low patient number was the main limitation of our study. Patient enrollment in such a study is difficult because of the relatively low frequency of CTEPH. BPA is the second treatment option after PEA in patients with CTEPH, which also limits the number of patients for enrollment. There was a wide degree of heterogeneity related to the hemodynamic condition of patients included in this study and their degree of response to treatment. Variation related to the degree of response to BPA might have complicated the observed effect of BPA-induced ECG alterations in our study. However, the alteration in the T wave on V2 was consistent even in this study population with a low patient number and a wide range of heterogeneity.

Conclusion

Simple and easily accessible ECG enabled us to estimate the level of hemodynamic improvement after BPA in CTEPH patients. We believe that this finding may have value in clinical practice.

CRediT authorship contribution statement

Ayhan Kol: Conceptualization, Methodology, Data curation, Formal analysis, Investigation. **Alper Kepez:** Conceptualization, Methodology, Data curation, Formal analysis. **Dursun Akaslan:** Data curation. **Batur Kanar:** Data curation **Halil Atas:** Conceptualization, Methodology, Data curation. **Bulent Mutlu:** Conceptualization, Methodology, Data curation.

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