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Electrocardiographic findings in children with different degrees of pulmonary regurgitation following surgical correction of tetralogy of Fallot

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Abstract

Background and aim: To analyse selected electrocardiographic (ECG) parameters in children after correction of tetralogy of Fallot (TOF).

Methods: The study group consisted of 65 patients with surgically corrected TOF aged 6 to 18 years, and the time since surgical correction ranged from 6 to 18 years. The patients were divided into two groups based on the degree of pulmonary regurgitation (PR) in ECHO-2D. Group I consisted of patients with mild/moderate PR, and Group II of patients with severe PR. The QT dispersion in standard resting ECG, QRS complex width and QT interval duration at rest and at the maximal exertion during a treadmill test were compared between the two groups.

Results: Group I included 52 patients and Group II included 13 patients. Mean QT dispersion was 67 ± 27 ms in Group I *vs* 91 ± 37 ms in Group II ($p < 0.05$). During the treadmill test, mean QRS duration at rest and at peak exertion in Group I was 128 ± 27 ms and 119 ± 27 ms, respectively, and 149 ± 10 ms and 165 ± 11 ms, respectively, in Group II ($p < 0.003$ and $p < 0.001$). Differences between QRS complex duration at peak exertion and at rest (ΔQRS) in Groups I and II were –9 ± 12 ms and +14 ± 7 ms ($p < 0.001$). During the treadmill test, mean QT interval at rest and at peak exertion in Group I was 392 ± ± 52 ms and 328 ± 63 ms, respectively, and 367 ± 25 ms and 370 ± 35 ms, respectively, in Group II (NS and $p < 0.08$). Differences between QT interval at peak exertion and at rest (ΔQT) in Groups I and II were –60 ± 56 ms and +2 ± 21 ms, respectively ($p < 0.001$).

Conclusions: In children with severe PR after TOF correction, no physiological shortening of QRS duration and QT interval during exertion is seen. The QT dispersion in resting ECG is higher in children with severe PR than in children with mild/moderate PR.

Key words: tetralogy of Fallot, QT dispersion, QRS complex, pulmonary regurgitation

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INTRODUCTION

Outcomes of surgical treatment in children with tetralogy of Fallot (TOF) are currently good. In the recent years, further significant improvement has occurred with single-stage corrective procedures performed even in younger patients. However, many patients after TOF correction still require attention due to various long-term problems including residual ventricular septal defect, pulmonary regurgitation (PR) of varying degree, secondary right ventricular (RV) outflow tract obstruction, and more remotely, life-threatening cardiac arrhythmias [1, 2].

The most commonly reported electrocardiographic (ECG) abnormalities predisposing to arrhythmia include QRS complex duration above 180 ms (170 ms in children), prolonged QT interval, and increased QT dispersion (QTd) [3, 4]. According to Kubicka [5], antiarrhythmic drug therapy in children following TOF correction should be considered in case of more than 10 ventricular premature beats per hour and/or more than 10 couplets per hour during Holter monitoring, ventricular arrhythmia during exercise test, and documented ventricular tachycardia (VT) with a history of syn-

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cope or presyncope. Treatment decisions should always be individualised.

Haemodynamic disturbances arising from residual defects in TOF necessitate limitations of physical activity following surgical correction due to a risk of cardiac arrhythmia, thus contributing to impaired exercise tolerance [3]. The most commonly seen haemodynamic abnormality in children following TOF correction is PR which progresses in some patients, resulting in irreversible RV dysfunction. The underlying causes and indications for pulmonary valve replacement in these circumstances are thus hotly debated in literature [6].

The aim of our study was to analyse selected ECG parameters in children with different degrees of PR after surgical correction of TOF.

METHODS

Study group

We studied 65 children aged 6–18 years (median age 10 years) after surgical correction of TOF. Patient age at the time of surgical correction was 4 to 36 (median 7) months, and the time since surgical correction ranged from 6 to 18 (median 10) years. In six (9.2%) children, correction was preceded by placement of a Blalock-Taussig shunt, and the surgical procedure was single-staged in the remaining patients. A residual, haemodynamically insignificant ventricular septal defect was noted after the surgery in four (6.1%) patients.

Echocardiography

Echocardiography including conventional and colour Doppler examination was performed with simultaneous ECG lead II recording. Examinations were performed by the same echocardiographer in all patients. Evaluated parameters included RV end-diastolic dimension (RVEDD) in M-mode imaging and the degree of PR by Doppler evaluation. Tables with normal values according to body surface area were used to assess RVEDD measured in M-mode [7]. In all cases, a ratio of the measured value and the predicted normal value for a given body surface area was calculated and expressed as percentage. The severity of PR was estimated semiquantitatively and divided into three grades, similarly to other studies in children. Pulmonary regurgitation was considered mild (grade 1) if the regurgitation jet was recorded using colour Doppler and pulsed wave Doppler only within the RV outflow tract, moderate (grade 2) if the regurgitant diastolic flow was recorded in the pulmonary trunk, and severe (grade 3) if the regurgitant diastolic flow was recorded in the pulmonary arteries [8]. Depending on the degree of PR, the patients then were divided into two groups. Group I consisted of patients with mild//moderate PR, and Group II of patients with severe PR.

Electrocardiography

Electrocardiographic data were analysed independently by two observers at the paper speed of 50 mm/s. If the measured values were discordant, the arithmetic mean of the two measurements was calculated. Interobserver differences were noted in 8.6% of all measurement and ranged from 2.6% to 7.6% (mean 4.4%). A standard resting 12-lead ECG was performed and R-R intervals, QRS complex duration and QT intervals were measured in all leads. The end of the T wave was defined as the point where the tangent to the descending arm of the T wave crossed the isoelectric line. If a U wave was observed, it was included in the calculations of the QT interval if its amplitude was more than 50% of the amplitude of the preceding T wave. In the remaining cases, the U wave was not included in the calculations of QT interval, and the end of the T wave was defined as the nadir between the T wave and the U wave. The QT interval and QRS duration measurements were performed in three subsequent beats and the arithmetic mean was calculated. The QTd was defined as the difference between QT interval values measured in the leads with the longest and the shortest QT.

Ventricular arrhythmias were evaluated in 24-h Holter monitoring. Arrhythmia was considered to be present if frequent ventricular ectopy (> 10 bpm) or complex arrhythmia including VT, ventricular flutter or ventricular fibrillation were noted.

Treadmill exercise test was performed using the Bruce protocol. Test was terminated at patients request due to fatigue precluding further exercise. No other indications for exercise test termination were noted. During the test, 12-lead ECG was continuously monitored. The R-R intervals, QRS complex duration and QT intervals were measured in all leads at rest and at the peak exercise. The end of the T wave, QT interval, QRS duration, and QTd were defined or measured, respectively, analogously to the resting ECG. The isoelectric line was defined drawing a straight line through the initial points of three subsequent QRS complexes. Arrhythmia occurrence during exercise was defined as the occurrence of ventricular arrhythmia during exercise or within 3 minutes following its termination.

The study was approved by the ethics committee at the Medical University of Warsaw.

Statistical analysis

We calculated mean values and SD for all evaluated variables. We compared results obtained in patients in Groups I and II. The Shapiro-Wilk test was used to evaluate normal distribution of the study variables. Differences between the mean values in both groups were evaluated using the Mann-Whitney U test. A p value < 0.05 was considered statistically significant. Distribution of the variables in the two populations was compared using the Fisher-Yates test.

Table 1. Comparision of ECG parameters at rest and peak exertion

Variable	Mild/moderate pulmonary regurgitation (n = 52)	Severe pulmonary regurgitation (n = 13)	P
Age [years]	11.1 ± 4.1	12.8 ± 3.6	0.45
Time since correction [years]	11.1 ± 4.0	12.7 ± 3.6	0.45
Single-stage correction [%]	96	69	**0.01**
Right ventricular end-diastolic dimension [mm]	115 ± 20	148 ± 23	**< 0.001**
Resting ECG:	**N = 52**	**N = 13**	
Heart rate [bpm]	90 ± 11	85 ± 10	0.42
QRS [ms]	128 ± 27	149 ± 10	**0.003**
Right bundle branch block [%]	73	100	0.16
QT [ms]	392 ± 52	367 ± 25	0.16
QTd [ms]	67 ± 27	91 ± 37	**0.03**
ECG at peak exertion:	**N = 28**	**N = 8**	
HR [bpm]	157 ± 15	161 ± 19	0.82
QRS [ms]	119 ± 27	165 ± 11	**< 0.001**
QT [ms]	328 ± 63	370 ± 35	**0.008**
QTd [ms]	76 ± 21	99 ± 35	**0.04**
ΔQRS [ms]	–9 ± 12	14 ± 7	**0.001**
ΔQT [ms]	–60 ± 56	2 ± 21	**< 0.001**
ΔQTd [ms]	15 ± 37	8 ± 27	0.14
Arrhythmia:			
Patients with ventricular arrhythmia	7 (13.4%)	3 (23.1%)	NS
VEB number per 24 h	4888 ± 4092	8345	NS
Patients with complex ventricular arrhythmia (VT)	3 (5.7%)	1 (7.7%)	NS

QTd — QT dispersion; ΔQRS — difference between QRS duration at peak exertion and QRS duration at rest; ΔQT — difference between QT interval at peak exertion and QT interval at rest (measured in lead II); ΔQTd — difference between QT dispersion calculated at peak exertion and QT dispersion calculated at rest; VEB — ventricular ectopic beats; VT — ventricular tachycardia

RESULTS

Based on clinical history data, all children were in New York Heart Association functional class I. In two patients, episodes of vasovagal syncope were observed.

In echocardiographic examination, RVEDD was on average 122 ± 24% of the normal value. A significant positive correlation was found between the duration of follow-up and the size of the RV expressed as a percentage of the mean normal value (r_{xy} = +0.371; $p < 0.05$; Fig. 1). Based on the degree of PR, 52 patients were included into Group I and 13 patients into Group II. The RVEDD was 115 ± 20% of the mean normal value in Group I compared to 148 ± 22% in Group II ($p < 0.05$).

Complete right bundle branch block was found in ECG in 51 (78%) patients. Mean QRS duration was 132 ± 26 ms, and mean QTd 68 ± 39 ms.

Exercise test was performed in 36 (55.4%) patients, including 28 patients in Group I and 8 patients in Group II. In all patients, the exercise test was terminated due to fatigue. No shortening of QRS or QT interval during exercise was found in 11 children in Group I and 8 children in Group II. Changes in QRS duration and QT interval at peak exertion compared to the resting values in both study groups are summarised in Table 1. Mean QTd at peak exertion was significantly higher in children with severe PR compared to children with mild/

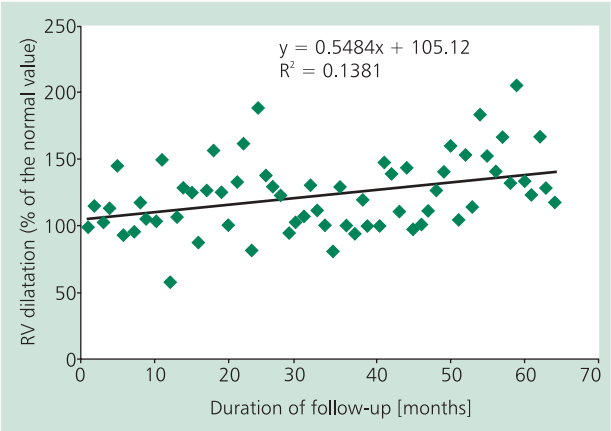

Figure 1. Correlation between the size of the right ventricle (RV) and the duration of follow-up

/moderate PR, while ΔQTd values did not differ significantly between these patient groups.

Ventricular arrhythmia in 24-h Holter monitoring and/or during exercise test was found in 10 (15.3%) patients, including complex ventricular arrhythmia (short episodes of non-sustained VT — nsVT) in four (6.1%) patients. In children with ventricular arrhythmia, mean resting QRS duration was 151 ms ± 10 ms compared to 129 ms ± 26 ms in patients without ventricular arrhythmia ($p < 0.05$).

In Group I, ventricular arrhythmia was found in 7 (13%) children (including 4 children with arrhythmia in Holter monitoring, 2 children with arrhythmia during exercise test, and one child with arrhythmia both in Holter monitoring and during exercise test). In three of these patients, complex ventricular arrhythmia (nsVT) was seen, and premature ventricular beats were noted in the remaining patients. In Group II, arrhythmia was found in 3 (23%) children, including one patient with arrhythmia in Holter monitoring (nsVT) and 2 patients with arrhythmia during exercise test (premature ventricular beats). In all patients with arrhythmia, ventricular ectopy was characterised by left bundle branch block morphology.

During follow-up (46.7 ± 26.8 months) of patients with ventricular arrhythmia, we noted no incidences of sudden death, cardiac arrest, unexplained syncope or other arrhythmia-associated symptoms.

DISCUSSION

Severe PR with associated RV dilation, complex arrhythmia, and a significant reduction of exercise tolerance during follow-up are among the indications for the implantation of pulmonary valve homograft in patients with repaired TOF. In practice, choosing the optimal timing of pulmonary valve replacement is very difficult, as patients often remain asymptomatic despite advanced haemodynamic changes. On the other hand, too late surgical intervention results in irreversible haemodynamic disturbances due to permanent myocardial structural damage. Thus, it is reasonable to search for additional parameters that would reflect increasing haemodynamic disturbances and help in patient selection for invasive treatment.

Our study showed lack of shortening of QRS duration during exercise in most children with severe PR, while it was usually preserved in patients with mild to moderate PR. These results are discordant with the findings of van den Berg et al. [3] who were unable to show significant differences in QRS duration before and after exercise in children with TOF compared to a healthy control group. Of note, however, mean QRS duration in standard ECG reported by these authors was shorter than in our study (113 ms *vs* 132 ms, respectively). Perhaps abnormal response of QRS duration to exercise manifests only in those with increased QRS duration in resting ECG. In a study by Budts et al. [9], abnormal QRS prolongation during exercise was noted in adult patients following repair of TOF. In the latter study, mean QRS duration in these patients was 153 ms. As suggested by these authors, lack of QRS shortening reflects impaired myocardial depolarisation which in turn leads to increasing haemodynamic disturbances and reduced exercise tolerance in such patients. Abnormal response of QRS duration to exercise may thus be useful in selecting patients with corrected TOF for reoperation with the use of pulmonary homograft or interventional treatment before permanent myocardial damage ensues [10, 11].

Increased QTd is also considered a predictor of life-threatening arrhythmia [11], but there are no data in the literature showing differences in QTd in resting ECG depending on the degree of PR. In our patients with severe PR, QTd in resting ECG was increased compared to patients with mild to moderate PR. Van den Berg et al. [3] noted increasing QTd during exercise in patients with increasing severity of PR, while such differences were not seen in resting ECG.

It is widely accepted that severe PR with associated RV dilatation and QRS duration > 180 ms in resting ECG in children are significant risk factors of life-threatening ventricular arrhythmia [5]. According to Rahman et al. [12] the relation between the size of the RV and QRS duration is not a direct one. As suggested by these authors, QRS duration is also affected by other factors such as duration of follow-up. This was in part confirmed by Helbing et al. [4] who showed that increase in QRS duration during long-term follow-up was a predictor of complex arrhythmia. In our study, we also found significantly longer QRS duration in children with ventricular arrhythmia compared to patients without arrhythmia.

In summary, depolarisation and repolarisation abnormalities found in patients after correction of TOF may in future prove helpful in selecting patients for replacement of an incompetent pulmonary valve even if haemodynamic disturbances are still not very severe, which might allow avoiding myocardial degeneration and irreversible structural changes, especially with the fact that new interventional treatments are becoming more available and safer.

Limitations of the study

Clinical significance of our findings is difficult to assess due to a limited number of patients (n = 36) who underwent exercise test. Perhaps further analyses of changes in QRS duration, QT interval and QTd following surgical correction of TOF will clarify whether these variables are of clinical importance as predictors of life-threatening arrhythmia or impaired haemodynamic function of the RV.

CONCLUSIONS

1. In children with severe PR after surgical correction of TOF, there is no physiological shortening of QRS duration and QT interval during exertion.
2. QT dispersion is higher in children with severe PR than in children with mild/moderate PR.

Conflict of interest: *none declared*

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Ocena elektrokardiogramu u dzieci po korekcji zespołu Fallota z różnym stopniem niedomykalności zastawki płucnej

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Streszczenie

Wstęp i cel: Celem pracy była analiza wybranych parametrów zapisu elektrokardiograficznego (EKG) u dzieci po operacji naprawczej zespołu Fallota z różnym stopniem niedomykalności zastawki tętnicy płucnej.

Metody: Grupę badaną stanowiło 65 dzieci w wieku 6–18 lat, po korekcji zespołu Fallota. Czas od wykonania zabiegu operacyjnego wyniósł 6–18 lat. Przeprowadzono badanie echokardiograficzne z badaniem przepływów metodą doplerowską konwencjonalną i kodowaną kolorem. Na podstawie stopnia niedomykalności zastawki tętnicy płucnej pacjentów podzielono na dwie grupy: grupę I stanowili chorzy z niedomykalnością łagodną i umiarkowaną, grupę II — dzieci z ciężką niedomykalnością. Porównano dyspersję odstępu QT w spoczynkowym badaniu EKG oraz czas trwania zespołu QRS i odstępu QT przed i na szczycie wysiłku podczas próby wysiłkowej między pacjentami z grupy I i II.

Wyniki: Do grupy I włączono 52 pacjentów, a do grupy II — 13 osób. W spoczynkowym EKG dyspersja QT w całej populacji wynosiła średnio 68 ± 39 ms, u chorych z grupy I — średnio 67 ± 27 ms, u pacjentów z grupy II — 91 ± 37 ms (test Mann-Whitney, $p < 0,05$). Podczas próby wysiłkowej u osób z grupy I średni czas trwania zespołu QRS przed i na szczycie wysiłku wyniósł odpowiednio 128 ± 27 ms i 119 ± 27 ms, natomiast u pacjentów z grupy II odpowiednio 149 ± 10 ms i 165 ± 11 ms. Różnica czasu trwania zespołu QRS na szczycie wysiłku i w spoczynku (ΔQRS) w grupie I wyniosła –9 ± 12 ms w grupie II +14 ± 7 ms. Średni czas trwania odstępu QT przed i na szczycie wysiłku u chorych z grupy I wyniósł odpowiednio 392 ± 52 ms i 328 ± 63 ms, a u pacjentów z grupy II — 367 ± 25 ms i 370 ± 35 ms. Różnica czasu trwania odstępu QT na szczycie wysiłku i w spoczynku (ΔQT) w grupie I wyniosła –60 ± 56 ms, a w II grupie — +2 ± 21 ms. Różnice ΔQRS i ΔQT między pacjentami z grupy I i grupy II były statystycznie istotne.

Wnioski: U chorych z ciężką niedomykalnością zastawki tętnicy płucnej często obserwuje się brak fizjologicznego skracania zespołu QRS i odstępu QT w czasie wysiłku. Dyspersja QT w spoczynkowym EKG jest większa u pacjentów z ciężką niedomykalnością zastawki tętnicy płucnej niż u dzieci z niedomykalnością łagodną i umiarkowaną.

Słowa kluczowe: zespół Fallota, dyspersja QT, zespół QRS, niedomykalność zastawki tętnicy płucnej

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