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CARDIAC MEMORY (T-WAVE MEMORY) AFTER ABLATION OF POSTEROSEPTAL ACCESSORY PATHWAY

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A b s t r a c t: *Background.* Cardiac memory is a phenomenon characterized by transient T-wave abnormalities occurring during normal sinus rhythm, after a period of altered ventricular depolarization, where the T-wave vector has the same direction as the vector of the previously altered QRS complex (T-wave inversion). It is a form of electrical remodelling of the ventricular, where the T-wave follows ("remembers") a previously altered QRS vector.

Methods and Results. Over a 5-year period (2002–2006), 525 consecutive patients underwent electrophysiological study. One hundred and one patients underwent ablation of the atrioventricular reentry tachycardia (AVRT) with an accessory pathway (AP). Forty-two of them were without delta wave on the electrocardiogram (concealed accessory pathway), and 58 patients had an open form of accessory pathways, with delta wave on EKG (Wolff-Parkinson-White syndrome) and only one patient had an accessory pathway between the right atrium and right bundle branch (Mahaim form). According to the location of the accessory pathway, 17 patients (29.3 %) had an accessory pathway in the right posteroseptal region. There was the highest percentage of the appearance of inversion of the T-wave in patients with this position of accessory pathway. T-wave changes were followed in the frontal plane (leads II, III, and aVF). Electrocardiogram (ECG) signs of cardiac memory were present in 16 of 17 (94.1 %) patients within one day after the ablation. The post-ablation T-wave vector had the same direction as the vector of the pre-excited QRS complex (and delta wave) creating inferior T-wave inversions. There was no correlation between the number or duration of energy applications and the extent of cardiac memory post ablation. A majority (90% of cases) of ECGs recorded 3 months after the procedure showed complete or almost complete normalization. None of the patients with T-wave inversion after ablation had a recurrence of preexcitation or tachycardia during the follow-up period of 12 ± 4 months.

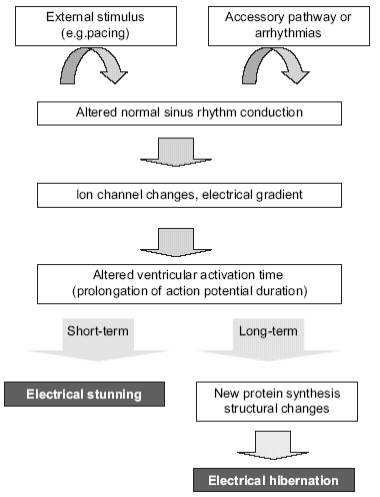
Conclusions. T-wave inversion in leads II, III and aVF with the disappearance of the delta wave after ablation of the accessory pathway in patients with Wolff-Parkinson-White syndrome (accessory pathway in the right posteroseptal region of the heart), is the most powerful marker of successful ablation.

Key words: T-wave memory, accessory pathway, catheter ablation, Wolff-Parkinson-White syndrome.

Introduction

T-wave abnormality was initially described in 1969 (Chatterjee), after ventricular pacing, and subsequently also after ventricular tachycardia, intermittent bundle branch block, and after periods of preexcitation in patients with Wolff-Parkinson-White syndrome (WPW syndrome). This phenomenon, which was named "cardiac memory" by Rosenbaum (1982), is characterized by persistent but reversible T-wave inversion as a result of abnormal activation of the ventricle.

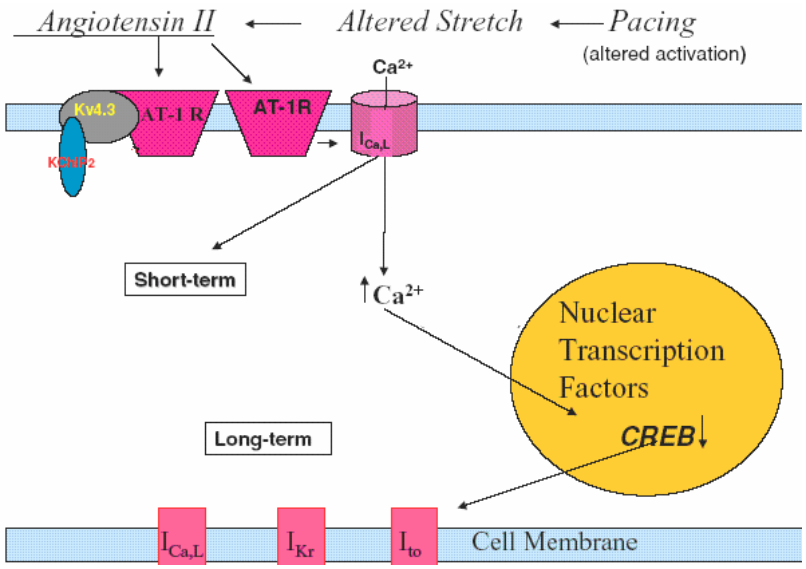
The magnitude of T-wave change increases with repetitions of the pacing periods or arrhythmias – referred to as 'accumulation' – and the T-wave changes persisted for a long interval (months or longer) after the return to the sinus rhythm. Because of this, there are two different periods for restoration after abnormal depolarisation: short and long-term cardiac memory. Zoghi suggests new terms for the short cardiac memory – electrical stunning, and for the long-term memory – electrical hibernation (Figure 1)



Zoghi M. *et. al.* Europace (2004) 6, 418

Figure 1 – Short and long term cardiac memory
Слика 1 – Краīка и долга̄ срцева меморија

Cardiac memory is an adaptation of the heart in the situation of opposite depolarisation vector via functional changes (phosphorylation) in ion channels (Rosen [2, 3] 1998, 2006). The mechanism which determines a short cardiac memory is a result of the stretching of cardiac cells after they start to release angiotensin II (Sadoshima and Izumo [5], 1993). Angiotensin II, via angiotensin II type-1 receptor (AT1), is an important mediator of stretch-induced hypertrophy, which increases protein synthesis and induces many genes for cardiac hypertrophy. Because of this, the calcium-intenstive transient outward potassium current (I_{to} receptor) starts to increase (Yu [6] 1999, Plotnikov [7, 8] 2003, 2004). The I_{to} receptor is responsible for early repolarisation (phase 1 of action potential when potassium ions leave the cell). The association between angiotensin II and alfa-subunit (Kv4.3) of the potassium receptor channel (I_{to}) was found by Doronin [9] [in] 2004. Activation of this channel is the mechanism of the short cardiac memory. The cyclic AMP response element binding protein-CREB (nuclear transcription factor) has a central role in the transition from short- to long-term cardiac memory, via a blockade of the AT1 receptor and activation of L- type Ca^{2+} channel (Patberg [10] 2003). In long-term cardiac memory, I_{to} potassium channel density decreases. (Figure 2)



Rosen MR. *et al.* J. Physiol (2006); 570; 209

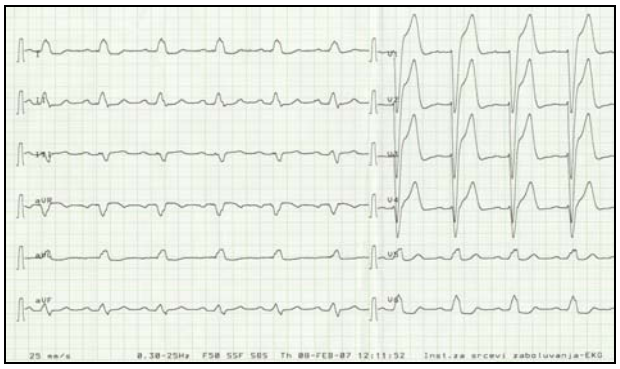
Figure 2 – Evolution of cardiac memory
Слика 2 – Создавање на срцевата меморија

T-wave inversion after cardiac pacing, ventricular tachycardia, bundle branch block and during ischaemic heart diseases

The differential diagnosis of precordial T-wave inversion (TWI) is a significant clinical challenge. Precordial TWI has a wide range of causes, from a normal ECG variant to hypertrophic cardiomyopathy, pericarditis, myocardial ischaemia and syndrome of diffuse precordial TWI associated with critical stenosis of the proximal left anterior descending artery (Wellens syndrome).

Prolonged alteration of the activation sequence in the heart ventricle has a variety of causes, including ventricular pacing (Chatterjee 1969), intermittent left bundle branch block (Luy 1944, Denes 1978) (Figure 3), ventricular tachycardia (Campell 1940, Geiger 1943) (Figure 4), ventricular extrasystoles (Levine, Lown 1952), and ventricular preexcitation (Nikolai 1981).

A



B

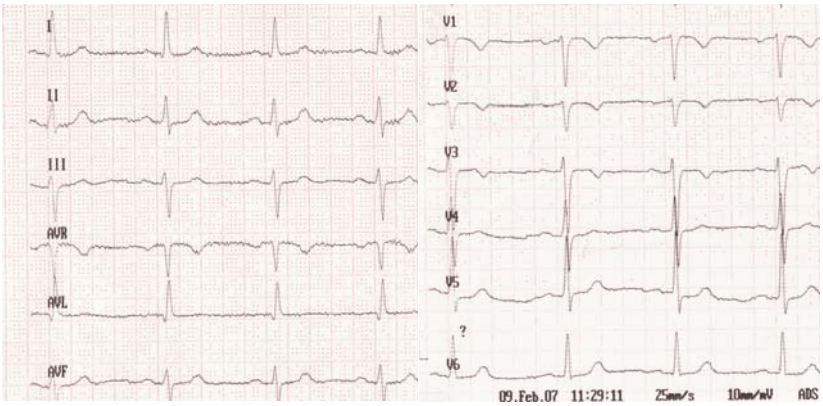
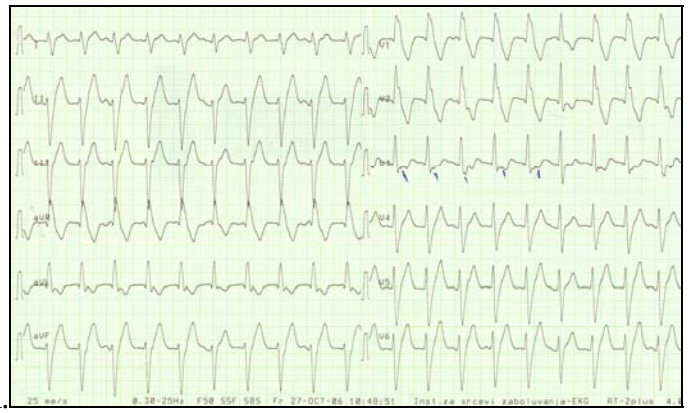


Figure 3 – A. Intermittent left bundle branch block; B. T-wave inversion (V1–V3) in same patients
Слика 3 – А. Повремен блок на левата главна гранка; Б. Т-бран инверзија (V1–V3) кај истиот пациент

These induce secondary T-wave changes not only during the period of altered activation sequence but possibly persisting after normal sinus rhythm activation. Terms such as "cardiac memory" and "accumulation" have been used to describe the phenomenon of T-wave changes persisting after normalization of the activation sequence, having increased magnitude and slower regression when the heart is exposed repeatedly to changes in activation sequence (Rosenbaum 1982).

A.



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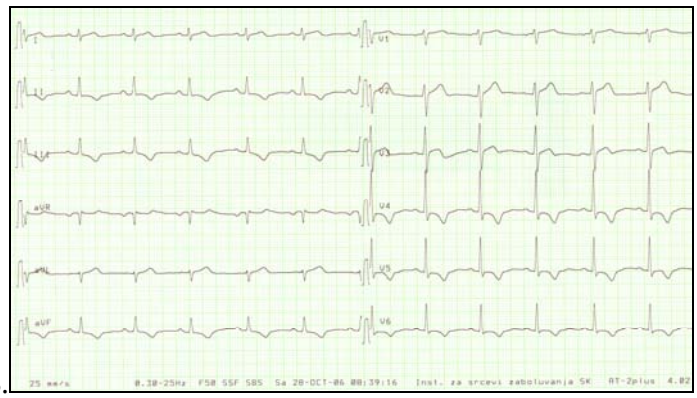


Figure 4 – A. Idiopathic left ventricular tachycardia; B. T-wave inversion during a sinus rhytam
Слика 4 – А. Идиопатска лево коморна тахикардија; Б. Т-бран инверзија за врема на синусен ритам кај истиот пациент

Post-pacing precordial T-wave inversion (TWI) (Figure 5), known as cardiac memory, mimics ischaemic precordial TWI, and there are no established ECG criteria that distinguish between them.

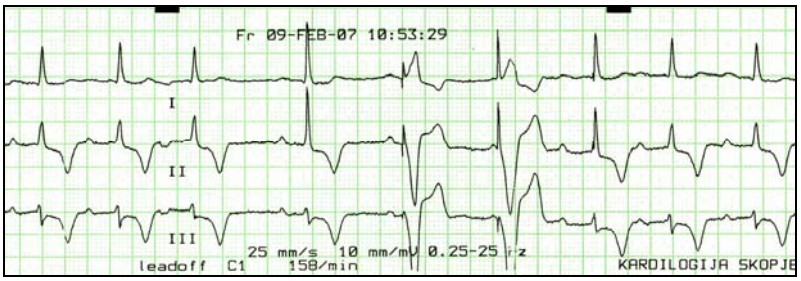


Figure 5 – T-wave inversion post cardiac pacing
Слика 5 – Т-бран инверзија по срцева електростимулација

In their study Josephson and Shvilkin [11] offer the combination of positive T (aVL), positive or isoelectric T (DI), and maximal precordial TWI (DII) > TWI (DIII) with 92% sensitive and 100% specific for cardiac memory, distinguishing it from ischaemic precordial TWI. (Figure 4)

Cardiac memory and Wolff-Parkinson-White syndrome

After intermittent (Figure 6) or permanent loss of ventricular preexcitation through an accessory atrioventricular connection, persistent T-wave abnormalities have been described. This phenomenon is a consequence of persistent abnormal ventricular repolarization secondary to the previously abnormal ventricular activation ("cardiac memory").

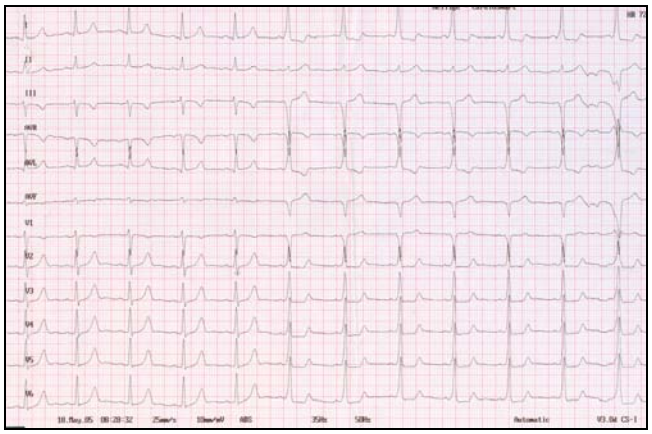


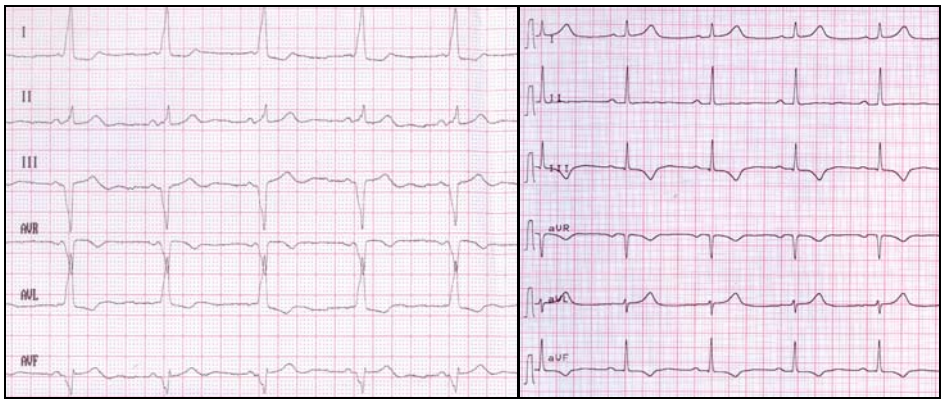
Figure 6 – Intermittent loss of ventricular preexitation (syndrome) with T-wave inversion in the leads with negative delta wave (DIII, aVF)

Слика 6 – Повремен губиток на коморната преексцитација (WPW синдром) со Т-бран инверзија во одводите кои се со негативен делта бран (DIII, aVF)

However, only anterograde conduction through an accessory pathway (manifest), with a delta wave on surface electrocardiography (Wolff-Parkinson-White syndrome) is associated with an alteration of the ventricular activation sequence. But if the accessory pathway is concealed (conducting retrogradely only), these patients do not have an altered ventricular activation, and they are without T-wave abnormality and without cardiac changes.

In early WPW studies there was little information about the occurrence and persistence of post-ablation T-wave abnormalities related to the accessory pathway location and the degree of preexcitation. Their investigation had excluded a relation between the T-wave alteration and radiofrequency ablation induced myocardial lesions by following cardiac enzymes and echocardiographic evaluations [14].

Kalbfleisch [12] found T-wave changes in 22 of 29 (76%) patients after ablation of accessory pathways in different locations. Wood [13] observed T-wave inversion in 47% of ablated patients in different locations. The highest occurrence of T-wave inversions was reported by Poole [15] in all 7 patients undergoing ablation of the posteroseptal accessory pathways. Similar results were published by Helguera [16], T-wave inversions in inferior leads in 96% of the patients after ablation of posteroseptal accessory pathways. The most recent study by Aunes-Jansson [17] shows a very high rate (98%) of T-wave inversions following ablation of 125 posteroseptal accessory pathways.



A. B.

Figure 7 – WPW syndrome (accessory pathway in right-postero-septal location) before (A) and after (B) the ablation with T-wave inversion in the leads which were with negative delta wave (DIII, aVF)

Слика 7 – WPW синдром (дополнителен пат на десно позади септално) пред (А) и по (Б) аблација со појава на Т-бран инверзија во одводите кои биле негативен делта бран (DIII, aVF)

Aim of the study

The aim of our study was to find a new marker for successful ablation of the accessory pathway, and to confirm the role of T-wave inversion as a sign of successful ablation.

Materials and Method

Over a period of 5 years, from 2002 until the end of 2006, 525 consecutive patients underwent electrophysiological study in our electrophysiological laboratory.

Electrophysiology testing and ablation protocol

Informed written consent was obtained from all patients before the electrophysiological study and radiofrequency ablation procedure. Antiarrhythmic agents were discontinued for at least 3 half-lives. Using standard technique, 3 quadripolar and 1 decapolar electrode catheters were introduced percutaneously (Daig, Cordis Webster). Mapping and ablation were performed by a 7F catheter with a deflectable curve (Medtronic, Cordis-Webster). Left-sided accessory pathways were ablated by a retrograde transaortic approach. Intracardiac electrograms were displayed and recorded on a multichannel oscilloscopic recorder. (CardioLab, Prucka Engineering) The pacing stimuli were delivered through a programmable stimulator (Bloom, radiofrequency current generator HAT 200 (Osypka) and Atakar II (Medtronic). The catheter position was monitored using fluoroscopy.

ECG interpretation (before RF ablation)

A simultaneous 12-lead electrocardiogram at a paper speed of 25 mm/s was recorded at the beginning of the ablation procedure as well as immediately and 60 minutes after successful ablation. Additional electrocardiograms were obtained 1 day after ablation and at 1 and 3 months follow-ups.

For the purposes of this study the focus was on the inferior frontal plane leads II, aVF and III, because they most clearly show cardiac memory. The T-wave polarity was classified as either positive (+), negative (–), biphasic (± or ±) or isoelectric (0), and compared with the delta wave and the dominant QRS force prior to ablation in each of the leads II, aVF and III.

In order to estimate the degree of preexcitation the QRS width (QRS duration including the delta wave) in these leads was measured prior to and immediately after the ablation procedure, and the difference was calculated.

Statistical analysis

Descriptive data are presented as mean ± standard deviation (SD). Categorical data were compared by contingency tables or cross-tabulation and statistically evaluated by the Chi-square test or the Wilcoxon–Mann–Whitney test. A p-value < 0.05 was considered statistically significant.

Results

T-wave alterations (cardiac memory) were observed in 16 out of 17 patients (94.1%) within one day after ablation. These were patients with accessory pathways in the right-postero-septal region of the heart, but only in patients with WPW syndrome (Figure 7).

There were 58 patients (57.4%) with an open accessory pathway, WPW syndrome (Table 1). The majority of the patients had single accessory pathways (55pts, 94.8%). Only in 3 pts (5.2%) were dual accessory pathways found (one on the left side, and one in the right postero-septal location). The location of the accessory pathways in the group of patients with delta wave is shown in Table 2 and the group without delta wave, concealed accessory pathway in Table 3.

Table 1 – Табела 1

Total patients with accessory pathways (preexitation syndrome)
AVRT – antrio-ventricular reentry tachycardia
Сите пациенти со дополнителен пат (преексцитациски синдром)
AVRT – предкоморно-коморна кружна тахикардија

AVRT (concealed accessory pathway)	**42**	**41.5%**
AVRT* (WPW syndrome)	58	57.42%
AVRT (Mahaim form)	1	0.99%
Total pts	101	
*AVRT with bystender AVNRT	1	
**AVRT with dual accessory pathway*	2	

Table 2 – Табела 2

Location of the accessory pathways, patients with delta wave (WPW syndrome)
Местоположба на дополнителниот пат, делта бран (WPW синдром)

Location of the accessory pathways	**Pts (58)**	**delta wave**
Right postero septal	17	29.3%
Left postero septal	9	15.5%

Location of the accessory pathways	**Pts (58)**	**delta wave**
Right free wall	0	0%
Left free wall	19	37.9%
*left free wall + right postero septal	2	
*left free wall + bystander AVNRT	1	
Right antero septal (midseptal)	7	12.0%
Left antero septal (midseptal)	3	5.1%

Table 3 – Табела 3

Location of the accessory pathways, patients with concealed accessory pathway
Местоположба на дополнителниот скриен пат

Location of the accessory pathways	**Pts (42)**	**Concealed AP %**
Right postero septal	26	61.9%
Left postero septal	1	2.38%
Right free wall	0	0%
Left free wall	13	30.9%
Left antero septal (midseptal)	1	2.38%
Mahaim	1	2.38%

The correlation between the location of the accessory pathways and the resulting T-wave abnormalities after successful ablation is shown in Table 4. Right and left postero-septal AP showed T-wave inversions in leads II, III, and aVF. In the group with AP in the right-postero-septal location the rate of T-wave inversion was the highest (16/17 pts, 94%). Half of the patients with left lateral AP demonstrated T-wave inversions in leads aVL after ablation (11/20 pts 55%). The lowest rate of T-wave inversion was in the group with AP on left-postero-septal and postero-lateral (3/8 pts, 37.5%). The average rate of T-wave abnormalies after ablation of AP in all 47 ablated pts was 63.8% (30/47 pts). In eleven patients ablation was not performed because of the location of AP, very near to the His bundle position (9 pts) and one patient with AP with very long refractoriness (S1S2 500/400 msec), without inducible tachycardia. In one patient with AP in the left-postero-septal position ablation was not performed because of the presence of a prosthetic valve in the aortic position. Repeated electrophysiology studies (redo studies) with ablation of AP were performed in 3 pts. Two redo studies were successful.

In the group of patients with concealed AP there was no T-wave inversion, no cardiac memory (Table 4), because in these patients there was no presence of altered ventricular activation during the preexcitation.

Table 4 – Табела 4

EKG sings of cardiac memory after ablation of accessory pathways
AP – accessory pathway; TWI – T-wave inversion
ЕКГ знаци на срцевата меморија по аблација на дополнителен пат
AP – дополнителен пат, TWI – Т-бран инверзија

Location of the accessory pathways	**(TWI – EKG leads)**	**WPW (TWI) 30/47 pts**	**Concealed AP (TWI)**
Right postero septal	(DII, DIII, aVF)	16/17 pts (94.1%)	0/26 pts
Left postero septal	(DII, DIII, aVF)	3/8 pts (37.5 %)	0/1 pts
Right free wall		0/0 pts	0/0 pts
Left free wall	(aVL, V6)	11/20 pts (55%) *1 pts without success	0/13 pts
Right antero septal		0/1 pts	
Right/Left antero septal (midseptal)		9 pts (no ablation)	0/1 pts
Left free wall (long AP refractoriness) Left postero septal (prosthetic valve)		2 pts (no ablation)	

Table 5 – Табела 5

Clinical and electrophysiological characteristics of the patients
AP – accessory pathway; TWI – T-wave inversion
Клинички и електрофизиолошки карактеристики на пациентите
AP – дополнителен пат, TWI – Т-бран инверзија

	TWI (+)	**TWI (–)**	**p**
Degree of preexitacion (QRS msec) – delta and QRS	110 ± 21.5 (85–135)	115 ± 18.7 (95–140)	no
AP refractoriness (msec)	246 (210–380)	251 (220–390)	no
Number of ablation	8.68 ± 9.23 (1–33)	9.12 ± 9.47 (1–37)	no

There was no correlation between the degree of preexcitation, measured as the distance from the beginning of the delta wave to the end of the QRS complex prior to radiofrequency ablation and appearance of cardiac memory in inferior leads. (Table 5)

The accessory pathway refractoriness was determined and classified as short (< 250 ms) or long (> 250 ms), and compared to post-ablation T-wave changes. The median value of the accessory pathway refractoriness was 290 ms (210–390 ms). There was no correlation between the refractoriness of the accessory pathway and post-ablation cardiac memory. There was no correlation between the number or duration of energy applications during the ablation of accessory pathways and the extent of cardiac memory post ablation.

The majority (about 90%) of ECGs recorded 3 months after the procedure showed complete or almost complete normalization. None of the patients with T-wave inversion after ablation had a recurrence of preexcitation or tachycardia during the follow-up period of 12 ± 4 months.

Discussion

Cardiac memory related T-wave inversions in inferior leads were observed in 94% of the patients within one day after successful radiofrequency ablation of an overt right-postero-septal accessory pathway, resolved in a majority of available ECGs within 3 months (reverse remodelling). In this study, T-wave changes occurred immediately after successful catheter ablation of manifest (WPW syndrome) but not in the case of concealed accessory pathways.

Previous WPW studies have focussed on comparing evidence of cardiac memory development in patients with overt, as opposed to concealed, accessory pathways. In contrast to previous studies we focussed our investigation on a homogeneous group of patients, all of them with a postero-septal accessory pathway. Cardiac memory developed in 47–100% after ablation of overt WPW in previous studies, on average in 74% (Table 6)

Table 6 – Табела 6

EKG sings of cardiac memory after ablation of accessory pathways in previous reports
ЕКГ знаци на срцевата меморија по аблација на дополнителен пат – претходни извештаи

Autors	**Patients (n)**	**AP (WPW)**	**Concealed AP**
Kalbfleisch *et al.*	45	22/29 (76 %)	0/16 (0%)
Poole and Bardy	7	7/7 (100%)	0/2 (0%)
Autors	**Patients (n)**	**AP (WPW)**	**Concealed AP**
Wood *et al.*	37	9/19 (47%)	0/6 (0%)
Helguera *et al.*	51	23/24 (96%)	2/27 (7.4%)
Geller *et al.*	90	38/64 (59%)	0/26 (0%)
Aunes-Jansson *et al.*	125	123/125 (98 %)	---

A correlation between the degree of preexcitation measured as QRS duration prior to ablation and the extent of post-ablation T-wave changes has previously been reported (Kalbfleisch, Geller), but such a correlation was not confirmed in our study.

Clinical implication

The differential diagnostic problem of distinguishing between T-wave changes as cardiac memory and ischaemic T-wave changes was recognized in 1977 by Engel. It is important for medical doctors to be informed and cautious of these ECG changes that can persist for several months after radiofrequency ablation of patients with WPW syndrome. The T-wave inversions seen after radiofrequency ablation of posteroseptal accessory pathways are located in the inferior leads and could therefore be misinterpreted as a sign of inferior wall ischaemia. Recently, Shvilkin and Josephson [11] studied this problem, and described an algorithm to differentiate cardiac memory (after right ventricular pacing), from ischaemic T-wave changes due to left anterior descendent artery stenosis by using the direction of the frontal plane T-wave vector.

Conclusion

T-wave inversion in leads II, III and aVF with the disappearance of the delta wave in patients with Wolff-Parkinson-White syndrome after ablation of the accessory pathway in the right posteroseptal region of the heart is the strongest marker of successful ablation.

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Р е з и м е

СРЦЕВА МЕМОРИЈА (Т-БРАН МЕМОРИЈА) ПО АБЛАЦИЈА НА ДОПОЛНИТЕЛЕН ПАТ ВО ПОСТЕРО-СЕПТАЛНА РЕГИЈА

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А п с т р а к т: Срцевата меморија е феномен што се карактеризира со повремени абнормалности на Т-брановите кои се појавуваат за време на нормален синусен ритам на срцето, по период на обратна (во друг правец) коморна деполаризација. Векторот на Т-брановите е во ист правец како претходно обратно деполаризираниот QRS комплекс (инверзија на Т-бранот). Тоа е облик на електрично ремоделирање на коморите, каде што Т-брановите го следат (помнат) QRS векторот кој е деполаризиран во обратен правец.

Материјал и метод: Во период од 5 години (2000–2006 година), кај 525 подователни пациенти беше направена електрофизиолошка студија. Кај 101 пациент со преткоморно-коморна кружна тахикардија беше направена аблација на дополнителниот пат. Четириесет и два пациенти беа со прикриен дополнителен пат (без делта бран на електрокардиограмот) и 58 пациенти беа со отворена форма на дополнителен пат, со делта бран на електрокардиограмот (Wolff-Parkinson-White синдром) и само еден пациент беше со дополнителен пат од типот на Mahaim. Според местоположбата на дополнителниот пат, 17 пациенти (29,3%) имаа дополнителен пат во десно постеро септалната регија. Во таа регија имаше највисок процент на појава на инверзија на Т-бранот. Промените на Т-бранот беа следени во предна рамнина (одводи DII, DIII и aVF). Електрокардиографските знаци за срцевата меморија беа регистрирани кај 16 од 17 пациенти (94.1%) во првиот ден по аблацијата. Векторот на Т-бранот по аблација имаше ист правец како векторот на преексцитацискиот QRS комплекс (делта бран) појавувајќи се како инверзија на Т-бранот. Немаше корелација помеѓу бројот и времетраењето на аблациите со степенот на појава на срцевата меморија по аблацијата. Најголем број од пациентите (90% од случаите) на електрокардиограмите во период од 3 месеци покажаа комплетна или скоро комплетна нормализација. Ни еден од пациентите со инверзија на Т-бранот немаше повторно појавување на преексцитација или клиничка тахикардија во период на следење од 12 ± 4 месеци.

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Заклучок. Инверзијата на Т-бранот во одводите DII, DIII и aVF со губиток на делта бранот по аблација на дополнителен пат кај пациенти со Wolff-Parkinson-White синдром (десно-постеро-септална регија), е најмоќен показател за успешна аблација.

Клучни зборови: срцева меморија, дополнителен пат, катетер аблација, Wolff-Parkinson-White синдром.

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