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Vectorcardiography shows cardiac memory and repolarization heterogeneity after ablation of accessory pathways not apparent on ECG ☆

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ABSTRACT

Background: Pacing induced cardiac memory is an established phenomenon, but following successful WPW ablation, cardiac memory was present on ECG in variable proportions of patients depending on accessory pathway (AP) location. We hypothesized that vectorcardiography (VCG), which is more sensitive than ECG, would show cardiac memory after WPW ablation independent of AP location.

Methods: Thirty-six patients were followed after successful AP ablation, 11 with overt posteroseptal (PS), 13 with overt left-sided (LS) and 12 with concealed APs (controls). VCGs were recorded the day before and after the procedure, ≥once/week for 6–8 weeks and after ≥3 months. T vector and T-vector loop parameters were analyzed and compared.

Results: After ablation of overt APs, there was a correlation between the directions of the preexcited maximum QRS-vector and the post-ablation maximum T-vector, confirming the presence of cardiac memory. Ablation of overt APs was followed by cardiac memory apparent in different directions. Thus, ablation of PS APs was followed by most pronounced changes in T-vector elevation and LS APs with significant changes only in T-vector azimuth. Cardiac memory disappeared within a month in >80% of cases. Furthermore, T-vector loop morphology changes suggested a period of repolarization heterogeneity immediately after ablation of overt APs.

Conclusions: According to VCG analysis cardiac memory was present after ablation of overt APs independent of location as consistently as after ventricular pacing, and disappeared within a similar time frame during normal ventricular activation. In addition, signs of transient repolarization heterogeneity were observed after ablation of overt APs.

1. Introduction

“Cardiac memory” is a variant of ventricular remodeling following a change in activation sequence, where after resumption of normal ventricular activation the T vector tracks the vector of the previously altered QRS complex [1]. It has been observed in relation to ventricular pacing [2], ventricular tachycardia [3], intermittent bundle branch block [4] and after periods of preexcitation in Wolff–Parkinson–White syndrome (WPW) patients [5].

After successful ablation in WPW patients, cardiac memory assessed as T-wave alterations on electrocardiography (ECG), has been observed in almost all patients with overt posteroseptal (PS) accessory pathways (AP) [6–8] but less frequently after ablation of overt APs in other locations, including the most common left-sided (LS) site [7,9–11]. If cardiac memory related electrophysiological remodeling as a phenomenon is as consistent as suggested by the results from the human pacing model [12], the AP location should not be crucial for cardiac memory development.

We have recently showed that vectorcardiography (VCG) analysis of recordings based on orthogonal leads is a more sensitive method for detecting repolarization changes after ventricular pacing induced cardiac memory than the 12-lead ECG [12,13]. VCG was therefore applied to assess the appearance and disappearance of cardiac memory after successful ablation of overt (manifest) APs in the PS and the LS location.

Our hypothesis was that the reported location-related difference reflects limitations inherent to ECG rather than biological differences and that cardiac memory would be present after ablation of all overt APs, independent of location.

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Since pacing induced cardiac memory was associated with signs of transient ventricular repolarization heterogeneity [13] this issue was also addressed in the analysis.

2. Materials and methods

2.1. Patients

Inclusion criteria were WPW-syndrome or paroxysmal supraventricular tachycardia due to a concealed AP (controls) *and* a clinical indication for ablation. Patients with overt APs localized either in the PS or LS region (based on crude ECG criteria during sinus rhythm) were included. Patients were allocated to the PS group when there was a transition from a dominating negative preexcited QRS complex in V_1 to a dominating positive QRS in V_2 and to the LS group when there was a positive delta wave in at least leads $V_{1–4}$. The control group with concealed APs, i.e. without preexcitation and therefore with normal ventricular activation, was not expected to express cardiac memory.

The study conforms to the principles outlined in the Declaration of Helsinki and was approved by the Ethics Committee of Karolinska Institutet and the University of Gothenburg. All patients gave their written informed consent to participate before the ablation procedure. Ten healthy subjects (5 women, mean age 41 ± 7 years, range 28–51) were included as an external control group with VCG recorded twice with one week interval. These individuals were staff or personnel, who had no acute or chronic illness and a normal ECG.

2.2. ECG and VCG recording

Before the ablation a baseline 12-lead ECG and VCG were recorded confirming preexcitation in the patients with overt APs and allowing assessment of the pre-ablation QRS vector, respectively. The VCG was recorded on a MIDA 1000 system (Myocardial Infarction Dynamic Analysis, Ortivus AB, Danderyd, Sweden), which utilizes 8 electrodes positioned according to the Frank orthogonal lead system (X, Y and Z). The sampling frequency for each electrode was 500 Hz. QRST complexes were averaged over a time period of 2 min, since our measurement condition could be considered as "steady state" at each session.

2.3. Ablation procedure

The patients were fasting and lightly sedated during the ablation, which was performed according to routine. Anti-arrhythmic drugs were withdrawn at least 5 elimination half-lives prior to the procedure. After each application, an ECG was recorded to verify the existence and morphology *or* disappearance of the delta wave. When the AP was ablated a 30 minute observation period followed, during which short episodes of atrial and/or ventricular stimulation were performed in order to verify the absence of AP conduction, before a final ECG was recorded.

2.4. Follow-up

ECG and VCG were recorded after 3 h and the day after the procedure and then at scheduled follow-up visits twice a week for 3 weeks, and thereafter weekly for another 3–5 weeks. The last follow-up visit was performed ≥3 months after the ablation. All recordings were performed after ≥5 min of rest in the supine position allowing rate adaptation of repolarization [14].

2.5. VCG analysis

The VCG method has been described before [13]. The magnitude and direction of the maximum vector in space were expressed as *amplitude* (*mV*), *azimuth* (*degrees*) and *elevation* (*degrees*); Fig. 1. T amplitude is the length of the maximum T vector in space (mV). T azimuth is the angle of the vector in the transverse plane (X–Z plane; 0° left, +90° front, −90° back, 180° right). T elevation is the angle in the craniocaudal direction defined from 0° (caudal direction) to 180° (cranial direction).

The T-vector loop is normally elliptical and oriented in one individual preferential plane and its configuration or morphology was expressed as *Tavplan* (*μV*) and *Tegenv* (*unitless*); Fig. 2.

Tavplan is the mean distance between the T-vector loop periphery and its preferential plane and thus describes the "aplanarity" or distortion or bulginess of the T-vector loop.

Tegenv is the quotient of the two highest eigenvalues (d1 and d2; ~diameters or axes) of the T-vector loop and describes the morphology (elliptical to circular).

Tarea (*μVs*) was assessed from the three-dimensional (3-D) QRST complex and defined as the "3-D" area between the curve and the baseline from the J point to the T end and calculated as $\text{Tarea} = (\text{Tx}^2 + \text{Ty}^2 + \text{Tz}^2)^{1/2}$. In analogy *QRSarea* (*μVs*) was defined as $\text{QRSarea} = (\text{QRSx}^2 + \text{QRSy}^2 + \text{QRSz}^2)^{1/2}$.

The direction of the maximum T vector in space after ablation was compared with the direction of the maximum preexcited QRS vector before ablation. The angle between the maximum QRS and T vectors (QRS-T angle) was also followed after ablation. The T-vector parameters from the first day after ablation were compared with the values 1 and 2 weeks later and after ≥3 months, within and between groups.

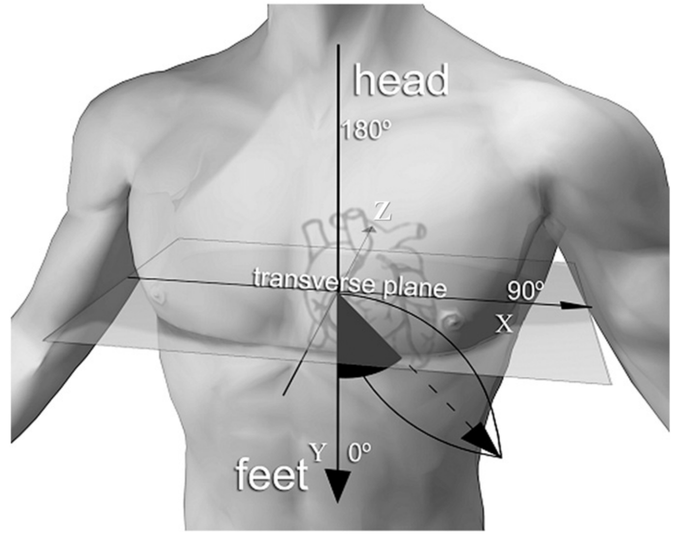

Fig. 1. Vectorcardiogram (VCG) of the T-vector loop with its maximum vector in space (arrow with broken line). T amplitude = length of the maximum T vector in space; (mV). T azimuth = the angle of the projection of the vector in the transverse plane (X–Z plane), defined as zero when the vector is pointing to the left. Forward vector directions are designated 0–180° and backward vector directions 0–(−180°). T elevation = the angle between the vector and an axis (Y-axis) perpendicular to the transverse plane, defined as zero when pointing downwards and 180° when pointing in the cranial direction. Reproduced from Ref. [13] with permission from the publisher.

2.6. Statistical analysis

Descriptive data are presented as mean ± SD. One-way ANOVA, as well as repeated measurements ANOVA, were used for comparison between and within groups, respectively. When this analysis gave significant results a post hoc analysis was performed using the t-test for dependent samples for within-group comparisons of VCG parameters after ablation and the t-test for independent samples for between-group comparisons. Linear regression was used for comparison between the maximum T vector after ablation and the preexcited maximum QRS vector before ablation. Fisher's exact two-tailed test was used for comparison of signs of cardiac memory on ECG in the PS and LS group.

A p-value <0.05 was considered statistically significant.

3. Results

Out of 36 enrolled patients 24 had stable preexcitation (11 PS and 13 LS) and 12 belonged to the control group (concealed APs).

The mean age of the 36 study patients (13 women) was 43 ± 16 years (range 18–74).

There was no statistically significant age difference between the 3 groups.

Echocardiography verified the absence of structural heart disease in 35 patients. One patient with a PS AP had an aortic regurgitation and impaired left ventricular function (ejection fraction 30%) and valve replacement was performed subsequent to the ablation.

Clinical characteristics of the study patients are shown in Table 1.

There were no significant differences in heart rate between the groups or between recording sessions (heart rates 65–74 bpm). At ablation the pathways were found in the general regions predicted by the surface ECGs although the exact location varied.

3.1. ECG

Fig. 3 shows ECG examples recorded the day before and one day after ablation in one patient each from the PS and one from the LS group.

All patients in the PS group had new T-wave inversions in 2–3 of the inferior leads (II, aVF, III) after ablation. At the last follow-up (>3 months after ablation) these T-wave inversions were all gone.

In the LS group, T-wave inversions were observed in the inferior leads in 2 (posterior and postero-lateral AP locations) and in lead aVL in another 2 patients.