

Title: The atrial T wave: the elusive electrocardiographic wave exposed by a case of shifting atrial pacemaker

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Abstract

The atrial T wave (Ta wave) is the body surface manifestation of atrial repolarisation and, unlike the P wave (atrial depolarisation), is little recognised. We report the case of a patient with shifting pacemaker which clearly demonstrates the effect of the Ta wave on ST segment and T wave. A simple conceptual model is used to explain the observed phenomenon. The case serves as a reminder of this often forgotten ECG wave and its potential effects on other ECG features.

Introduction

It was in the late 19th century that Einthoven designated P, QRS and T as the distinctive features of the electrocardiogram (ECG) [1]. These well known designations correspond to atrial depolarisation (P wave), ventricular depolarisation (QRS complex) and ventricular repolarisation (T wave). Perhaps its low amplitude and almost complete concealment by the large ventricular deflections ensured that the ECG feature related to atrial repolarisation was neglected. However, a growing research interest in atrial repolarisation necessitated a naming convention and Hering is credited with ascribing the phrase 'T wave of the auricle' and its abbreviation 'Ta wave' in 1912 [2].

The Ta wave directly follows the P wave but with opposite polarity and its amplitude is about a third of the P wave [3]. Its duration can extend to more than 400 ms after the end of the P wave, so a substantial part of atrial repolarisation occurs during ventricular depolarisation and repolarisation [4]. As such the Ta wave can contribute to ST depression or elevation and concerns about its effect on diagnostic accuracy have been reported [5].

The majority of studies analysing the Ta wave have done so in the context of AV block when the complete atrial depolarisation and repolarisation cycle may occur outside any obscuring ventricular activity [2,4,6]. In sinus rhythm without heart block only a very small segment of

the Ta wave is observable from which polarity but not duration can be obtained [3,7]. Here we present a case of a patient with serial Ta wave (and P wave) polarity changes which clearly illustrates the effects on the ECG of the Ta wave during sinus rhythm without heart block. We also show that these effects are replicated by a simple conceptual model.

Case report and discussion

The case is a 49 year old male with 12-lead ECG recorded during **catheter ablation** for atrial fibrillation but in sinus rhythm at the time of the recording. The ECG P wave exhibited distinct polarity changes (Figure 1), progressing from initially negative (Figure 1B) to biphasic (Figure 1C) to positive (Figure 1D) and resolving to negative polarity (Figure 1E) after a few seconds. The corresponding PR intervals are 100 ms for the negative P wave and 160 ms for the positive P wave. This is suggestive of a wandering pacemaker with the pacemaker source located at the sinus node for the positive P wave and located low in the atria, closer to the AV node, for the negative P wave. It was expected that the P wave polarity changes would be accompanied by corresponding polarity changes in the Ta wave: **the Ta wave being positive for negative P waves and negative for positive P waves**. Although the large ventricular complex mostly obscured the Ta wave, by comparing the differences in the ECG waveform coincident with the Ta wave we were able demonstrate the effect of atrial repolarisation polarity changes on the ECG. Of note was the elevated ST segment and triangulation of the T wave that was readily apparent in beats with positive Ta waves (negative P waves) (Figure 1B and 1E) compared to beats with negative Ta waves (positive P waves) (Figure 1D).

Using a simple conceptual model implemented by computer simulation **in Matlab (R2013b, The MathWorks Inc., Natick, MA, USA)**, PTa polarity changes and their effect on ST/T

interval observed in the patient were replicated (Figure 2). The model, originally proposed by Wohlfart for simulating ventricular repolarisation [8], generated the ECG PTa wave segment as the difference between two out of phase action potentials: $ECG = AP1 - AP2$, where the action potentials $AP1$ and $AP2$ are specified by

$$AP(t) = 1 / \left(1 + e^{-K_1 t} \right) \times K_2 \left[\left(1 - K_3 \right) e^{-K_4 t} + K_3 \right] e^{-K_5 t} \times 1 / \left(1 + e^{K_6 (t - K_7)} \right)$$

Further details of the model can be found in reference 8.

For the present study two identical action potentials representing the earliest and latest regions of the atrial myocardium activation were constructed by appropriate choice of model parameters (Figure 2B). ECG PTa segments were generated as the potential difference between the late and early action potentials (Figure 2C). By reversing the early and late activating regions it was possible to simulate P and Ta wave polarity changes (left and right columns in Figure 2). Figure 2C indicates that the model generated Ta waves of appropriate amplitude and polarity for the corresponding simulated P waves. To construct ECG with both atrial and ventricular components the PTa segments were added to a synthesised QRST complex (Figure 2D) to generate simulated ECGs with superimposed atrial and ventricular activities (Figure 2E). The PR interval was easily controlled by appropriate choice of the relative position of the ventricular beat relative to the atrial beat.

From the model the Ta wave was seen to elevate or depress the ST segment and T wave according to its polarity (Figure 2E). Hence, the simple conceptual model accurately simulated the effect of Ta wave polarity changes on the ST and T wave segments observed in the patient. ECG morphology comparisons for positive and negative PTa wave polarities for the patient ECG and simulation are shown in Figure 3. Amplitude of the ST interval increased by 0.1 mV and T wave amplitude increased by 0.05 mV for a change in Ta wave

polarity from negative to positive. The effect of the Ta wave following the low amplitude biphasic P wave was also accurately simulated by the model (dotted lines in Figure 3).

In conclusion this case is the first to demonstrate Ta polarity changes and resulting effect on ST interval and T wave in a patient with wandering pacemaker. The case serves as a reminder of the often neglected atrial repolarisation phase of the ECG.

References

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Figure captions

Figure 1. The patient ECG exhibited P wave polarity changes. 10 s duration of lead II (A) and detail of individual beats illustrating progressive P wave polarity changes from negative (B) to biphasic (C) to positive (D) and back to negative (E). Arrows indicate ECG segments containing the beats shown in B-E. **Locations of P wave and Ta wave are annotated below each beat.**

Figure 2. Computer simulation replicating ECG lead II morphology changes due to reversal of atrial conduction direction from wandering pacemaker. **Left side panels show the simulation of a positive P wave/negative Ta wave consistent with initiation of atrial depolarisation at the SA node and propagating in an inferior direction. Right side panels show the simulation of a negative P wave/positive Ta wave consistent with initiation of atrial depolarisation lower in the atrium and propagating in a superior direction.** Principal atrial depolarisation vector directions for positive and negative P wave in lead II (A). Phase shifted action potentials representing early and late activated regions (B) generating P_{Ta} segments of opposite polarities (C). Synthesised QRST complex (D). Simulated ECG lead II (black trace) generate by adding the P_{Ta} segment to the synthesised QRST complex (blue trace) (E).

Figure 3. Beat complexes overlaid to illustrate the effect on the ECG waveform of different PTa wave polarities for the patient ECG (left panel) and the simulated ECG (right panel). The beat with positive Ta/negative P wave (solid trace) shows marked ST segment elevation and T wave triangulation compared to the beat with negative Ta/positive P wave (dashed line). The beat with the biphasic P wave (dotted line, patient ECG) had ST amplitude between the other two beat morphologies and was simulated by a flat (zero amplitude) PTa segment.