The Effect of Beat Interval on Ventricular Repolarisation in Atrial Fibrillation

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Abstract

Atrial fibrillation (AF) is characterised by rapid beat interval changes. The aim of the study was to investigate the effect of such changes on ECG ventricular repolarisation characteristics.

In 10 AF recordings beat averaging of lead V4 was used to generate averaged T waves where the preceding beat interval (R-R) was either short (625+/-25 ms) or long (1075+/-25 ms). The amplitudes of T wave (T amp) and T wave end, defined as the TU nadir, (TUn amp), and the intervals for R wave to T wave peak (R-T) and R wave to T wave end (R-TUn) where measured from these average beats. Difference in measured T wave characteristics between short and long beat intervals were quantified.

All measurements increased significantly for long preceding beat intervals compared to short: T amp (mean± SD) 0.31±0.17 mV (short) vs 0.35±0.20 mV (long) (p = 0.04); TUn amp 0.00±0.02 mV (short) vs 0.03±0.03 mV (long) (p = 0.009); R-T 251.7±13.5 ms (short) vs 264.2±12 ms (long) (p = 0.002) and R-TUn 376.5±31 ms (short) vs 392±26.5 ms (long) (p=0.027).

ECG T wave characteristics are significantly affected by preceding ventricular beat interval in AF.

1. Introduction

Ventricular repolarisation, the relaxation phase of the cardiac cycle, is expressed on the body surface as the ECG T wave. The T wave results from spatial and temporal differences across the ventricles of the repolarisation phase of the ventricular action potentials [1]. It is well known that as heart rate slows, and accordingly beat interval (R-R interval) lengthens, action potential duration increases resulting in a lengthening of the T wave [2]. Previous research has provided insight into the effect of heart rate on T wave amplitude. During the post-exercise recovery period in healthy subjects the T wave became asymmetrical and decreased in amplitude as heart rate decreased [3] and was explained by changes in action potential dispersion and repolarisation duration [4]. Another study, considering Holter recordings, suggested T wave amplitude increased linearly with increasing R-R interval in healthy subjects but less so for patients with acute myocardial infarction [5]. So far there have been few studies looking at ventricular repolarisation during the abnormal heart rhythm AF. AF is a common arrhythmia which is characterised by rapid changes in ventricular beat interval [6,7]. As such it provides the opportunity to investigate the effect of rapid beat interval changes on characteristics of the T wave. In AF the ventricular components of the ECG are contaminated by the continuous atrial fibrillatory component [8]. This 'contamination' must be removed to allow accurate measurement of the ventricular features of the ECG such as T wave peaks and T wave end. Here we use beat averaging with careful selection of qualifying beats to enable the accurate measurement of T wave features under the conditions of short and long preceding beat intervals. Hence the aim of this study was to quantify the effect of the beat interval changes on the ventricular repolarisation characteristics in AF.

2. Method

2.1 ECG database

The ECG lead V4 of 10 patients during AF were analysed. The sampling rate for the recording was 500Hz and amplitude resolution of 5 μV. The recording length was 15 minutes.

2.2 ECG processing

A beat averaging algorithm was used to generate averaged beats so removing the contaminating atrial fibrillatory activity from the ventricular features. For each recording two averaged beats were obtained by

creating average beats where the preceding beat intervals was short (defined as a preceding beat interval within the range 625 ± 25 ms) or long (defined as a preceding beat interval within the range 1075 ± 25 ms). The averaging process has been described previously when measuring U waves during AF [9].

Manual measurements of ECG baseline and T wave amplitudes and intervals were obtained by displaying the average beats individually on a computer screen at a size corresponding to ECG paper speed of 50 mm/s and 20 mm/mV using bespoke Matlab software. Observers (MSA, PL) independently marked a stable isoelectric baseline in the period immediately before QRS onset along with T wave peak and TU nadir time points. The location of the R wave was already known from the beat averaging process. T wave amplitude (T amp) and T end amplitude (TUn amp) were automatically calculated from the manually selected baseline, T peak and TU nadir points. Similarly, the intervals R to T wave peak (R-T) and R to TU nadir (R-TUn) were automatically calculated. Figure 1 illustrates the measurements used in the study.

Each T wave characteristic had paired groups of measurements associated with short and long preceding beat interval for which statistical differences were assessed with the Wilcoxon signed rank test following the Kolmogorov-Smirnov test to assess normality of data distribution.

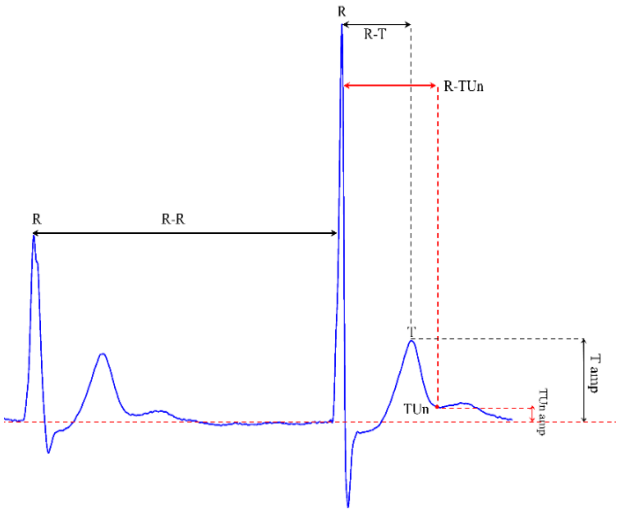

Figure 1. An averaged beat with the ventricular repolarisation characteristics indicated: T wave amplitude (T amp), R-T interval (R-T), TU nadir amplitude (TUn amp) and R-TU nadir interval (R-TUn). The preceding beat interval (R-R) was either short (625 ± 25 ms) or long (1075 ± 25 ms).

3. Results

Figure 2 illustrates the two average beats generated from one of the AF recordings of the study. The T wave for the average beat with the long preceding beat interval shows clear increases in amplitude at the peak and at the end of the T wave, while the intervals between R wave and T peak and T end have also increased relative to the T wave with the short preceding beat interval.

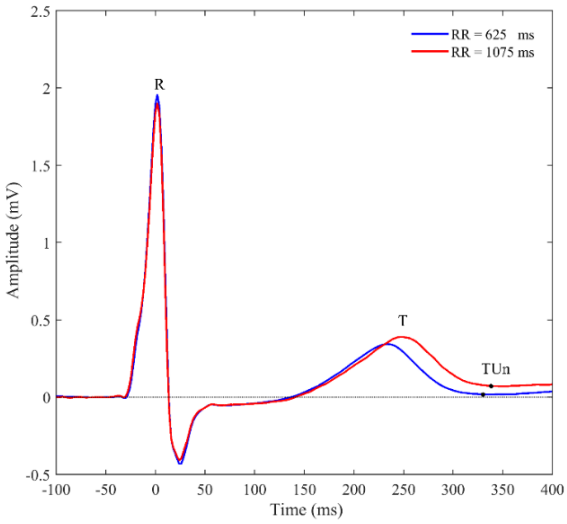

Figure 2. Average beats in the same recording generated for beats with short (blue trace) and long (red trace) preceding beat intervals. Amplitudes and intervals increased for the beat with long preceding beat interval.

The measurements for all recordings are shown in figure 3 and the statistical data are summarised in table 1. There were statistically significant increases in amplitudes and intervals for long compared to short preceding beat intervals.

Table 1. Measurement statistics for T wave properties for short and long preceding beat intervals, mean (±SD), and p value

Preceding beat interval	Short	Long	P value
T wave (mV)	0.31(±0.17)	0.35(±0.20)	0.049
R-T (ms)	251.7(±13.5)	264.2(±12.0)	0.002
TUn (mV)	0.00 (±0.02)	0.03(±0.03)	0.010
R-TUn (ms)	376.5(±31.0)	392(±26.5)	0.027

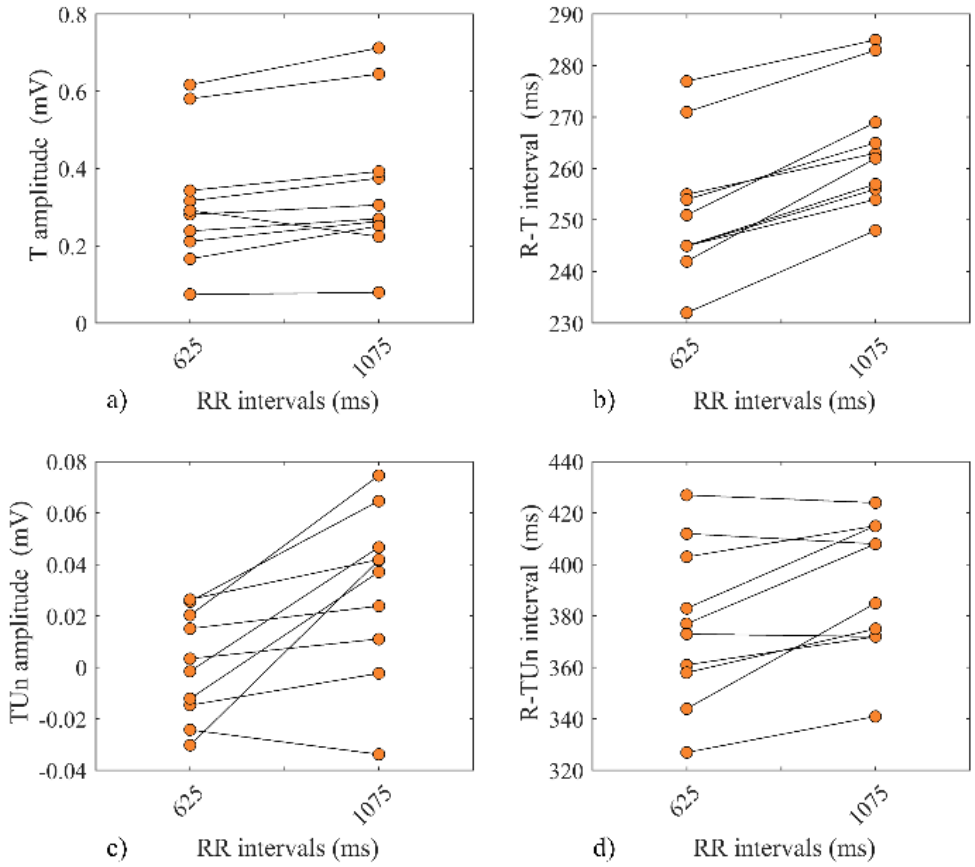

Figure 3. Paired groups for ventricular characteristics for short and long preceding beat intervals in 10 AF recordings. a) T wave amplitudes. b) R-T intervals. c) TUn amplitudes, and d) R-TUn intervals.

4. Discussion

AF is characterised by rapid ventricular beat interval changes which provides a unique model for studying the effects of such changes on ventricular repolarisation characteristics.

The study indicates that beats preceded by longer beat intervals have T waves with larger amplitude and prolonged duration compared to beats preceded by shorter beat intervals. QT lengthening is a well-known effect of heart rate slowing (R-R interval increasing) so our finding of increased R-T and R-TUn intervals accords with this. Our finding of increased amplitudes at the peak and at the terminal part of the T wave may suggest increased dispersion of repolarisation for beats with longer preceding beat intervals, although other factors may also contribute to T wave amplitude changes [4]. A linear increase in T wave amplitude with increasing R-R interval was observed in healthy subjects during long term Holter monitoring [5], but beat interval changes in healthy subjects are generally modest outside of exercise and slow changing unlike those in AF. Nonetheless our results accord with the findings of that study. In contrast healthy subjects during the post exercise recovery period exhibited the opposite response to increasing R-R interval because their T waves decreased in amplitude [3] suggesting exercise imparts a different response of ventricular repolarisation to heart rate changes and which is different to that we have observed during AF.

In conclusion, longer preceding beat intervals during AF give rise to larger and longer T waves.

References

[1] MR Franz, “Ventricular repolarization, T-wave genesis, and risk prediction," *Ann Noninvasive Electrocardiol* 2001;6(1):1–4.

[2] C Antzelevitch, S Litovsky and A Lukas, “Epicardium versus endocardium cardiac electrophysiology: From cell to bedside”. (Philadelphia, PA: Saunders) pp 386–95

[3] P Langley, D Di Bernardo, A Murray, “Quantification of T wave shape changes following exercise,*”Pacing Clin Electrophysiol* 2002;25(8):1230–4.

[4] Di Bernardo, P Langley, A Murray, “Effect of changes in heart rate and in action potential duration on the electrocardiogram T wave shape,” *Physiol Meas* 2002 ;23(2):355–64.

[5] L Johannesen, U Grove, J Sørensen , M Schmidt, C Graff, J-P Couderc, “Analysis of T-wave amplitude

adaptation to heart rate using RR-binning of long-term ECG recordings," *Comput Cardiol* 2010; 37: 369–372
[6] K Padmavathi, K Sri Ramakrishna, "Classification of ECG signal during atrial fibrillation using autoregressive modelling," *Procedia Comput Sci* 2015;46(Icict 2014):53–9.
[7] P Kirchhof , S Benussi, D Kotecha, A Ahlsson, D Atar, B Casadei, et al., "2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS," *Eur Heart J.* 2016;37(38):2893–962.
[8] L Sörnmo, M Stridh, D Husser, A Bollmann, SB Olsson, "Analysis of atrial fibrillation: from electrocardiogram signal processing to clinical management," *Philos Trans A Math Phys Eng Sci. The Royal Society*. 2009;367(1887):235–53
[9] P Langley, JP Bourke, A Murray, "The U wave in atrial fibrillation," *Computing in Cardiology (CinC) 2015*; p. 833–6.

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