Analysis of electrocardiogram recordings with advanced non-linear methods for the evaluation of atrial fibrillation organisation

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Abstract – In this study, atrial fibrillation (AF) organisation has been estimated using an advanced non-linear time series analysis method called Lempel-Ziv (LZ) complexity with a k-means coarse-graining approach. The results show that this technique can predict paroxysmal AF organisation with a maximum accuracy of 90% and suggests that non-terminating paroxysmal AF signals are less organised (more complex) than terminating AF signals. Further studies using larger databases or combining LZ complexity with other non-linear methods should be conducted.

I. INTRODUCTION

AF affects up to 1% of the general population and is the most commonly encountered supraventricular arrhythmia in daily clinical practice [1]. However, the physiological mechanisms provoking the onset and termination of AF episodes are still inexplicable. To better understand AF mechanisms, considerable research have been carried out on the analysis of AF in non-invasive electrocardiogram (ECG) recordings using advanced non-linear methods, which have proven to be promising tools for revealing useful information that could be used for early prediction and better treatment of the arrhythmia. LZ complexity is a non-linear technique based on a coarse-graining process that reflects the arising rate of new patterns along a given time series and as such, provides a way of estimating the organisation of the series. The purpose of the present study is to analyse the organisation of AF using LZ complexity with k-means coarse-graining.

II. METHODS

Two databases were analysed: a paroxysmal AF database, consisting of 24 terminating AF episodes (T group) and 26 non-terminating AF episodes (N group), and a persistent AF database comprising 14 non-recurring AF episodes (nr group) and 21 recurring AF episodes (re group). In each database, AF organisation was estimated via the computation of the main atrial wave (MAW) and atrial activity (AA) LZ complexity using k-means coarse-graining and a two symbol conversion, at sampling rates (fs) of 64, 128, 256, 512, 1024 and 2048 Hz. Differences between LZ complexity values of the two groups in each database were evaluated at all fs using the Kruskal-Wallis test or Student’s t-test, as appropriate, and were considered significant when p-value<0.01. If significant differences between groups were found, the diagnostic accuracy of the LZ complexity method was evaluated using Receiver Operating Characteristic (ROC) curves.

III. RESULTS

The results obtained show that the AA and MAW LZ complexity values are higher in the N group and the re

IV. DISCUSSION

A high LZ complexity value indicates a highly complex sequence. Thus, it can be inferred from the results that non-terminating paroxysmal AF and recurring persistent AF signals are more complex (less organised). As shown in Table 1, the diagnostic accuracy of LZ complexity increases as fs increases, with the highest accuracy being achieved at 2048 Hz. This was also the case in a recent study on AF organisation where the same paroxysmal AF database was analysed using LZ complexity with median and mean coarse-graining [2], which suggests that more accurate information about the MAW signal is retained at higher fs, allowing subtle differences between groups to be highlighted. The results also suggest that fs should be at least 256 Hz to accurately evaluate AF organisation using LZ complexity with k-means coarse-graining. The maximum accuracy obtained in this study (90%) is higher than that obtained using median coarse-graining (88%) and equivalent to that obtained using mean coarse-graining (90%) in [2].

V. CONCLUSIONS

LZ complexity with k-means coarse-graining is effective in characterising paroxysmal AF from the MAW with a high diagnostic accuracy (90%). LZ complexity analysis of AF organisation should be conducted with larger databases and at sampling rates higher than 2048 Hz, or in combination with other non-linear methods to examine whether this accuracy can be improved further.

REFERENCES


Table 1: Sensitivity, specificity and diagnostic accuracy when the LZ complexity of the N and T groups were significantly different.

<table>
<thead>
<tr>
<th>Signal</th>
<th>MAW</th>
<th>MAW</th>
<th>MAW</th>
<th>MAW</th>
<th>MAW</th>
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<tbody>
<tr>
<td>fs (Hz)</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1024</td>
<td>2048</td>
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<tr>
<td>Sensitivity (%)</td>
<td>76.92</td>
<td>65.38</td>
<td>88.46</td>
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<tr>
<td>Specificity (%)</td>
<td>62.50</td>
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<tr>
<td>Accuracy (%)</td>
<td>70.00</td>
<td>76.00</td>
<td>84.00</td>
<td>90.00</td>
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