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Principal Component Analysis to Quantify Anaesthetic Effects on Atrial Fibrillation Morphology

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Abstract— In this study the effect of the most useful anaesthetic was evaluated in patients with atrial fibrillation (AF). Principal component analysis (PCA) was applied as a novel method to represent the electrogram recordings in a more efficient manner using fewer channels. Subsequently, PCA was applied again in order to reduce the data set to a few representative activations with the measurement of the average dissimilarity between consecutive activations of an intracardiac signal. In addition, PCA was applied directly to the activations extracted from each dipole with the purpose of last step was to analyze temporal and spatial differences. The proposed indexes showed different behaviour patterns along the atrial area during the anaesthetic effects.

I. Introduction

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice, with a prevalence rising nearly to 10% in the elderly [1]. AF is an arrhythmia originated at the atria (the upper heart chambers), and is due to the coexistence of multiple re-entrant atrial wavelets instead of a single one per cardiac beat.

Among the factors contributing to the genesis or maintenance of circulating wavelets, the circadian variations of Autonomic Nervous System (ANS) may play a significant pro-arrhythmic role [2], [3].

The goals of treatment for AF include restoring the heart to normal rhythm, slowing the heart rate, and preventing blood clots. Treatment options may include nonsurgical procedures, or surgical procedures, such as electrical cardioversion or ablation where the patients are usually under the influence of intravenous anaesthetic agents.

The most common agent is propofol, which is a rapidly acting intravenous anaesthetic. The rapid redistribution and metabolism of propofol results in a short elimination half- life of approximately one hour, making it suitable for short-lasting sedation. In addition, during the complete process electrical atrial activity can be recorded simultaneously (electrograms), providing an interesting source of data to get insight into themechanisms of AF.

Since the localized intracardiac electrograms recorded during the procedure are a mixture of both local and global cardiac activity, it can be difficult to distinguish overall trends. Therefore, we propose to use Principal Component Analysis (PCA) to enhance the characterization of the fibrillatory patterns, summarizing the data using a smaller Lumber of components and rejecting background noise. In addition, PCA is applied to the main components in order to extract the dominant representative activations, as a measure of the similarity between consecutive activations of the intracardiac signals. With this analysis we extract the most representative components in space and time in both states, in basal conditions and during the anaesthetic effects.

PCA techniques have been already applied previously in the same database in order to extract the main information [4], as well as in other cardiac electrophysiology, such as in the study of ventricular repolarization [5], the estimation of fibrillatory waves in AF recordings [6], and in this paper another application concerning intracardiac recordings during atrial fibrillation is proposed.

II. Materials

AF intracardiac recordings were registered in 18 patients submitted to an AF ablation procedure immediately befote and after propofol sedation (an iv bolus of 1.5-2 mg/kg, depending on weight and time to hypnosis). A 24-pole catheter (Orbiter, Bard Electrophysiology, 2-9-2 mm electrode spacing) was inserted through the femoral vein and positioned in the right atrium with the distal dipoles into the coronary sinus to record left atrial electrical activity as well. The medium and proximal electrodes were located spanning the right atrial peri-tricuspid area, from the coronary sinus ostium to the upper part of the interatrial low paraseptal region including low right septum and low left septum. Using

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this catheter, 12 bipolar intracardiac electrograms from the right and left atrium, were digitally recorded at 1 kHz sampling rate (16 bit A/D conversion; Polygraph Prucka Cardio-Lab, General Electric). Thirty to 60 seconds recordings were analyzed and compared before and during the anaesthetic effect.

III. Methods

B. Preprocessing

The intracardiac signals reflect the irregular and complex activation of the tissue in close proximity to the electrodes located along the atria. Despite two regions are successively depolarized by the same wavefront, there is a delay between activation that is the time required to cover the inter-dipole distance. In order to remove the delay between the observed depolarization at the two sites, the electrograms were aligned. The alignment was done by the application of crosscorrelation to each two closely associated in time activations. Correlation coefficient became maximum when the patterns in both complexes were overlapped and it was indicative of signal alignment of two atrial depolarizations.

C. Application of Principal Component Analysis

In order to remove the redundancy of the electrograms and evaluate the joint trends of these signals, PCA is applied. This process is employed to emphasize the common properties of the original signals and concentrate them in a reduced set of new variables, also known as the principal components (PCs).

PCA is a popular data processing and dimension reduction technique [7]. PCA seeks the linear combinations of the original variables such that the derived variables capture maximal variance, with the restriction of being mutually orthogonal. The objective is to find a linear transformation of the original variables, ordered by high proportion of the variation of the old variables, in a set of new uncorrelated variables, also known as the principal components (PCs).

Actually, each of the PCs is associated to an eigenvalue (or analogously a singular value), where the first component corresponds to the largest eigenvalue, and the following components are subsequently associated to the remaining eigenvalues in a decreasing order. In fact, the larger the *ith* eigenvalue, the higher variance in the original data is represented by the *ith* PC.

Because of the way atrial signals propagate from a source in the atria to the electrodes, large signals will be measured at all electrodes and hence the dipoles will be highly correlated. The primary interest here is the large signals, as they relative easy can be extracted without too much noise. Therefore PCA is an appropriate tool to reduce the number.

1) Spatial & Temporal Activation Pattern Analysis: PCA was applied separately for the signals before and during anaesthetic infusion. In addition, several analysis based on different atrial regions were performed separately: (1) Leith atrium (LA) (dipoles 1-2, 3-4 and 5-6) and (2) right Atrium (RA) (dipoles 15-16, 17-18, 19-20 and 21-22), respectively.

From the first PCs extracted from the recordings were obtained the activation patterns. They were extracted from the signal as windows centred on each activation time and having a fixed length equal to the inverse of the signal main frequency. The alignment was done by the application of cross-correlation between to each pair of activations. Correlation coefficient became a maximum when the patterns in both complexes were overlapped and it was indicative of signal alignment of the two-atrial depolarisations.

PCA was applied to the constructed matrix with the aligned activations, and the first k eigenvectors having an associated cumulative normalized variance higher than 75% were selected. The original data matrix was then represented on the new orthogonal basis by considering only the PCs. The analyzed parameter was the cumulative variance of these components.

2) Temporal Activation Patterns: From the recordings from each dipole located in the LA and the RA were obtained the activation patterns. PCA was applied to the constructed matrix with the alienated activations from each dipole, and the first k eigenvectors having an associated cumulative normalized variance higher than 70% were selected. The original data matrix was then represented on the new orthogonal basis by considering only the PCs. The analyzed parameter was the cumulative variance of these components.

D. Statistical Analysis

Variance was the parameter to compare. This parameter is expressed as mean ± SD. Independent and paired t-tests were used for comparison between the 2 groups of results. Results were considered to be statistically significant at $p < 0:05$.

IV. Results

The obtained results will be classified accord to the different proposed analysis.

B. Spatial & Temporal Activation Pattern Analysis Results

As a result of the application of PCA to the both groups on the different atrial areas, LA and RA, it is possible to distinguish between which groups has more organised electrical activity by the analysis of the cumulative variance.

1) Left Atrium: PCA After the application of PCA on the 3 leads situated in the LA, the results for the amount of variance captured by the first component were 63.61±15.98 at baseline to 62.02±13.84 during propofol state, ($p = 0.462$) with a difference of 1.59±8.98.

From the first component, after the data transformation into the representative activation patterns, PCA was applied in

TABLE 1
VARIANCE OF LA ACTIVATIONS AS FUNCTION OF NUMBER OF EIGENVECTORS ON BASAL AND PROPOFOL STATES

	BASAL	PROPOFOL	p
LA 1PC	48.71±10.22	51.62±10.81	0.433
LA 2PC	58.05±10.46	61.46±10.11	0.314
LA 3PC	63.91±10.21	67.28±9.20	0.294
LA 4PC	68.61±9.49	71.95±8.47	0.269
LA 5PC	72.42±8.65	75.95 ±7.70	0.210
LA 6PC	75.58 ±7.81	79.11± 7.09	0.173
LA 7PC	78.30 ±7.11	81.82 ±6.53	0.141

other to take as output index the cumulative variance associated with a limited number of projections. The differences between both states were not statistically significant in any case (Table 1).

1) Right Atrium: Considering only the first components as the global trend, the results of the cumulative variance were 50.94±10.22 at baseline to 54.20±11.20 during the anaesthetic infusion, (0.153) with a difference of -3.26±9.24.

From the first component, after the data transformation into the representative activation patterns, PCA was applied in order to take as output index the cumulative variance

TABLE 2
VARIANCE OF RA ACTIVATION AS FUNCTION OF NUMBER OF EIGENVECTORS ON BASAL AND PROPOFOL STATES

	BASAL	PROPOFOL	p
RA 1PC	58.43±9.93	62.81± 8.96	0.022
RA 2PC	69.53±9.11	73.51±7.73	0.023
RA 3PC	76.28±8.47	79.05 ±6.70	0.075
RA 4PC	80.75±7.66	83.25±6.00	0.079
RA 5PC	84.04±6.72	86.48±5.47	0.065
RA 6PC	86.65 ±5.99	88.84±4.92	0.071
RA 7PC	88.73 ±5.31	90.72±4.40	0.069

associated with a limited number of projections. This parameter was higher during the anaesthetic effects, and the differences between both states became statistically significant in the first components (Table 2).

B. Temporal Activation Pattern Analysis Results

In this study the variance of the PCs extracted from the activations of the data registered in each dipole were compared along the atria, in basal and propofol states.

1) Left Atrium: Considering: The recordings from four dipoles located in the RA were analyzed. The accumulated variance from the main two components in both states was compared from each dipole was compared with a paired t-tests, and the differences of variance between the first PCs of the activations of dipoles situated on the LA were not statistically significant. In addition an independent statistical test was applied to the parameters obtained from the dipoles located in the LA in order to find out the same differences

TABLE 3
COMPARISON OF VARIANCE OF ACTIVATION SIGNALS FROM DIFFERENT DIPOLES SITUATED IN THE LA

	BASAL	p	PROPOFOL	p
PC1dip1-2–3-4	2.61±17.37	0.504	8.87 ±18.61	0.433
PC2dip1-2–3-4	2.60±18.15	0.493	8.19±18.44	0.314

along the LA during basal and propofol effects. The variances from the PCs from the activations of dipole 1-2 were compared with the rest of the dipoles in the LA, dipoles 3-4, and 5-6, with a variance for the first component in the propofol state of 54.94±10.48 vs. 46.07±14.35, in the dipoles 1-2- and 3-4, respectively with a difference of 8.87±18.61 and a statistical signification of 0.042. (Table 3).

1) Right Atrium: The recordings from four dipoles located in the RA were analyzed. The accumulated variance from the main two components in both states from each dipole with paired t-tests. The comparison of the main components variance for the dipole 15-16 showed a statistically significant difference (PC1 59.47±10.60 vs. 64.55±9.08, basal and propofol, respectively p=0.001). In the rest of the dipoles situated on the RA the variance differences were not statistically significant.

In addition the variation an independent statistical test was applied along the dipoles located in the RA in order to find out differences along the RA during basal and propofol

TABLE 4
COMPARISON OF VARIANCE OF ACTIVATION SIGNALS FROM DIFFERENT DIPOLES SITUATED IN THE RA

	BASAL	p	PROPOFOL	p
PC1dip15-16–17-18	7.41±20.27	0.081	3.54 ±21.16	0.352
PC2dip15-16–19-20	6.83±17.25	0.050	3.51±21.06	0.345
PC1dip15-16–19-20	10.30±10.11	0.001	4.39±13.55	0.194
PC2dip15-16–19-20	8.53±8.69	0.003	2.43±13.37	0.473
PC2dip15-16–21-22	8.49±8.84	0.007	4.48±12.30	0.172
PC2dip15-16–21-22	6.96±8.03	0.002	5.00±11.15	0.097

effects. The variance from the PCs from the activations of dipole 15-16 were compared with the rest of the dipoles of the RA, dipoles 17-18, 19-20 and 21-22, with a variance for the first component in the propofol state of 5.47±10.60 vs. 55.93±11.86, in the dipoles 15-16- and 17-18, respectively with a difference of 3.54±21.16 and a statistical signification of 0.352. (Table 4)

V. Conclusion

In this paper a novel method based on PCA has been applied to quantify the organization of the atrial electrical activity during AF. As shown in the results section, the proposed parameters are able to capture subtle changes in the dynamics of atrial signals induced by propofol infusion during AF and these findings follow the same tendency than other indexed provided by previous studies [8].

In order to carry out a more efficient study, with the main activation patterns, PCA was applied. The data can be adequately described using far fewer factors than original variables. Thus, observing fewer scores than original variables, with no significant loss of information, can solve the data overload problem.

In organised recordings, PCA found a small number of principal components explaining a large fraction of the variance of the activation patterns. In contrast, disorganised recordings characterised by activation patterns morphologically different to each other corresponded to a large number of principal components each carrying a small part of the total data variance.

As a result, with the administration of propofol an increase in the organization of the RA was observed, with non-significant differences in the LA. In addition, the variance from the most representative components of the dipoles situated in the RA and the LA varied during the propofol infusion. These differences along the RA were statistically significant in basal conditions. Moreover, the LA has a similar behaviour in both states, showing more differences between dipoles in the propofol state. The physiological significance of these findings is not easy to interpret. Atrial fibrillation tends to be maintained in LA, with the RA acting as a by standard in many occasions [9].

The subjacent information in the morphology of the atrial electrical activity during AF, and the efficiency of PCA as a tool to provide self-standing measures of the extent of organisation of the atrial activity from electrograms during this arrhythmia are the main contributions of this paper. In contrast to previous studies to evaluate the organization [10], [11], [8], PCA measure the extent of repetitiveness in time of the atrial activations within a main component as global trend of this atrial region. As a result, in signals containing activation patterns that are morphologically similar to each other, PCA entrains the whole data variance into one or a few principal components.

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