行政院國家科學委員會補助專題研究計畫成果報告

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※ 正常與不正常華人平均信號心電圖 ※
※ 在時間領域與頻率領域之研究 ※
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計畫主持人：臺北醫學大學 醫學資訊研究所 楊騰芳

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□出席國際學術會議心得報告及發表之論文各一份

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一、中文摘要

心室性遲緩電位之存在已被證明與產生心律不整的介值有關連。這些產生心律不整之介值可在心肌中表現出傳導進行的延遲以及心室激化的延緩而具有支離破碎的電力活動,這些電力活動與心室性心律不整的發生具有因果關係。平均信號心電圖被用來偵測心室性的遲緩電位以利於對心臟血管病患未來產生心室性心律不整事件的危險加以預測。華人及西洋人時間值域平均信號心電圖的正常值領域界定在近年來由本研究者已有研究報告,而頻率領域之平均信號心電圖的測量項目則尚未有人系統化的研究發展。在另一方面,人工智慧領域（例如：類神經網路判斷系統以及模糊邏輯診斷系統）當被運用於心臟電氣學領域之診斷研究。因此,本研究之主要目的乃在於探討應用人工智慧來幫助偵測平均信號心電圖（在時間及頻率值域）中心室性遲緩電位之存在。同時也對信號處理技術在平均信號心電圖的發展有本土化之研究。

本研究者將會建立臨床數據資料及平均信號心電圖的數據。這些平均信號心電圖數據將會用來輸入於人工智慧診斷系統中以便於訓練及設計這些系統。此些研究將與台灣科技大學王教授之研究群合作,而信號處理技術之發展研究將與台灣科技大學陳教授之研究群合作來完成,經過數學統計學 ROC 曲線之運算後,最佳截取點會被決定出來,而且最合適的人工智慧模型系統將會造出來以便未來的評估及修正。經由上述這些研究步驟,華人及西洋人的平均信號心電圖（包括時間值域及頻率值域）均可以詳細研究完成,且其診斷心室遲緩電位之標準也可以因此確立。而人工智慧自動心臟平均信號心電圖之診斷系統也可因此完成,對於心臟電氣學之臨床研究診斷有所助益。

關鍵詞：*平均信號心電圖,高解析度心電圖,心室遲緩電位,心室性心率不整,人工智慧,類神經網路,模糊邏輯,頻率領域分析,時間領域分析,正常值,年紀,性別,種族*。

Abstract

The presence of ventricular late potentials (VLPs) has been associated with an arrhythmogenic substrate characterised by fragmented electrical activities due to delayed ventricular activation and slowed propagation of conduction in the myocardium, which in turn seems to be related to the development of ventricular arrhythmias. The signal-averaged electrocardiogram (SAECG) has been used to detect ventricular late potentials in order to stratify patients at risk of future arrhythmic events on account of their underlying cardiovascular diseases. Several researches of the normal limits of the time domain SAECG in Chinese and Caucasians have been performed by the principal researcher in recent years. Whereas measurements from the frequency domain SAECG has not been systemically investigated. On the other hand, the advance of artificial intelligence (AI), namely artificial neural networks classification system and Fuzzy logic diagnostic system, has been applied in the field of Electrocardiology. Therefore, it is thought the

application of AI to the detection of VLPs by use of SAECG time domain and frequency domain parameters might be useful in the field of non-invasive electrocardiology. It is also possible to investigate the appropriate signal processing techniques in generating SAECG measurements.

The clinical materials and SAECG database will be collected as well as established by the principal researcher. This database will be used as input to train the AI diagnostic systems and the topologies of the AI systems will be developed and designed with the cooperation with Professor Wang's group and the signal processing techniques will also be developed with Professor Chen's group. After the statistical manipulation through the Receiver Operation Characteristic (ROC) curve the best cutoff point will be determined and the most appropriate AI configuration will be chosen and used for the further evaluation and revision. Through these researches the research on SAECG of Chinese and Caucasians can be completed. The diagnostic criteria can be established and the SAECG automated AI interpretation programme can be finished in order to aid the clinical diagnosis in electrocardiology.

Keywords: *Signal-averaged electrocardiogram, High-resolution electrocardiogram, Ventricular late potentials, Ventricular arrhythmias, Artificial intelligence, Artificial Neural Networks, Fuzzy logic, Frequency domain analysis, Time domain analysis, Normal limits, Age Sex.*

二、緣由與目的

Background and Purpose of the Present Study

(1) Background

(a) Materials collection and database establishment: Chinese versus Caucasians

The principal researcher has involved in the study of defining sex dependent normal limits of time domain analysis SAECG parameters in Caucasians at 1994. This researcher has also performed the study of normal limits of time domain SAECG measurements in Chinese at 1997. Whereas there were no large series of normal limits of the frequency domain parameters either of Chinese or Caucasians being published till recently. Thus, it is thought possible to establish the normal limits of SAECG time domain and frequency domain parameters both in Chinese and Caucasians through the present study.

(b) History and development of methodology in ventricular late potentials detection

Signal averaging principles have been utilised by Galton as early as 1875 to enhance human features in portraits. The first application of signal averaging in medicine to improve the detection of electroencephalographic signals was made at 1947 by Dawson. He was probably the first to present this application to the Royal Physiologic Society of London, where he compared the technique with the one used in Radar detection. In 1963, Hon & Lee used Computer of Average Transients (CAT) device to extract the fetal heart beat signals from maternal skin surface electrograms.

In 1968, Jarrett and Flowers' group reported a computer-based modification of the original signal averaging technique which is essentially the approach used today. In 1973, the first successfully extracted His potentials from the body surface were reported. Progress in bringing this application into clinical cardiology has been limited because of the relatively low level of the His bundle signal on the body surface electrocardiograms (i.e. 1-10 microV compared to the QRS amplitude of 1000-2000 microV for V5 or V6). Also in 1973, Boineau and Cox showed that the delayed and fragmented electrograms were presented in the ischemic cannie myocardium. Waldo and Kaiser also described the bridging of diastole by electrical activity preceding ventricular arrhythmias. Scherlag, Hope and Williams in 1974 had demonstrated the relationship between delayed ventricular activation and ventricular arrhythmias. In 1977, El Sherif and Hope created a model for observing the delayed activity related to the generation of the ventricular arrhythmias.

In 1981 Simson MB reported the ventricular tachycardia risk detection post-myocardial infarction by using signal averaged ECG. In 1994, Yang and Macfarlane reported the sex dependent normal SAECG diagnostic criteria based on Caucasian normals.

(c) Technical aspects of signal-averaged electrocardiography

The process of signal averaging technique is designed to detect the low amplitude signals in the terminal QRS complex and early ST segment by eliminating noise interference of the surface ECG. Noise source including skeletal muscle myo-potentials, electrode skin interfaces, amplifiers, and 60 Hz power line current and its harmonics. Parameters of VLPs are significantly dependent on noise level after signal averaging. Using conventional criteria for the detection of VLPs in SAECG, healthy individuals become false positive at low noise levels. In conventional time domain analysis of SAECG, the criteria for VLPs are very dependent on prior bi-directional filtering and on the accurate determination of the end of the QRS complex. An alternative method is Fourier transformation of frequency domain, which has also not yield a better results, for it also requires a precise localisation of the offset of the QRS complex. Wavelet analysis technique is a new time-scale method that makes it possible to detect small, transient signals, even if they are hidden in large waves. It should obviate the main limitations of the other techniques. This wavelet analysis technique has been demonstrated by Morlet et al better in terms of receiver operating characteristics (ROC) comparing to the conventional time domain analysis.

(d) Time domain and frequency domain analysis of signal-averaged electrocardiography

Spectral methods have been developed specifically to detect VLPs of SAECG. Spectro-temporal Mapping (STM) uses multiple segments in the terminal part of the QRS complex, which are subsequently transformed to the frequency domain with fast Fourier transformation. STM is based on the hypothesis that VLPs are only present in segments at the end of QRS complex, whereas noise interferences are equally distributed throughout all segments. Visual inspection of the spectrum is recommended and the Factor of Normality (FON) is calculated. However, this FON should not be used alone for the interpretation of STM for the detection of VLPs in SAECG. Fourier analysis shows poor frequency resolution with short data segments, so a segment size of 300 msec was chosen by the most researchers. Window functions have to be applied in order to eliminate spectral artefacts due to edge discontinuities. This process can further reduce frequency resolution by a factor of 2 to 3.

More sophisticated methods have also been developed in recent years, which were characterised by a very high frequency resolution with short segment sizes (i.e. auto-regressive techniques, e.g. Adaptive Frequency Determination and Maximum Entropy Methods). This technique might be more helpful for a detail analysis of the SAECG content, namely, frequency content of VLPs, His bundle activity, analysis within the QRS complex, influence of the anti-arrhythmic agents. In general, auto-regressive technique is less stable and less repeatable than Fourier transformation and more susceptible to noise interference. They require optimal recording units with low noise, little distortion of signal, 16-bit analogue to digital converter.

(e) Relationship of the presence of ventricular late potentials in signal-averaged electrocardiography and ventricular arrhythmias

The presence of VLPs in SAECG predicts the likelihood of future ventricular arrhythmic events in the post-myocardial infarction patients. They can also be used in the dilated cardiomyopathy patients. VLPs arise from the border zone of a myocardial infarcted scar, where fibrotic isles cause a conduction delay during sinus rhythm. The stream of normal ventricular conduction prevents a reentrant circuit, because the slowly propagating activation wave front cannot penetrate the refractory fibrotic scar tissue. The large mass of slowly conducting tissue which produces VLPs on the body surface, just indicates a high probability that substrate for reentrant tachycardia is also present. The presence of VLPs during the first week after infarction is associated with subsequent ventricular dilatation. These may be a manifestation of cell slippage and arise before gross topographical enlargement and may serve as a predictor of ventricular enlargement.

(f) Artificial intelligence: artificial neural network versus fuzzy logic

Artificial neural networks (ANN) have been used by this researcher on the automated computerised ECG diagnosis of myocardial infarction and left ventricular hypertrophy. ANN has also been used in the separation of atrial fibrillation from sinus rhythm with supra-ventricular &/or ventricular ectopics. ANN has the advantage in the application to the field of medical diagnosis where the criteria are ill-defined and the rule s are difficult to formed, especially where the overlapping is difficult to define. Fuzzy logic is also a newly progressed artificial intelligence method. Till recently, no publication has been reported to use this technique in the electrocardiological diagnosis.

(g) Diagnostic criteria defined in time domain signal-averaged electrocardiography

In 1991, a task force of the ESC, AHA and ACC published a set of sex independent diagnostic criteria for the detection of VLPs for SAECG as follows:

1. FQRSd > 114 msec
2. LAS40 > 38 msec
3. RMS40 < 20 microV.

This set of criteria yields a specificity of 85% for men and 91% for women in the 195 healthy Caucasian individuals.

In 1994, Yang and Macfarlane have revised a set of sex dependent diagnostic criteria for the detection of VLPs for SAECG as follows:

1. FQRSd > 114 msec for men
   FQRSd > 104 msec for women
2. LAS40 > 38 msec
3. RMS40 < 20 microV.

This set of criteria yields a specificity of 97% for men and 100% for women in the 195 healthy Caucasian individuals.

(2) Purpose of This Research

(a) First Year

1. Central laboratory founded for database establishment and study materials collection. The SAECG database in Chinese can be established and clinical database can also be collected for future research and criteria establishment.
   (Performed by Professor Ten-Fang Yang's group and Dr Ing-Fang Yang's unit)
   (Echocardiographic examination will be obtained and transferred to the image processing group led by Professor Hsin-Teng Sheu's group)
2. Development of the signal processing methodology of time domain and frequency domain analysis of SAECG in order to detect the VLPs. This process can aid the foundation of the local application of signal processing in the field of electrocardiology.
   (Cooperated with Professor Chih-Ming Chen's group)
3. Design and develop the Artificial Intelligence Diagnostic System (AIDS) include: Artificial Neural Networks (ANN) versus Fuzzy Logic (FL). This will be the first experience to apply ANN and FL in the diagnostic system in electrocardiology.
   (Cooperated with Professor Nai-Jian Wang's group)

(b) Second Year

1. Normal and abnormal ranges of measurements in SAECG will be defined and classified.

Statistics of the collected materials will be performed at the core laboratory at Taipei

Medical College. Distribution and characteristics will be found.

2. Various methods will be compared in the signal processing of SAECG parameters and their accuracy will be defined through the already collected normal and abnormal database.

The most appropriate technique for either time domain (includes wavelet technique) or frequency domain (spectro-temporal mapping) will be determined using the already collected materials through the statistical process.

(Cooperated with Professor Chih-Ming Chen's group)

3. Model of the Fuzzy Logic Diagnostic System (FLDS) will be developed through the manipulation of the already collected normal and abnormal database.

(Cooperated with Professor Nai-Jian Wang's group)

4. Artificial Neural Networks will be trained with various topologies to determine the best configuration by the already collected normal and abnormal database.

(Cooperated with Professor Nai-Jian Wang's group)

(c) Third Year

1. Signal-Averaged Electrocardiographic diagnostic criteria for the detection of ventricular late potentials will be established through the evaluation of normal and abnormal populations.

2. Evaluation of the well-trained artificial neural network classification system and the fuzzy logic diagnostic system through the test set materials.

(Cooperated with Professor Nai-Jian Wang's group)

3. Time domain and frequency domain technical analysis of the Signal-Averaged Electrocardiographic diagnostic criteria through the Artificial Intelligence Diagnostic Systems.

(Cooperated with Professor Chih-Ming Chen's group and Professor Nai-Jian Wang's group)

(3) Impacts of the Present Research

(a) First Year

Collection of the study materials will be performed and clinically normal database and abnormal database will be collected from the outpatient clinics and hemodialysis unit. Signal processing techniques including proper filtering effect and noise level will be investigated. Methodology for time domain and frequency domain measurements of Signal-Averaged Electrocardiography will be established. Models of artificial intelligence diagnostic system through either artificial neural network or fuzzy logic for the detection of ventricular late potentials by Signal-Averaged electrocardiogram will be developed. All these can enhance the application of signal processing technique and artificial intelligence to the diagnostic aspects of electrocardiology.

(b) Second Year

Statistics of Chinese normal and abnormal materials will be evaluated and manipulated in order to compare with the database of Caucasian's in Glasgow Royal Infirmary. Through this stage, the influence of age, sex, and race on measurements of Signal-Averaged electrocardiographic parameters can be illustrated. Time domain and frequency domain ranges will also be calculated. Training experience of the artificial neural networks and determination of the most appropriate fuzzy logic topology will also be obtained from this stage.

(c) Third Year

Sensitivity and specificity of the present Caucasian criteria will be evaluated and newly devised criteria for Chinese and Caucasians will be established. Time domain and frequency domain measurements will be evaluated through the newly collected test sets to determine the best techniques for the detection of ventricular late potentials by Signal-Averaged electrocardiography. Artificial neural network classification system and fuzzy logic diagnostic systems will also be evaluated and revised to the best performance.

(4) Current Status of the Present Study

There was a only report about the normal limits of time-domain analysis of SAECG parameters in Children at Singapore. Another study has reported the noise level influence on the measurements of SAECG in healthy subjects. Most of the papers deal with the time domain analysis of the SAECG for they are more reproducible than the frequency domain analysis of the SAECG. Although there were reports using ANN in the wave form detection of VLPs in SAECG, there has been no one use artificial neural networks or fuzzy logic system in the diagnosis of the presence of ventricular late potentials in signal-averaged electrocardiography. From the present research, it is possible to establish Chinese specific diagnostic criteria for the SAECG and AIDS will also be developed and simultaneously signal processing technique in electrocardiology can also be founded.

三、研究成果

平均信號心電圖在血液透析腎衰竭病人之表現

背景：

一種非侵襲性的技術來偵測平均信號心電圖上的遲緩電位可以預測惡性心室性心律不整及猝死。大約一半的末期腎衰竭病人的死亡率(6-9%)是因為心臟血管疾患而來。而最終的病情常是心室性心律不整。本研究之目的在評估血液透析是否可以以改變平均信號心電圖的常數而減少心室性心律不整的危險。

方法及材料：

平均信號心電圖在 122 個正常台灣人身上利用 Siemens Mega Cart 機器來記錄。同時末期腎衰竭病患23 人也用來比較血液透析前後 30 分鐘的平均信號心電圖。血液生化學檢查也同時由廔管的動脈端抽取。利用時間領域分析，過濾 QRS(FQRS)小於 40microV 的信號期由(LAS40)及最後 40msQRS 期間的根號平均平方值(RMS40)都被計算出來。血液透析的有效值(kt/v,URR,nPCR)都也被計算出來。

結果：

	FQRS	LAS40	RMS40
B 血液透析前	81.06 ±18.40	35.00 ±31.64	34.39 ±17.43
A 血液透析後	95.22 ±35.66	35.45 ±33.30	36.43 ±30.06
C 對照組	98.20 ±22.02	40.99 ±26.25	28.81 ±21.23

二側 t 檢查用來作統計學檢驗。FQRS(C)和(B)在統計學上之差異有意義(PC 0.001)，其他的數據均無統計學上之差異。多重迴歸利用 FQRS(B)&(A)之差異來作反應變數，而電解值數據，kt/v,URR,nPCR,BSA 來作預測變數，P 值均小於 0.05。

結論：

1. 血液透析可有有效改變 FQRS 近正常值。
2. 血液透析造成的電解值變化及 FQRS 之改變有直接之關係。
3. 血液透析之有效度與 FQRS 之加成正比。

Signal-Averaged ECG in Chronic Renal Failure Patients Under Maintenance Hemodialysis

Background:

A non-invasive technique to identify late potentials on the signal-averaged ECG (SAECG) can predict malignant ventricular arrhythmias and sudden death. Approximately half of the annual mortality (6-9%) of end-stage renal failure (ESRF) patients can attribute to the cardiovascular diseases. Among them, ventricular arrhythmias are the most common terminal events. The purpose of this study is to evaluate the effectiveness of hemodialysis in reducing the risk of ventricular arrhythmias.

Materials and methods:

SAECG was recorded using a Siemens Mega cart machine from 122 healthy Taiwanese subjects as the normal control. Another SAECG group of 23 consecutive ESRF patients were also recorded 30 minutes

before and after the hemodialysis sessions. Blood chemistry data were also taken at the same time from the arterial side of the fistula. For time-domain analysis, filtered QRS duration (fQRS), duration of low amplitude signals<40 μV (LAS_{40}) and root mean square voltage of signals in the last 40 ms of the QRS intervals (RMS_{40}) were calculated. Efficiency data of hemodialysis (Kt/v, URR, nPCR) were also calculated.

Results:

	fQRS	LAS_{40}	RMS_{40}
Control (C)	98.20 ± 22.02	40.99 ± 26.25	28.81 ± 21.23
Before HD (B)	81.06 ± 18.40	35 ± 31.64	34.39 ± 17.43
After HD (A)	95.22 ± 35.66	35.45 ± 33.30	36.43 ± 30.06

Two-sided *t* tests were used for the statistic analysis. fQRS (C) and (B) is significantly different (P<0.001). All other comparative data were all not different. Multi-regression analysis uses fQRS (B) and fQRS (A) difference as the response variables, and electrolyte data, Kt/V, nPCR, URR, body surface area as predictory variables, the P value is all <0.05.

Conclusions:

(1) Hemodialysis can effectively prolong the fQRS toward normal control.
(2) Hemodialysis-induced changes of electrolyte (Na, K, and Ca) are directly related to the alteration of fQRS.
(3) Efficiency of hemodialysis (Kt/V, URR, and nPCR) is proportional to the increased fQRS.

Keyword:
Signal-averaged electrocardiography (SAECG), Hemodialysis (HD), End-stage renal disease (ESRD)

Background and purpose

Approximately half of the annual mortality (6-9%) of end-stage renal failure (ESRF) patients can attribute to the cardiovascular diseases. Owing to the concomitant changes in hemodynamic status, electrolyte level, acid-base balance and body fluid redistribution occur during and after the dialysis period, ventricular arrhythmia has been demonstrated as one of the most common cardiovascular causes of death in ESRF patients undergoing maintenance dialysis therapy. Signal averaging of the body surface electrocardiography is a computerized method of analyzing high resolution ECGs that has been used as a non-invasive technique for the past two decades to identify patients at risk for ventricular tachyarrhythmias. This technique identifies low amplitude electrical signals at the end of QRS complex, termed ventricular late potentials (LPs), which represent delayed conduction through diseased myocardium and, thus, a potential substrate for reentrant ventricular tachycardia. Clinical indications for signal-averaging electrocardiography (SAECG) and the role of the SAECG in the management of patients at high risk for ventricular arrhythmias were fully developed in recent years. In healthy subjects and in many disease states, the SAECG has revealed an excellent reproducibility. It is also reported that the detection of an abnormal LPs on SAECG can identify high-risk patient group for seriously ventricular arrhythmic events and sudden cardiac death. The purpose of this study is to utilize the LPs on SAECG to evaluate the effectiveness of this non-invasive electrocardiological technique in reducing the risk of ventricular arrhythmic events in ESRF patients under maintenance hemodialysis therapy, and their comparisons with a normal healthy Taiwanese population.

Materials and Methods

Patient population

There were one hundred and twenty-two normal subjects (105 male and 17 female) recruited in the present study. They were students and teaching staff of the National Taiwan University of Science and Technology. All the recruited subjects had normal medical history, physical examination, chest X-ray, 12-lead electrocardiograms, echocardiograms and normal renal function test. At the same time (from Jan. 1998 to Sep. 1999), 23 (14 male and 9 female) of 49 CRF patients undergoing long-term maintenance hemodialysis therapy at Jen-Chi General Hospital were included in this study. Patients with the signs of congestive heart failure (6), baseline conduction abnormalities (e.g. atrial fibrillation and bundle branch block (4), arterial hypotension (6) at the end of the dialysis procedure, drop-out (4), antiarrhythmic therapy (4) and ECG evidence of a complete left or right bundle-branch block (2) were all excluded in this program. Mean average patient age is 65±15 years (range 22-78 years) and median time on maintenance hemodialysis therapy is 62±37 months (range 12-252 months). Thrice weekly maintenance hemodialysis therapy using Althin® artificial kidneys were performed with bicarbonate dialysate fluid for an average of four hours' period among these CRF patients. Serial blood chemistry check-up for every tested subject thirty minutes before and immediately after the hemodialysis sessions through arterial end of the fistula to show the biochemical and hemodynamic changes is recorded accordingly to analyze the efficiency of reducing arrhythmic risk via hemodialysis itself.

SAECG

All subjects tested were measured at rest, in a supine position, with a Frank corrected orthogonal XYZ lead system used to obtain ECG signals. A target beat was first obtained from the XYZ lead raw data. All incoming beats were correlated with this target beat. QRS complexes with more than 97% correlation with the target beat were accepted for averaging. A minimum of 300 beats was averaged for each subject. The process of averaging was terminated when the noise level was less than 1.0 micro. In subjects in whom the noise level was more than 1.0 microV, averaging was continued beyond 300 beats to a maximum of 600 beats. Signal averaged X, Y, Z leads were recorded according to the recommendation of the Task Force of the European Society of Cardiology (ESC), the American Heart Association (AHA), and the American College of Cardiology (ACC) (Breithardt G., et al 1991). The signal-averaged electrocardiograms were recorded with the Siemens Elema Mega cart ECG machine. Three parameters of the QRS vector magnitude evaluated are filtered total QRS (fQRS) duration, duration of low amplitude signals in the terminal portion of QRS complex that were less than 40 microV (LAS 40) and the root-mean-square voltage of the last 40 ms of the filtered QRS (RMS 40). The averaged QRS complex was filtered with a spectral bi-directional Butterworth filter having a high-pass frequency of 40 Hz and a low-pass cutoff at 250 Hz to avoid filter artifact or ringing. Values of these measures are dependent on the high pass corner frequency. Body mass index will be calculated by weight (kg) / height^2 (m^2). Body surface area (BSA) used will be derived from the height (H) and mass (M) of each person by the formula of Du Bois and Du Bois (1916):

$$\text{BSA (cm}^2\text{)} = \text{M (kg)}^{0.425} \times \text{H (cm)}^{0.725} \times 71.84$$

Statistical analysis

Data will be adopted for normality and expressed as mean standard deviation. Comparisons will be analyzed by Student's ***t***-test for both paired and unpaired data to analyze the significance of SAECG differences between measurements obtained before and after dialysis and in normal controls. A regression coefficient will be also calculated. A $P < 0.05$ will be considered as statistically significant. In the abnormal distribution group, non-parametric Mann-Whitney test will be used to compare the collected data.

Results

	fQRS	LAS_{40}	RMS_{40}
Control (C)	98.20 ± 22.02	40.99 ± 26.25	28.81 ± 21.23
Before HD (B)	81.06 ± 18.40	35 ± 31.64	34.39 ± 17.43
After HD (A)	95.22 ± 35.66	35.45 ± 33.30	36.43 ± 30.06

Two-sided *t* tests were used for the statistic analysis. fQRS (C) and (B) is significantly different (P<0.001). All other comparative data were all not different. Multi-regression analysis uses fQRS (B) and fQRS (A) difference as the response variables, and electrolyte data, Kt/V, nPCR, URR, body surface area as predictory variables, the P value is all <0.05.

Conclusions:

Abnormal SAECG parameters can be recorded in a high proportion of ESRF patients undertaking maintenance hemodialysis. Hemodialysis itself can effectively improve SAECG parameters towards normal and may further abolish LPs in these patients. This task may be the results of several combinations, such as: removal of fluid overload and electrolyte change. In brief,

(1) Hemodialysis can effectively prolong the fQRS toward normal control.

(2) Hemodialysis-induced changes of electrolyte (Na, K, and Ca) are directly related to the alteration of fQRS.

(3) Efficiency of hemodialysis (Kt/V, URR, and nPCR) is proportional to the increased fQRS.

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