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Electrophysiocardiogram
For the first time EPCG has been recorded on human body surface

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ABSTRACT

Since ECG was invented in 1903, this is the first time in history that a full information multi-band and multi-linear electrophysiological cardiogram has been used to successfully scan and record on the human body surface. Since it is able to record various multi-band, multi-track linear electric signals of cardiac electrophysiological activities that correspond to different regions of the entire heart, it has thus been denominated as "electrophysiocardiogram" (EPCG). A traditional ECG is always represented by a characteristic wave form, which resembles a string. For a long period of time, ECG has had a lot of mysteries surrounding it, it maybe because ECG has a lot of mixed signals buried in such convolutionary forms, which limits the amount of the signals that are discernable and determinable. For the first time, the EPCG technology has allowed cardiac signals to be convoluted into the linear wave form, which is then processed through various new approaches featuring multiple frequency bands, multiple dimensions and multiple patterns, and consequentially recorded as the following types of signals within the ranges of P wave and T wave: multiple frequency band signals, signals of different regions and different locations, forward waves and negative waves. Therefore, EPCG may help to solve many puzzling scientific questions regarding heart, such as exactly how many electric signals are involved in heart excitation, pacing, conduction and action, as well as many other intriguing questions about heart, and thus would become a very helpful tool in clinical practice.

1. Introduction

The P-QRS-T wave forms recorded by ECG, including invasive EP cardiogram also single string liner waves, resemble the shape of a string as they appear. ECG is a type of morphological exhibition, in which both P wave and T wave are half sinusoidal waves, while QRS are pulse waves. It mainly shows convolutionary electrophysiological signals within high frequency range. Accordingly, for a long period of time, ECG has been seen as one of the medical disciplines with the most mysteries. As for electrophysiocardiogram (EPCG), it is a novel scanning and recording graph for electrophysiological biological signals, which features multiple regions, multiple linear wave forms, multiple frequency ranges, as well as positive and negative dual amplitudes. It has separated various frequency bands based on features of time, amplitude and space. As a result, it is able to utilize a natural scanning track to record more delicate and detailed local anatomic site signals buried in the time ranges of P wave and T wave (Fig. 2). EPCG detects continuously generated potentials of each heartbeat from body surface, with its signal resembles an electrophysiological linear image [1,12–13]. In this article, by way of analyzing the detection images obtained from 1500 cases of normal human subjects, EPCG has scanned and recorded the electrophysiological wave groups of two major cardiac portions, the signals of one of the wave groups are aggregated around the major peaks of P wave and T wave and comprise both positive waves and negative waves (the sums of these amplitudes are respectively equivalent to the amplitudes of P wave and T wave obtained in traditional ECG), which thus represent the electric signals of atrial myocardium and ventricular myocardium; while the signals of other wave group gather in the vicinities above or below X axis, wherein when located above X axis, the respective amplitudes are about 0.15 mm/mV, and when located below X axis, the respective amplitudes are about 0.05 mm/mV; it is believed that these natural small wavelets may be related to the potentials of automatic conduction system (Fig. 3). In addition, before the starting point of P wave, SAN and SAN leading waves have also been recorded in EPCG (due to limited space, only the P wave part is described in this article). Based on the graphs recorded by EPCG, it is conceivable that each heartbeat may pass through an axis of the automatic conduction system sequentially as follows: the signal is firstly conducted from SAN to atrial region, then to AVN, and next to His bundle and Bundle branches

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sequentially, and final to Purkinje's initial. Moreover, as the specific local automaticity, specific pacing, specific time course of conduction potentials, specific cellular responsive heart rate fast or slow, specific ion composition and the like of each atrial anatomic location are slightly different; their respective frequencies are thus different as well [2–6]. The foregoing may be one major reason resulting in new regional and local wave forms shown in EPCG (Fig. 3). In both traditional ECG and the new EPCG, what have been shown in P wave and T wave are aggregations of signals of high frequencies, ultra high frequencies, very high frequencies and extremely high frequencies, in which about 95% electric signals are believed to be originated from atrial myocardium and ventricular myocardium. Furthermore, in EPCG, the small electric signals of automatic conduction system are an aggregation of signals of low frequencies, ultra low frequencies, very low frequencies and extremely low frequencies. In this regard, the signals shown in EPCG are in line with physical laws. Through further analysis on the graphs shown in (Fig. 5), it could be known that the respective SA node potentials and AV node potentials located on top of the figure exhibit slow response frequencies, which show slowly increasing and very slowly decreasing electric currents. Accordingly, during the time courses of SA node and AV node, EPCG displays a number of small wavelets, since both of them are histologically formed by slow response cells. Meanwhile, the respective Atrial potentials, Bundle branches potentials and Purkinje potentials located on top of the figure exhibit fast response frequencies, which show rapidly increasing and very rapidly decreasing electric currents. Accordingly, at these three locations, EPCG displays single small wavelet, since each of the three locations is histologically formed by fast response cells. Therefore, EPCG is also in line with known electrophysiological regularities. However, His bundle is an exception. It shows rapidly increasing and negatively decreasing electric currents. Searching previously published literatures, it has been found that the small wavelets (within the range of P wave) recorded in the vicinities above or below X axis in EPCG are actually agreeable with the implications of signals in respective time course segments within the range of P–R interval conjectured by Hoffman and Damato et al. [4,5,12–14] (Fig. 4). Therefore, the new EPCG electrophysiological cardiograms anticipated to make a landmark step to open a new door for eventually revealing the mysteries of cardiac electrophysiology.

2. Methods and results

2.1. Principles and methods

In this study, we have utilized the device newly invented by PhysioSign, which is able to automatically separate the signals captured on body surface into two modules. The entire apparatus system comprises systematic hardware, software and disruptive signal processing technologies, as well as a series of related algorithms and formulas. EPCG is able to automatically separate the convolutionary signals into a plurality of different linear wave forms within various frequency ranges. For example, within the frequency range from 1 to 150 Hz, the signals can be divided into 16 respective linear wave forms, with each one covering 9.4 Hz (Fig. 4); while in the case when the signals are divided into 32 linear wave forms, each one would cover 4.7 Hz (Figs. 1, 2, 3, 5). As for the module of self-adaptive electric signal frequency range, various frequency bands have been recognized and separated, which include: low frequencies, intermediate frequencies and high frequencies, in particular ultra low frequencies, very low frequencies, extremely low frequencies, ultra high frequencies, very high frequencies and extremely high frequencies. The crucial differences between PhySign's device and traditional ECG instruments are highlighted by its success in employing a novel Adaptive Mixture Technology within the ECG Signal Spectrum enabled by PhySign's Smart Data Acquisition Module. PhySign's Adaptive Mixture Technology is based on a collection of USA and International patents. Along with traditional ECG scanning/ recording, PhySign is also able to accurately extract a variety of time-domain ECG electric potentials in the 0 to 150 Hz range, and perform automated integrating signals recognition. The resulting ECG wavelet signals are displaying the natural signals of various parts of the heart with interfering artifacts being minimized.

2.2. Recording conditions

The study has been conducted in a quiet shielded electrophysiological testing room. In a test, a subject's skin is firstly pretreated with a special sandpaper, and then certain special electrodes are used to perform the test, in which the arrangement of electrodes are the same as that in a 12 lead ECG. In addition, both traditional ECG and EPCG have been detected synchronously. Moreover, the detection factors including acquisition

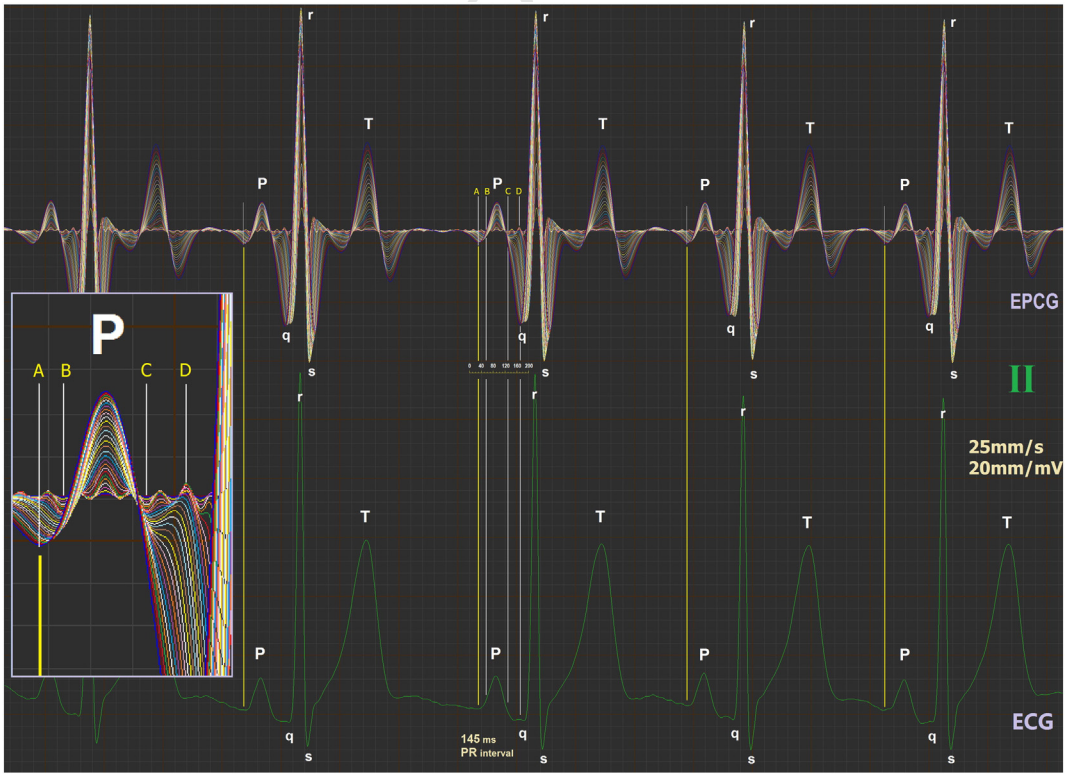

Fig. 1. The lead II, the upper is EPCG and the lower is existing ECG, both with 25 mm/s scan speed, 20 mm/mV amplitude. The yellow vertical line is the starting point of P wave and the P-QRS-T for two wave forms are corresponding completely. Their amplitude can be adjusted and the time histories of X axis will not be effected. The PR interval can be measured and they are among the 4 vertical lines. The EPCG features are: P and T show the wave form of both positive and negative values and, the two maximum values adding together form the positive value of the existing ECG (half P and half T upward). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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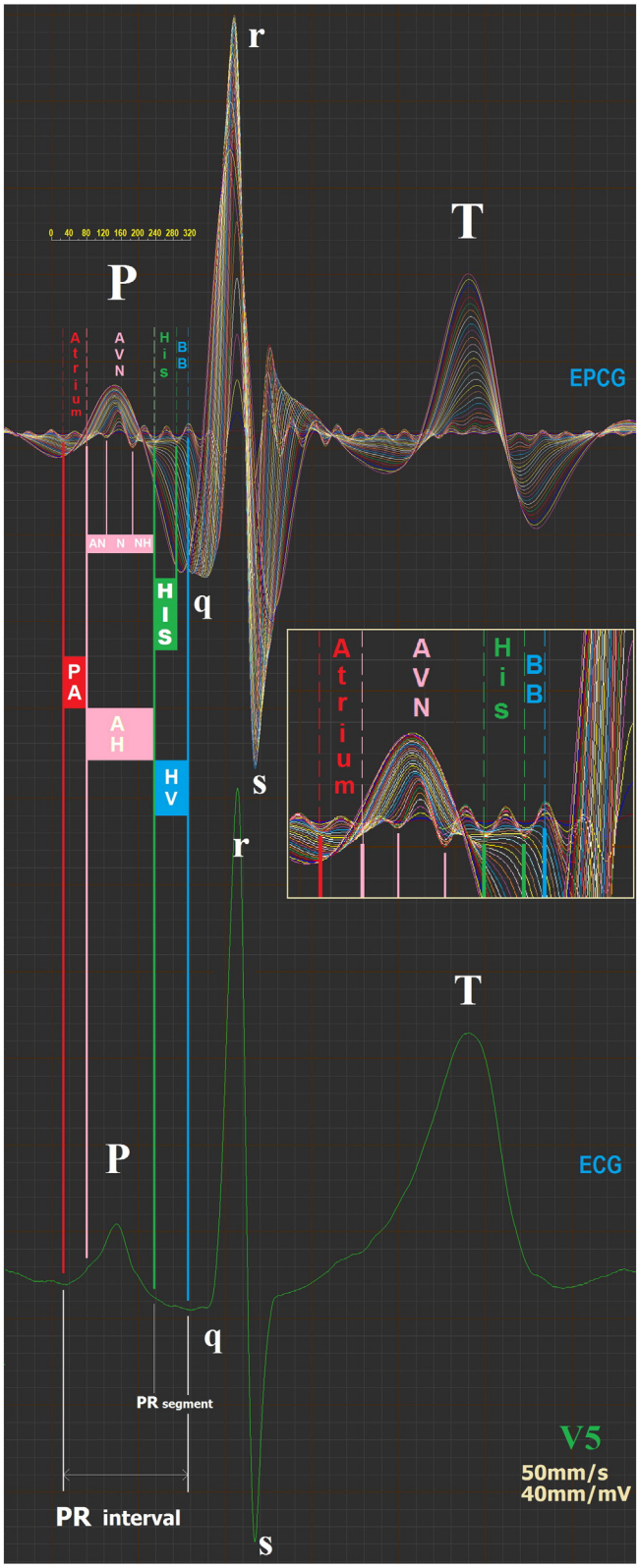

Fig. 2. The lead V5, the upper is EPCG and the lower is existing ECG, both with 50 mm/s scan speed, 40 mm/mV amplitude. EPCG isolates the convolution signal into 32 linear wave forms, each with 4.7 Hz. Between the red and pink vertical lines there is a wavelet which maybe the Atrial wave; 3 wavelets visible between the red and green vertical lines could be the AV node waves; and within the 2 green lines, a wavelet may be the Bundle of His wave; the one between the green and the blue lines may be the Bundle Branches wave. From Q to R upward that is parallel to the X axis, a wavelet seemed faintly to be the Purkinje initial. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

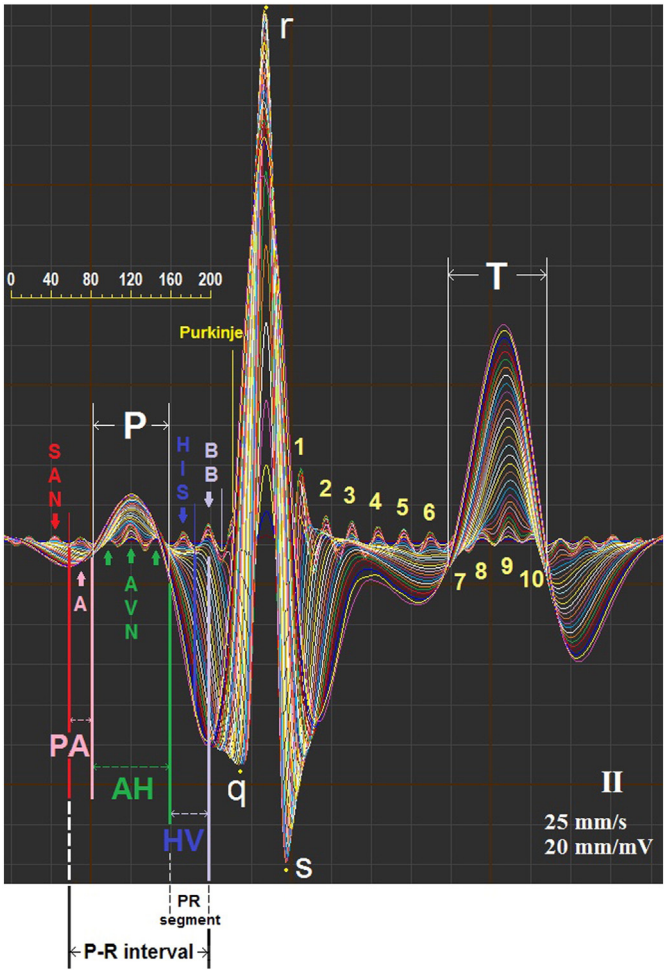

Fig. 3. EPCG displays holographic signal of cardiac. The wave form of positive and negative data may be formed by phase, so the cardiac signal exists not only the sine wave, but the cosine wave as well. The wavelet assembled upward the X axis with 0.15 mm/mV and those at inferior of X axis with 0.05 mm/mV amplitude. These could be the signals of the area of atrial self conduct system and the conduction of ventricular myocardial cell which only engages 5% of the whole cardiac signals. However, the high and wide P and T waves including the negative wave form may be the macrofiber electric signal of both atrial and ventricular myocardial that occupy almost 95% of cardiac signals. It may relate to the anatomy structure of clockwise and anticlockwise of myocardial. Both the large and tiny wave signals characterize the sine and cosine.

time, scanning speed and amplitude and the like can be optionally selected. Furthermore, the present study does not utilize any electromyographic (EMG) filter and anti-drift filter; rather it has utilized certain patented special working frequency filters invented by the authors of this article.

2.3. Results

{1} 1500 cases of normal human subjects have been tested in this study. The visualized new wave forms of electrophysiocardiogram (EPCG) have been successfully scanned and recorded in 100% of the tested human subjects [12–14]; in both P–R interval and P–R segment, new local regional wave forms have been shown in EPCG, which are characterized by visualized new wavelets that are regular, standard and quantitative. {2} 110 cases of patients who either have been installed with pacemaker or are waiting for radiofrequency ablation surgeries have been tested. The results show that each of them has shown an EPCG wave form graph that is different from that of normal human subjects; in which 28 cases of the patients could not be labeled for their PA, AH and HV intervals in the previous invasive electrophysiological tests, since their His bundle potentials were undetectable; while these signals have been shown and successfully labeled in the new EPCG. {3} EPCG shares certain similarities with traditional ECG, including that their P-QRS-T correspond to each other, their time courses correspond to each as well. Nevertheless, they also significantly differ in certain aspects, for example, in EPCG, the major peaks of both P wave and T wave are forward waves with certain negative waves shown on the left and right sides thereof, at the same time, some small wavelet forms have been shown in the vicinities above or below X axis, which are all located within the range of PR interval; in addition, the following features could be clearly discerned by

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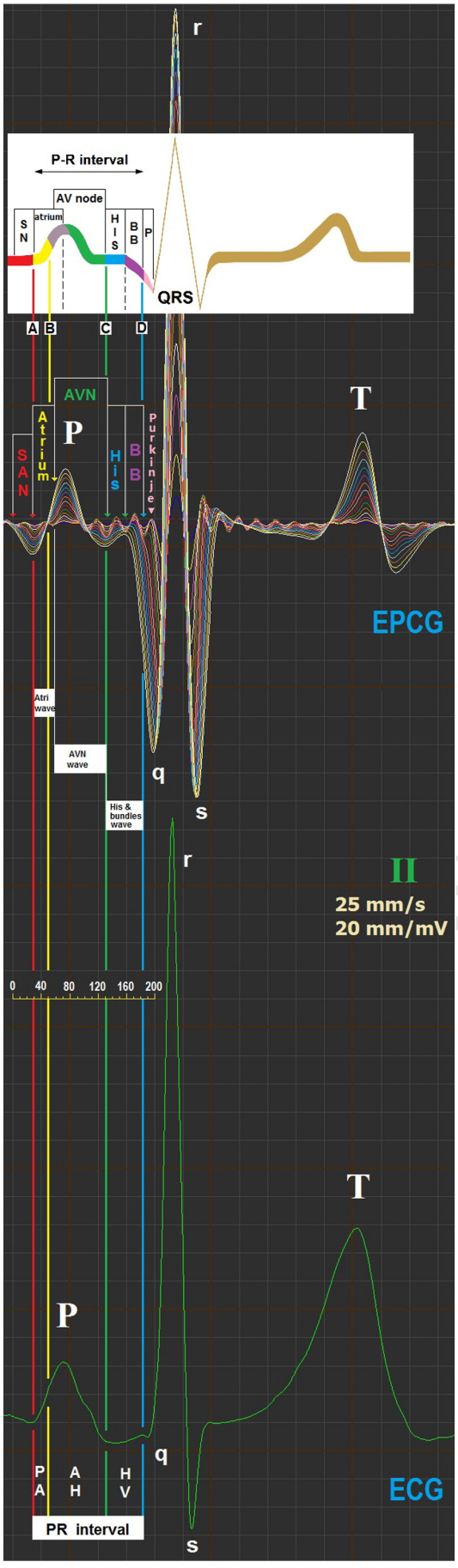

eyes and precisely labeled as well, including PA, AH and HV intervals [7–11]. {4} EPCG is also able to display P leading wave and the wave at Purkinje's initial end (Fig. 5). {5} EPCG is able to precisely measure PR segment, while in traditional ECG, the ending point of PR segment is essentially either circular curves or isoelectric region and ending with the one set of the QRS complex, which results in overwhelming difficulties for achieving precise measurements. {6} EPCG may be capable of achieving a visualized positioning effect for conduction block, as well as facilitating diagnosis and pathological analysis for complex cardiac arrhythmias and many other specific local tissue disorders.

3. Conclusions

Electrophysiocardiogram (EPCG) is able to scan and record tiny electrophysiological potentials, which may be closely related to the "automatic conduction system potentials" and "ventricular myocyte action potentials". It displays new small wavelet forms in the multi-band electrophysiological signals generated from continuous heartbeats, in which the new small wavelet forms comprise the signals before P wave, in P wave, above P wave, below P wave, in PR interval, in PR segment, and in QRS convolutionary and overlapping regions (Purkinje initial portion, Figs. 1, 3, 4, 5). In this way, it can help to more deeply understand and interpret the local potentials generated at each anatomic site during the physiological processes of pacing, excitation, conduction and action, help to solve many puzzling questions in clinical practice as well as meet certain clinical requirements. More importantly, it is able to provide visualized quantitative data of the electric signals at specific locations of SA node and AV node, while it is well known that the foregoing two locations are the source of cardiac arrhythmias. In this study, the statistical results of the data obtained from the 1500 cases of normal human subjects demonstrate that they are all within the physiological value range of a normal human. In addition, the data obtained from the 110 cases of invasive controls have been subjected to Spss analysis of variance (ANOVA). The results show that the difference between the EP group and the EPCG group is insignificant, the intergroup difference between EP (PA, AH, HV) and EPCG (PA, AH, HV) is insignificant, wherein $P > 0.05$, which indicates no statistical difference.

4. Discussions

The following questions need to be answered in future studies on EPCG, such as whether electrophysiocardiogram (EPCG) has scanned and recorded new physiological signals that have never been recorded previously; whether EPCG is able to measure PA, AH and HV intervals (Fig. 4) by virtue of separating with the ABCD vertical lines, based on the information obtained from respective Y axis amplitudes of the newly obtained wavelets and from respective starting points and ending points of those small wavelets shown close to X axis; concerning the buried local potentials shown in the P–R interval in EPCG, if they are not the respective potentials of SAN, AVN, Atrial, His bundle and bundle branches, then what they are; why the measured values of those wavelets following separations by vertical lines are agreeable with the respective PA, AH and HV values of a normal person, and so on. In addition, in EPCG, the new atrial wave forms shown in the vicinities above or below X axis, the negative waves of P wave, as well as the leading waves at the starting point of P wave are all waiting for further study and exploration in the context of related clinical diseases and disorders, which may allow EPCG to become a new field in cardiac science after ECG.

Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.

Fig. 4. EPCG uses 16 fractional frequency linear wave forms, with common II leads, 25 mm/s scan speed and 20 mm/mV amplitude. The advantage of it is that it has the Purkinje signal revealed from QRS. The upward shows the signal implication in PR interval of existing ECG speculated by Hoffman and Damato and the inferior is existing ECG.

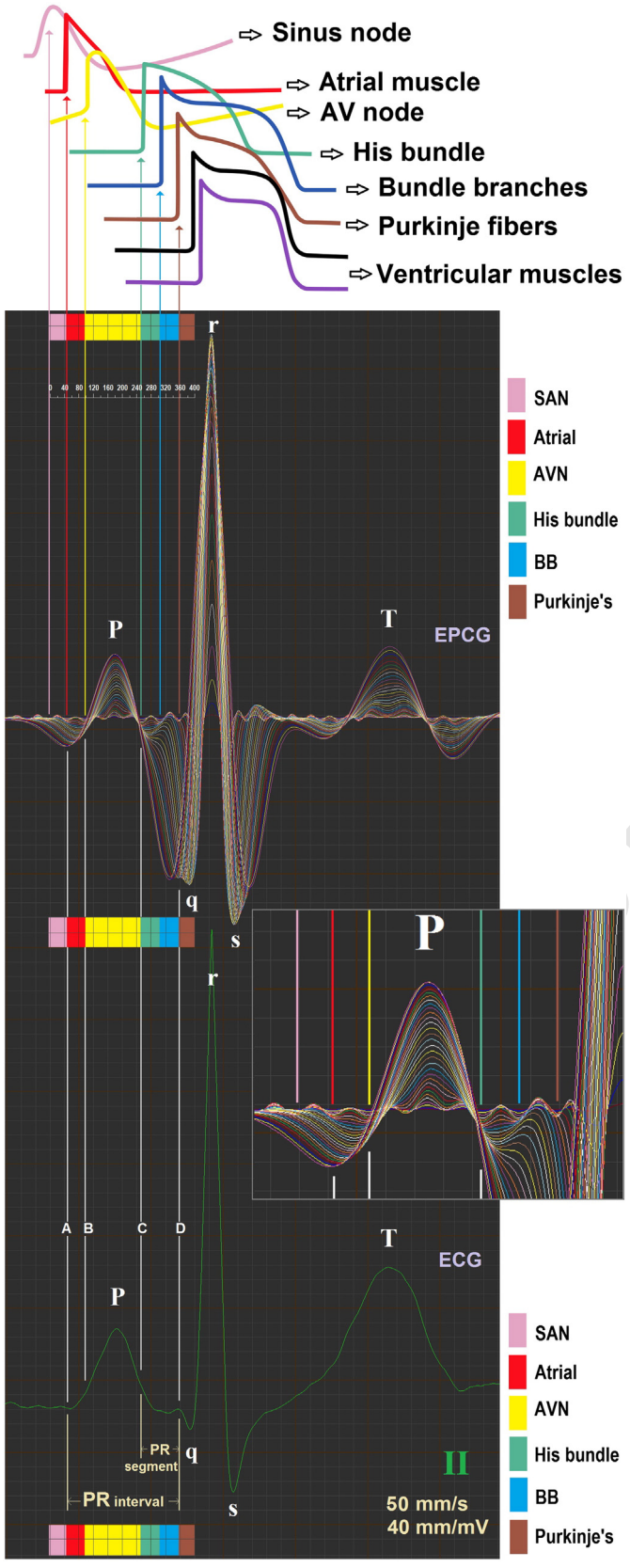

Fig. 5. The upper part is the potential diagram of self-conducting system. The middle part shows application of 32 linear different frequency wave forms with the lead II, 50 mm/s scanning speed and 40 mm/mV amplitude. Six wavelets are visible among the PA, AH and HV and furthermore, the concealed Purkinje fiber can be macroscopic in brown and vertical D (right side), in which the half wave be drawn in QRS and the other half appears outside the QRS (left side). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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