

# Surface electrocardiogram: Could atrioventricular nodal and His bundle potentials be recorded beat by beat on “Saah electrocardiogram”?

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## ABSTRACT

**Objective:** The P-QRS-T wave on surface electrocardiogram (ECG) reflects the changes in atrial and ventricular electrical properties. However, the atrioventricular conduction system potentials cannot be recorded to date. This study aimed to explore the possibility of micropotential of the atrioventricular conduction system recorded by surface “SAN-Atrial-AVN-His (Saah) ECG.”

**Methods:** We randomized 100 healthy volunteers (50 females and 50 males; mean age 25.12±1.62 years) to receive “conventional 12-lead ECG” and “Saah ECG,” which were recorded by the “Saah ECG” machine. We recorded and further analyzed “conventional 12-lead ECG” and “Saah ECG.” According to the microwavelets before the QRS complex, the PR interval was the sum of three intervals: PAs interval (PA interval recorded on surface ECG), AHs interval (AH interval recorded on surface ECG), and HVs interval (HV interval recorded on surface ECG). The PR interval, PAs interval, AHs interval, and HVs interval were measured.

**Results:** Not only the P-QRS-T waves but also the microwavelets before the P wave, before the QRS complex, and after the QRS complex were recorded in 100 healthy volunteers. The PAs interval, AHs interval, and HVs interval were 22–37 (31.23±2.93) ms, 60–103 (76.07±13.43) ms, and 39–55 (49.29±4.44) ms, respectively. The PAs interval, AHs interval, and HVs interval were consistent with the intracardiac measurements (PA, AH, and HV intervals) obtained in previous studies. Compared with female volunteers, male volunteers had a longer AHs interval ( $p<0.05$ ).

**Conclusion:** Not only the P-QRS-T waves but also the microwavelets before the P wave, before the QRS complex, and after the QRS complex were recorded on surface ECG. The wavelets before the QRS complex may be related to atrioventricular nodal, His bundle (bundle branch) potentials. (*Anatol J Cardiol* 2017; 18: 110-4)

**Keywords:** electrocardiogram, P-QRS-T wave, new wavelets, atrioventricular conduction system potentials

## Introduction

In 1903, the string galvanometer technique of electrocardiogram (ECG) was invented by Willem Einthoven (1). Since then, it has endured more than one century of uninterrupted and flourishing use. An ECG exam is the most common and simple method for the diagnosis of cardiovascular disease (2). Hervey regarded ECG as “the middle one of the five fingers” approaching to the diagnosis of cardiovascular disease (3). Although ECG has been used and improved since many years, it has developed zero meaningful breakthroughs on basic information (P-QRS-T wave) throughout the years. The microwaveform of the specialized conduction system cannot be recorded to date; thus, the clinical requirements for analysis of arrhythmia cannot be met. With the help of the PhysioSign research team, we used the new instrument [“SAN-Atrial-AVN-His (Saah) ECG,” model PHS-A10] designed and developed by PhysioSign, Inc. (Los Angeles, USA). Along with traditional ECG scanning/recording, PHS-A10 can

accurately extract various time-domain ECG electric potentials in the 0–150 Hz range and perform automated integrated signal recognition. Therefore, not only the P-QRS-T waves but also the microwavelets on surface ECG were initially recorded using the “Saah ECG” machine. We analyzed the positions and characteristics of the microwavelets and the “intervals” of these new wavelets before the QRS complex in 100 healthy subjects. We present the findings of our preliminary analysis of “new wavelets” recorded on surface ECG.

## Methods

### Materials

The study population consisted of 100 healthy postgraduate students (50 females and 50 males) in Jinzhou Medical University, with a mean age of 25.12±1.62 years (range, 23–28 years). The volunteers were randomly selected. Smokers and individuals with any type of systemic disease were excluded from the study.

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The study was approved by the local ethics board. Informed consent was obtained from all the participants. We used a "Saah ECG" machine (model PHS-A10) designed and developed by PhysioSign, Inc. (Los Angeles, USA) to record surface ECG.

### Methods

Resting supine 12-lead ECGs in sinus rhythm were recorded. Two independent observers who knew the purpose of the study but were blinded to the study design and the results of all investigations evaluated ECGs.

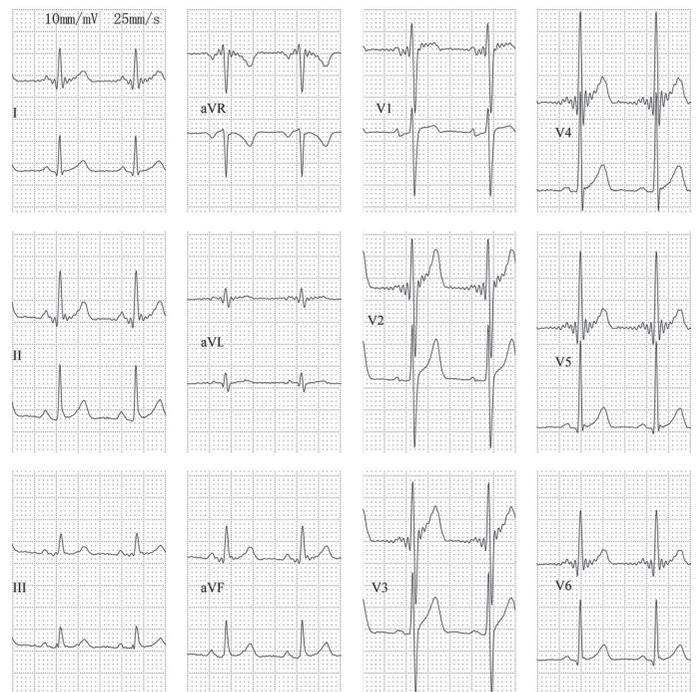
### Recording conditions

The subject's skin was firstly pretreated with sandpaper, and then, special electrodes (non-cytotoxic silver/silver chloride substrate) were used to perform the test, in which the arrangement of electrodes was the same as that in conventional 12-lead ECG. In addition, both "conventional ECG" and "Saah ECG" were synchronously detected using the "Saah ECG" machine (Fig. 1). The surface ECGs were recorded at the standard ECG paper speed of 25 mm/s and 10 mm/mV. Then, the measuring speed of 25 mm/s and amplitude of 20 mm/mV (for the purpose of selecting measuring points under the condition of magnification) in long trace leads were selected. The microwavelets before the P wave, before the QRS complex (in the P wave and PR segment) and after the QRS complex (the ST segment and upstroke of the T wave) could be recorded using the "Saah ECG" machine (Fig. 2A–C segments, the wavelet mechanism is discussed in Discussion section, part two).

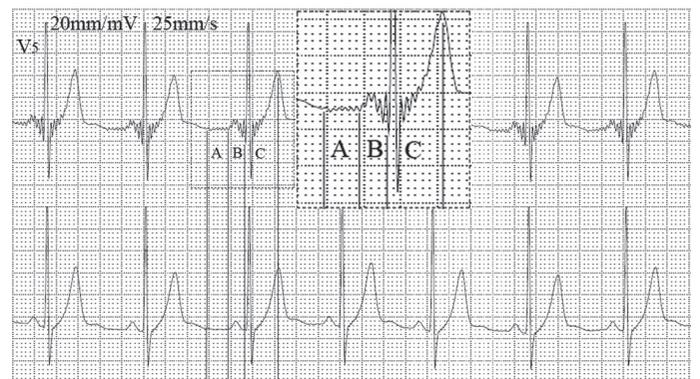
Mapping of PAs intervals, AHs intervals, and HVs intervals on surface ECG was as follows: the PAs interval (the time interval from the initiation of the P wave to the first notch of the P wave), AHs interval (the time interval from the first notch of the P wave to the initiation of the second wavelet with a higher amplitude close to the QRS complex), and HVs interval (the time interval from the initiation of the second wavelet with a higher amplitude close to the QRS complex to the start of the QRS complex). The values of each interval measured on the computer are shown in Figure 3. Under the condition of the paper speed of 25 mm/s and gain of 20 mm/mV (for the purpose of selecting measuring points under the condition of magnification), the lead with the earliest and distinct starting point of the QRS complex was selected (always in lead II or V5). Then, the selected lead was amplified (four magnification) on the computer to determine the distinct measuring point. The values of each interval (ms) were measured on the computer. Measurements comprised three cardiac cycles, and the average of these measurements was taken. The correlation coefficients for the interobserver and intraobserver variability were 0.92 and 0.93, respectively.

### Statistical analysis

The results are given as mean±standard deviation (SD). Independent t-test was used to compare the indexes of "Saah ECG" between males and females. All statistical analyses



**Figure 1.** The 12-lead "Saah ECG" (upper trace in each lead) and "conventional ECG" (lower trace in each lead) are recorded simultaneously



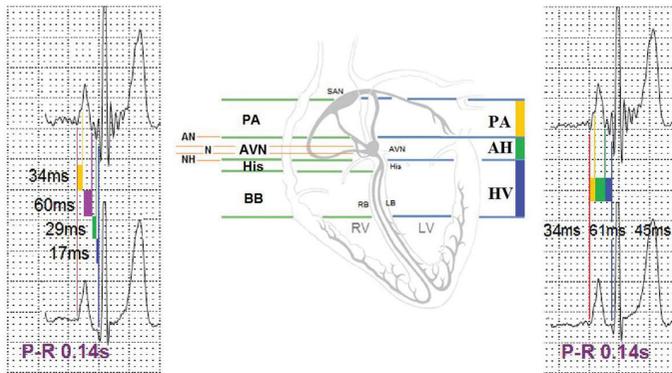
**Figure 2.** The "new wavelets" recorded on surface ECG. The "Saah ECG" (upper trace) and "conventional ECG" (lower trace) of lead V<sub>5</sub> are recorded simultaneously. "A" shows wavelets before the P wave. "B" shows wavelets before the QRS complex. "C" shows wavelets after the QRS complex

were performed using SPSS 16.0. A p value of <0.05 was considered significant.

## Results

### Positions and characteristics of "new wavelets"

The "new wavelets" before the P wave and before and after the QRS complex could be recorded in 100 healthy volunteers (Fig. 1, 2). 1) With regard to the "new wavelets" before the P wave, three to six wavelets before the P wave were revealed. The total time was 140–200 ms. 2) With regard to the "new wavelets" before the QRS complex, four to six wavelets before the QRS complex were recorded. Two to four overlapped in P



**Figure 3.** According to the microwavelets before the QRS complex, the PR interval is the sum of three intervals: PA<sub>s</sub> interval (the time interval from the initiation of the P wave to the first notch of the P wave), AH<sub>s</sub> interval (the time interval from the first notch of the P wave to the initiation of the second wavelet close to the QRS complex), and HV<sub>s</sub> interval (the time interval from the initiation of the second wavelet close to the QRS complex to the start of the QRS complex)

waves and in the terminal of P waves. After that, there were two wavelets in the PR segment with a higher amplitude. 3) With regard to the "new wavelets" after the QRS complex (the ST segment and T wave), four to seven wavelets in the ST segment and upstroke of the T wave with a decreasing amplitude were recorded.

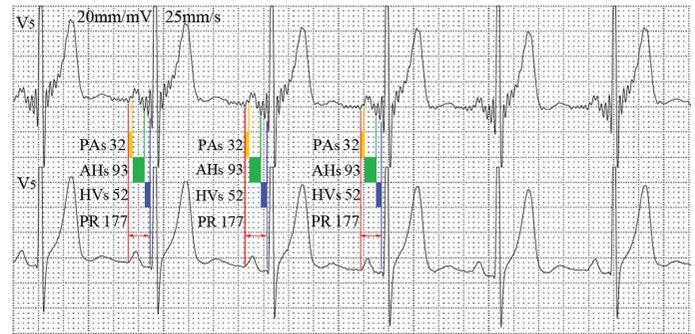
**PR interval, PAs interval, AHs interval, and HVs interval analysis**

In 100 healthy volunteers, PR intervals were in the normal range. The PAs interval, AHs interval, and HVs interval were consistent with the normal range of the intracardiac measurement (PA interval, AH interval, and HV interval) obtained in previous studies (Table 1, Fig. 4). Compared with female volunteers, male volunteers had a longer AHs interval ( $p < 0.05$ ).

**Discussion**

**Are microwaveforms real and are they recorded beat by beat on surface ECG?**

Our study of "Saah ECG" in 100 healthy volunteers confirmed that not only the P-QRS-T wave but also more micro-



**Figure 4.** The PAs, AHs, and HV<sub>s</sub> intervals are measured on surface ECG. The "Saah ECG" (upper trace) and "conventional ECG" (lower trace) of lead V<sub>s</sub> are recorded simultaneously. ■ indicates the PAs interval (32 ms), ■ indicates the AH<sub>s</sub> interval (93 ms), and ■ indicates the HV<sub>s</sub> interval (52 ms)

wavelets before the P wave, before the QRS complex (in the P wave and PR segment), and after the QRS complex (the ST segment and upstroke of the T wave) can be recorded on the "Saah ECG." We present the findings of our preliminary analysis of new wavelets according to the activation sequence of the heart as well as the position of these wavelets as follows: 1) The wavelets before P waves may be related to the sinoatrial node potentials. In our study, the total time of the wavelets before the P wave was obviously longer than that of intracardiac measurement of 45–125 ms (4, 5), suggesting that the meanings of these wavelets are different from those of the wavelets recorded in the intracardiac electrophysiology study. 2) The wavelets before the QRS complex (in the P wave and PR segment) may be related to atrioventricular nodal, His bundle, and bundle branch potentials. 3) The wavelets after the QRS complex (the ST segment and upstroke of the T wave) may be corresponding to phase 2 and 3 of heart epicardial action potential or ion current.

**Why can "Saah ECG" record the microwaveform before the QRS complex while conventional ECG cannot?**

PHS-A10 ECG is a new device created by PhysioSign, Inc. using the latest technology of the software and the hardware as well as the signal processing technology. PhysioSign's PHS-A10 is employing an Adaptive Mixture Technology within

**Table 1. Comparative study of PAs, AHs, and HVs intervals recorded on "Saah ECG" in health subjects and PA, AH, and HV intervals recorded on the intracardiac study in the literature**

	PR (mean±SD)	PA (mean±SD)	AH (mean±SD)	HV (mean±SD)
Saah ECG (n=100)	123–190 (152.75±14.98)	22–37 (31.23±2.93)	60–103 (76.07±13.43)	39–55 (49.29±4.44)
Male (n=50)	154.57±13.52	31.08±2.77	81.95±14.70*	48.97±4.54
Female (n=50)	150.92±16.25	31.48±3.08	71.20±10.00	49.60±4.36
T	1.220	-0.690	3.881	-0.710
P	0.225	0.492	0.000	0.480
Normal range of intracardiac measurements in the literature <sup>□</sup>	120–200	20–60	50–120	35–55

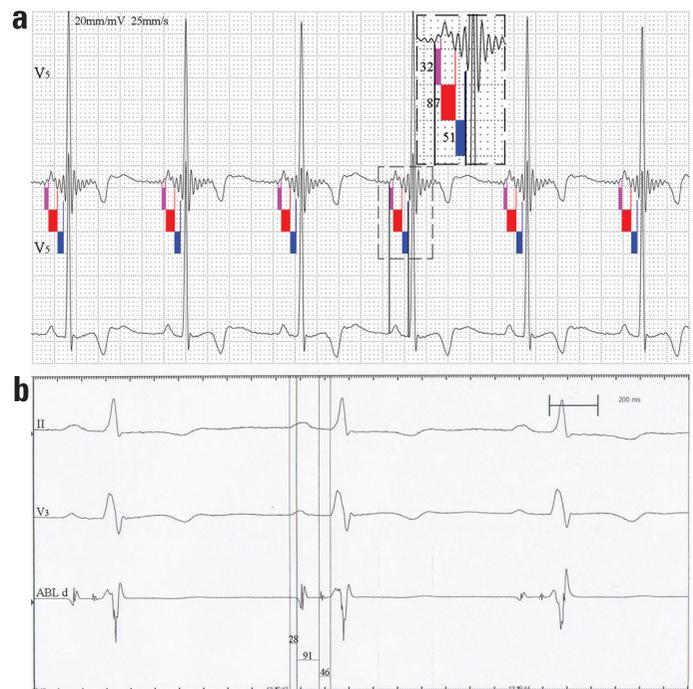
The results were given as mean±SD. SD indicates standard deviation. All values are in ms. Compared with females, \*indicates  $p < 0.05$ . □ indicates normal range of intracardiac electrophysiology in the literature (4–13)

the ECG Signal Spectrum enabled by PhysioSign's Smart Data Acquisition Module. Along with traditional ECG scanning/recording, PHS-A10 can accurately extract various time-domain ECG electric potentials in the 0–150 Hz range and perform automated integrating signals recognition. Therefore, not only the P-QRS-T waves but also the microwavelets can be recorded on surface ECG.

### The wavelets before the QRS complex may be related to atrioventricular conduction system potentials

In theory, the wavelets before the QRS complex (in the P wave and PR segment) should be related to atrioventricular conduction system potentials. The first wavelet in the P wave may reflect intraatrial (from the sinoatrial node to the atrioventricular node) conduction potentials and the second to the fourth wavelets may be related to atrioventricular nodal potentials (there is obvious individual difference among the timings of atrioventricular node conduction). Two wavelets in the PR segment close to the QRS complex with a higher amplitude may be related to His bundle and bundle branch potentials. According to the microwavelets before the QRS complex, the PR interval was the sum of three intervals: PAs interval, AHs interval, and HVs interval. A finding in our study was that the PAs interval, AHs interval, and HVs interval were consistent with the intracardiac measurement [PA interval (4–7), AH interval (6–13), and HV interval (6, 7, 10–12)] obtained in previous studies. Our study suggested that the AHs interval reflects the conduction time across the atrioventricular node and the HVs interval reflects the conduction time from His bundle (bundle branch) excitation to the onset of ventricular activation.

In order to further study the clinical significance of microwavelets before the QRS complex, we studied the wavelets in patients with arrhythmia. There were characteristic wavelets before the QRS complex that could be recorded in the patients with a supraventricular origin (sinus, atrial, or junctional). In patients with a ventricular origin (premature ventricular contraction, ventricular tachycardia, or ventricular pacing), there was no characteristic waveform before the wide QRS complex (14). Furthermore, in patients with an atrioventricular block, we observed that a characteristic waveform before the QRS complex contributed to the location of the atrioventricular block (15). We are performing comparative analysis of PAs, AHs and HVs intervals recorded on surface "Saah ECG" and PA, AH, and HV intervals recorded on His bundle electrogram in patients undergoing radiofrequency catheter ablation of paroxysmal supraventricular tachycardia. Our preliminary analysis showed that PAs, AHs, and HVs intervals were consistent with the intracardiac measurement (PA, AH, and HV intervals), as shown in Figure 5. These preliminary studies have confirmed that the wavelets before the QRS complex (in the P wave and PR segment) may be related to atrioventricular nodal, His bundle (bundle branch) potentials.



**Figure 5.** PAs, AHs, and HVs intervals recorded on preoperative "Saah ECG" (a) in one subject undergoing radiofrequency catheter ablation of dual A-V nodal pathways and PA, AH, and HV intervals recorded on His bundle electrogram (b). The "Saah ECG" measurements are consistent with the intracardiac measurements

### Study limitations

Our study has some limitations. The study population consisted of 100 healthy postgraduate students; thus, it included only young population that cannot represent different age groups. Besides, there was lack of statistical comparison with intracardiac data (only compared with the normal range of intracardiac electrophysiology observed in previous literature). These limitations will be addressed in future research.

### Conclusion

Our study further confirmed that not only the P-QRS-T waves but also the microwavelets before the P wave, in the P wave, in the PR segment, in the ST segment, and upstroke of the T wave were recorded on surface ECG. According to wavelet analysis in the PR interval, it confirmed that the specialized conduction system potentials (atrioventricular node potentials, His bundle potentials, and bundle potentials) can be recorded beat by beat on surface ECG.

Atrioventricular conduction system potentials are recorded noninvasively, which sets a foundation for new research, and large numbers of clinical and animal experiments are required in order to verify the clinical significance, scale index, normal scope, diagnostic criteria, and mechanism of these microwaveforms.

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