Three-Year Experience with a Wireless ECG Sensor

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Abstract - **The success of performing long-term ECG measurements depends on how much the device is interfering with the user. A small and unobtrusive sensor on the skin in conjunction with a smartphone today presents a viable option because such a configuration allows also online access to cardiac services. Despite the limited choice of electrode placement, it has been shown that the ECG sensor may replace the ambulatory ECG (Holter ECG) in many cases. In this paper, we present our experience on setting up an ECG sensor to obtain the best information about heart arrhythmias. We also add experience in unconventional use of the sensor in abdominal ECG and recommendations for the future use of such devices.**

I. Introduction

The quality of ECG recordings depends largely on the electrodes, especially if ECG is measured for days. A stable long-term galvanic contact with the skin is of high importance if standard adhesive ECG electrodes for Holter monitoring are used. If the ECG device is small, lightweight and with short wires, like the patch-type ECGs, the user quickly forgets that he/she has the device on the body (unobtrusiveness). Than the main problem with prolonged ECG measurements is the sensitivity of the skin (skin irritation) to the compounds of the self-adhesive ECG electrodes, which happens with a considerable percentage of subjects (43% [1]). If this is the case and if the system is designed so, the user can reposition the device on another location on the body by using new electrodes and continue the measurement. It is of great help if the user can see the ECG signal on-line on an appropriate display, such as a smartphone. If the user is not involved positively in such procedures, it is likely that he/she will end the measurement prematurely.

In this paper, we present measurement results from our three-year experience with a one-channel ECG device (ECG sensor) attached to the skin with two standard Ag/AgCl electrodes and connected wirelessly to a smartphone where the measurements are stored. In particular, we present examples that show the particularities and problems encountered during the measurements. The paper is organized as follows. Section II gives details about the performed measurements and the involved subject, the ECG sensor and the measurement procedure; Section III presents and discusses some of the most particular and problematic measurements; and finally, Section IV concludes the paper and gives recommendations for future users on how to improve the quality of their measurements.

The authors acknowledge the financial support from the Slovenian Research Agency under the grant P2-0095.

II. Materials and Methods

A. Subjects

In the year 2015, users of the ECG sensor were colleges and their friends who wanted to see how the sensor works in everyday life, at night, during sport activities and even at the dentist. The ECG sensor, coupled with a smartphone for displaying the measurements, allowed the users to see his/her ECG on-line on a display, in contrast to the measurement of a standard 12-channel ECG when the person is lying and has no visual access to the measurements. In the years 2016 and 2017, when a commercial version of the ECG sensor was available (Savvy ECG [2]), many users measured their ECGs not only a day or two, but for weeks and months.

In total, we collected around 530 days of ECG recordings from 67 people. We had two groups of users. In the first one are 50 volunteers who approached us to test the Savvy ECG sensor. We have data about age and sex for this group. In the second group, there were 17 people for whom we received ECG recordings from a pilot study that is still ongoing at the Community Health Centre Ljubljana (CHC Ljubljana). We do not have any data about age or sex about the second group. The data for both groups are summarized in Table 1.

B. ECG sensor

Savvy ECG (Saving, Ljubljana) is one-channel ECG device and is the core of a system for personal cardiac monitoring. It is a small (dimensions: 130 x 35 x 14 mm) and light (weight: 21 g) body gadget fixed to the skin of the user by two standard self-adhesive electrodes. In most cases, self-adhesive wet Ag/AgCl electrodes (Skintact, T60) were used. The Savvy sensor measures a single lead ECG, differentially between the two electrodes at the distance of 8.5 cm. The sensor is covered with a waterproof and biocompatible plastic housing. It has a long autonomy (up to 7 days) and a low power wireless connection (BT4) to a Smartphone or other personal device. The ECG is sampled at 125 Hz and transmitted wirelessly to a person's smartphone running the application MobECG (Saving, Ljubljana) for visualization and interpretation of the measurements. We used the program VisECG (Jožef Stefan Institute, Ljubljana) for presentation and analysis of the recordings.

TABLE I. RECORDINGS FROM TWO GROUPS WITH TOTAL OF 530 DAYS OD ECG RECORDINGS

Groups	***Participants***	***Sex (male/female)***	***Age (mean ± SD)***	***ECG (hours)***	***Hours/recording (average)***
Volunteers	50	24/26	52.1±19.2	12186	156
CHC Ljubljana	17	-	-	533	31-

The Savvy sensor is the commercial version of a previous differential ECG body sensor prototype intended for personal cardiac monitoring [3]. The device can support solutions to every-day problems of the medical personal in hospitals, health clinics, homes for the elderly and health resorts. Its exceptionally lightweight design allows for unobtrusive use also during sports activities or during exhaustive physical work. The ECG measurements obtained with the sensor are already proven to be suitable for medical use, e.g., monitoring in cardio oncology [4] and reconstruction of the standard 12-chanell ECG [5-7]. Even though the ECG is obtained only from one differential lead, it has been demonstrated that the quality of the signal is sufficient for basic ECG analysis, like heart beat detection [8] and detection of heart rate variability [9], or more advanced ECG analysis, like clustering of heart beats [10]. Moreover, the sensor has been used also in veterinary for successful monitoring of the cardiac activity in dogs [11, 12].

C. Placement of the ECG sensor

The ECG sensor has a short flexible wire that connects the body of the sensor (holding one electrode) with the second electrode. There are nine recommended positions of the ECG body sensor [13], which can provide appropriate amplitude of the measured ECG signal. Usually, the sensor is placed on the position of the V1 and the V2 leads of the standard 12-channel ECG such as that the voltage difference V2-V1 is measured. This position is taken as the one that is not obtrusive for both woman and men. Furthermore, in the V2-V1 lead, the P wave is often present with enough amplitude to be used in the analysis of arrhythmias.

III. RESULTS

In this section, we present some of the measurement results with examples that show the particularities and problems encountered. All ECGs are shown with speed 25mm/s and without using any additional filtering. A mark of 1 mV is present at the beginning.

A. Measurement examples

In Fig. 1, an example of a quality recording is shown. Such high QRS amplitude is seldom seen in lead V2-V1. Although the P wave is small (0.06 mV) and biphasic, it is still usable for analysis of time intervals. The small P waves in the V2-V1 lead, in comparison to the QRS, is a sign that the ECG sensor is not placed optimally for monitoring atrial signals. In such cases, we can also see that the shape of the P wave is changing throughout the breathing cycle (not present in Fig. 1). This condition is rarely seen in standard 12-lead ECG leads.

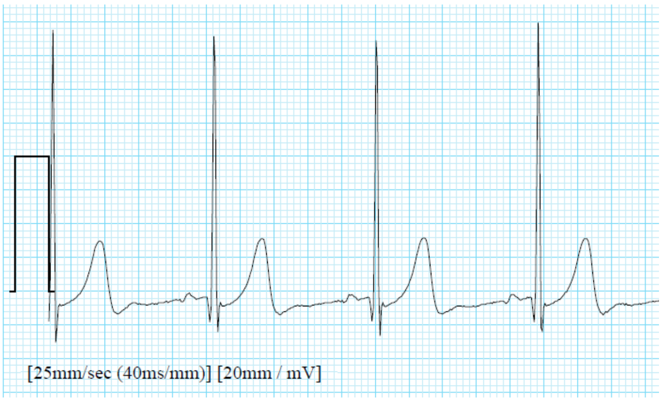

Figure 1. ECG (lead V2-V1) at 3:35 PM at rest with small P wave amplitude and large QRS

During sleep, a person often turns in bed. This situation is shown in Figure 2, where the amplitude of the ECG waves is at first small. When the body turns in sleep, the base line changes, myopotentials appear and finally the amplitude of the ECG waves is stabilized at a much higher level. Such changes are often seen in the V2-V1 lead during sleep. The presence of myopotentials indicates muscle effort; therefore, in such recordings, it is recommended not to filter them out.

Figure 2. Large amplitude change in the V2-V1 lead during sleep (ECG recording from the same person as in Fig. 1)

Atrial fibrillation produces irregular ventricular rhythm. In Fig. 3, the atrial signal is clearly seen in the V2-V1 lead although the amplitude of the QRS in this lead is low. The ECG was recorded early in the morning when an electro conversion from atrial fibrillation to normal rhythm was planned.

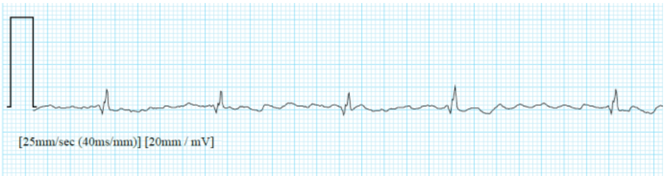

Figure 3. Atrial fibrillation and low QRS voltage in V2-V1. The wavy line is the signal from the fibrillating atria

After the electro conversion, the atrial fibrillation disappears. The heart is in the sinus rhythm and the ECG sensor at position V2-V1 clearly shows the P wave with an amplitude of 0.15 mV and small but clear QRS complex (Fig. 4).

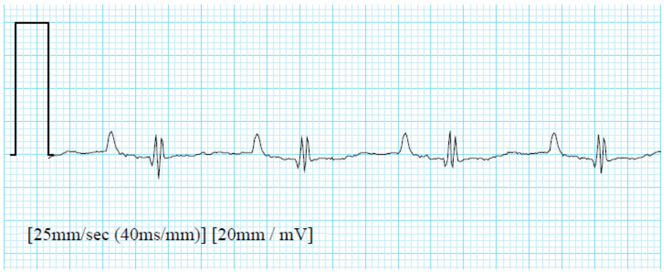

Figure 4. ECG from the same person as in Fig. 3 a day after electro conversion was successfully performed

An example of a recording during sleep, which documents many asystoles of more than 3 seconds (two of them present in the figure) is shown in Fig. 5.

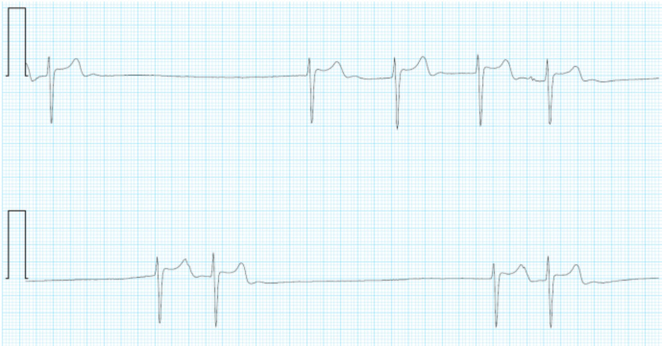

Figure 5. Arrhythmia in sleep. Long pauses lasting more than 3 seconds

B. *Quality of the recordings*

As already mentioned in the Introduction, good electrodes are required to make good ECG recordings. We got many bad ECG recordings, especially if they were made while moving the body (doing sports, walking, etc.). We have found that partially dried electrodes were often used in such cases. Although the electrode manufacturer (Skintact) warns that electrodes are only usable for 7 days once the pouch is open, the instructions are written on the back side of the pouch with letters that are too small to be seen by the users. In addition, users usually do not follow the instruction how to handle an already open package – "Close the opened pouch and fold-over top of pouch once or twice." Failure to observe these instructions leads to poor recordings because the electrodes become dry and lose their properties (low impedance, low noise) in a very short time.

C. *Unconventional use of the ECG sensor for abdominal ECG*

A modified ECG sensor with higher amplification of the analog input was used to measure tiny cardiac signals from the fetus on the mother's abdomen. More details are reported in a previous paper [14]. One example of the recording, where no filtering has been used, is shown in Fig. 6. The amplitude of the signal from the heart of the fetus is only 10-15 microvolts. By shielding the sensor with hands only, it was possible to block the power-line interference (50 Hz) completely. This successful measurement was made at home by expecting parents themselves.

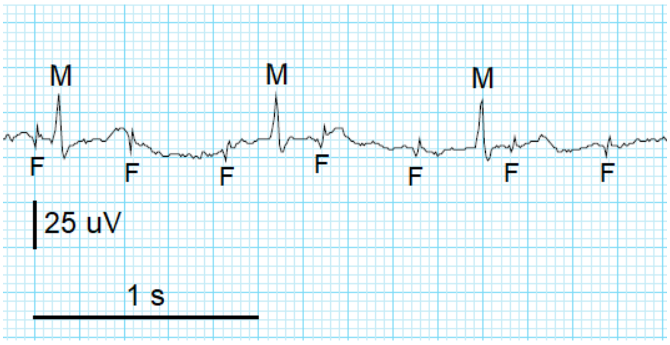

Figure 6. Abdominal ECG with QRS complexes of the mother (M) and the fetus (F) in the 5th month of pregnancy

IV. CONCLUSIONS

In three years of performing measurements with the wireless ECG sensor, we have gathered experience that can be useful for future users to improve the quality of their measurements. It can be summarized as recommendations for future use as follows:

a) For long-term ECG measurements, users should be involved in procedures in a positive way, so that the ECG sensor represents an assistant rather than a burden. On-line ECG display on the smartphone can greatly help if the user is aware at least of the basics of the ECG.

b) The user needs to be informed about the appropriate placement of the electrodes and the manipulation with the ECG sensor and the smartphone. Otherwise, the measuring equipment becomes a black box. If a user cannot handle the devices alone, another person (caregiver) should assist him/her.

c) For high quality recordings, the electrodes should be handled carefully according to the manufacturer's instructions. Otherwise they will get dry (especially wet Ag / AgCl electrodes) and the quality of ECG will be lost.

d) Using two proximal electrodes - as is the case with our ECG sensor with a distance between the electrodes of around 8 cm - it is normal that the amplitudes of the ECG waves are effected both by breathing and, in particular, by the position of the body (on the side, on the back). Such phenomena are not seen in the standard 12-lead ECG.

e) The myopotentials present in unfiltered ECG recordings help to identify the underlying conditions. Therefore, it is not recommended to use additional filtering.

f) In our measurements, the best placement of the ECG sensor is on the positions of the V1 and the V2 lead of the standard 12-lead ECG. At these positions, the sensor measures the voltage difference V2-V1 with good atrial signal (P wave) in many cases. If the P wave should be used in the analysis and the amplitude is not large enough, the ECG sensor should be repositioned to obtain higher P waves.

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