The Quality of Automatic Artifact Identification in Ambulatory Impedance Cardiography Monitoring

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Abstract— **In Ambulatory Impedance Cardiography (AICG), a large number of motion artifacts might occur in recordings collected during exercises. The adequate identification of the artifacts is the most important task for automatic analysis of the AICG signals. The aim of this study was to manually assess the efficiency of the classification algorithm described in our earlier papers. We intended to identify which point detected on ECG and impedance cardiography (ICG) curves is more likely to provide false indications. It was found that in most cases the artifacts were created by false recognition of the point of closing of the aortic valve (97%, range 91-100%). Modifications of the appropriate part of the algorithm were suggested.**

Keywords— **Impedance cardiography, motion artifacts, ambulatory monitoring, noise, signal quality.**

I. Introduction

Continuous monitoring of cardiac hemodynamics using impedance cardiography (ICG) signals seems to be a promising technique with possible applications in ambulatory conditions (AICG) [1-4]. The most important problem in ICG data analysis is a large number of motion artifacts occurring mainly during exercise tests. Those problems are even more pronounced in holter-type ambulatory impedance cardiography systems due to the motion of the patient [2, 4].

The amplitude of the first derivative of the ICG signal is roughly two orders smaller than that of ECG. Thus, any disturbance in electrode–skin contact results in a significant decrease in signal quality. Careful skin preparation, positioning, and firm fixing of electrodes can significantly reduce the rate of artifacts [5,6,7].

Willemsen et al. concluded that their system (the VU-AMS ambulatory monitor for impedance cardiography) provided reasonable values of systolic time intervals in real-life situations, but its applicability for absolute stroke volume and cardiac output determination remained to be established [3]. However, their reservations regarded only stroke volume and cardiac output values obtained during exercise.

Sometimes, AICG recordings are too noisy to analyze. Figure 1 presents noisy and relatively clean recordings obtained in a related study when the subject walked on stairs and remained in a supine position, respectively (adapted from [8]).

However, it is still important to know the rate of artifacts during AICG holter recordings. This problem was considered in another paper [7], where it was found that the average rate of useful signals for a part-day and overnight recordings was (mean ± SD) 0.63±0.26 with a range of 0.21-0.98. Those rates were obtained as the worst case for five-minute segments taken from the whole period of each day-and-night recording.

An important problem in AICG automatic analysis is the correct recognition of the Q point in the ECG and points on the ICG curve allowing calculation of hemodynamic parameters.

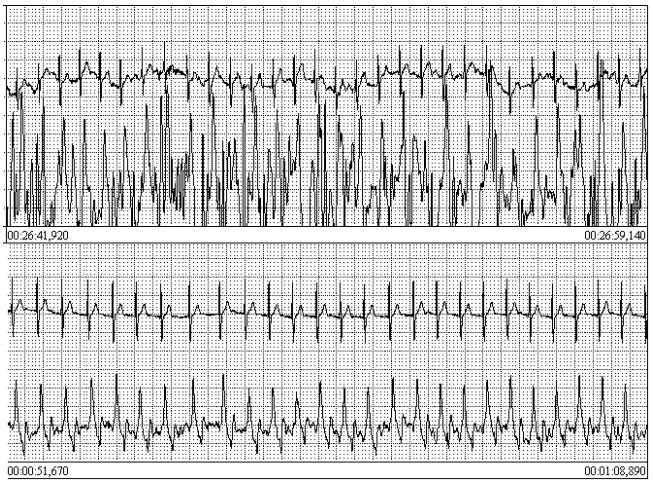

Fig. 1 Noisy (top strip) and artifact-free recordings (bottom strip) obtained in a previous study (adapted from [8])

In several studies, we used the AICG system (ReoMonitor) designed, constructed and verified in our laboratory [1, 4, 7, 8]. In this system, the automatic classification of each cycle as normal or artifact was performed based on a wide range of predetermined, physiologically acceptable values of cardiac parameters [9-12], with slight adaptation of time variables (systolic time intervals, STI) to the current heart

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rate (HR). Unfortunately, as a result of these assumptions, some evident artifacts might be automatically classified as normal and some normal data as artifacts.

The aim of this paper was to manually assess the efficiency of the algorithm for binominal classification of normal/artifact cycles described in our earlier papers [1, 4, 7, 9, 10] and determine which point detected on the ECG and ICG curves is most prone to false indications. We expected that the study might suggest modification of our algorithm.

II. Methods and Material

A. Impedance cardiography signal analysis

Figure 2 presents a typical impedance cardiography trace – changes in the first derivative of the Z signal denoted as dz/dt (2nd channel), recorded alongside one ECG lead (1st channel). It also presents the way of describing characteristic points in the dz/dt trace, which were used for determining the variables necessary to calculate cardiac hemodynamic indices. Characteristic points in the ECG and ICG signals (dz/dt) may be described as follows:

Q – the beginning of ventricular depolarization (beginning of the QRS complex in ECG),

R – the peak of electrical stimulation of the cardiac chambers in the QRS complex;

B – the beginning of ejection from the left ventricle determined from dz/dt signal;

C – the moment corresponding to the maximum flow through the aortic valve, which allows determination of dz/dt_{max} (the maximum value of the first derivative of the ICG signal)

X – the moment of closure of the aortic valve.

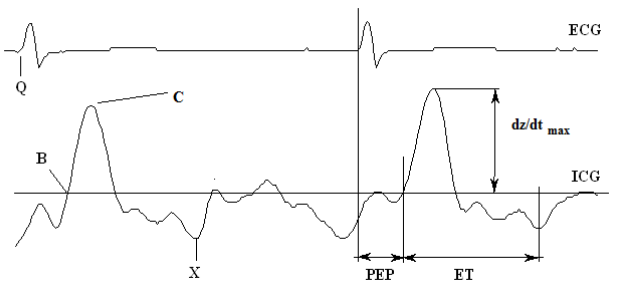

Fig. 2 A typical impedance cardiography trace - changes in the dz/dt (first derivative of ΔZ) signal, denoted as dz/dt (2nd channel), recorded simultaneously with one lead of ECG (1st channel). Please note the way of describing characteristic points in dz/dt trace and way of determining PEP, ET (LVET) and (dz/dt)max (adapted from [4]).

The detection of the characteristic points described above is essential to estimate cardiac parameters such as: stroke volume (SV), cardiac output (CO) and systolic time intervals (STI). Systolic time intervals, e.g. pre-ejection period (PEP), left ventricular ejection time (LVET or ET) and electromechanical systole (EMS, the sum of PEP and ET), can be considered measures of cardiac muscle contractility.

B. Testing data and statistical analysis

In our analysis, we used a portion of the data collected in the previous study [8], when signals from 14 young healthy male volunteers (23-28 years) were acquired. To analyze the worst case, we selected the 100-second segments which demonstrated the highest rates of artifacts during walking on stairs in the first 6 subjects.

A cycle was automatically identified as an artifact when at least one of the following events occurred: ET was outside the range of 160-380 ms, PEP was outside 50-160 ms, the RR interval was outside 330-2000 ms, or dz/dt_{max} was outside 0.4-3.0 Ω/s.

We manually analyzed the cycles classified as artifacts for 100 consecutive beats. The rates of automatically detected artifacts did not differ significantly from the unselected data (0.27 vs. 0.23). For each characteristic point (Q, B, C, X), the number of improper detection was counted and the ratios of false detections to total artifacts (called "Impact" in Table 1) were calculated for each subject.

Data were analyzed using basic descriptive statistics for detection of each characteristic point.

III. Results

A. Artifact number and critical points detection

The total number of beats classified as artifacts observed in 100-second segments has a mean of 26.0±18.4 (23, 22, 28, 12, 7 and 64 for subjects 1-6, respectively).

Table 1 Summarized results of manual verification of automatic classification of detection of key ECG and ICG points in 100 s intervals

Variable	Impact	Range
Point Q-ECG	0.22	0.13-0.35
Point B-ICG	0.48	0.29-0.65
Point C-ICG	0.27	0.14-0.50
Point X-ICG	0.97	0.91-1.0

The summarized results of manual verification of automatic classification of critical ECG and ICG points are

presented in Table 1. The impacts for each identified point (Q, B, C, and X) do not sum to one since there might be more than one incorrectly identified point in any given beat.

The highest rate of artifacts (0.97) was due to the false identification of the point of aortic valve closure (X). In almost half of cases (0.48), the point of beginning of aortic valve opening (B) was poorly identified. Detection of Q in ECG was the least common source of artifacts in the noisy fragments of ACG recordings (0.22).

IV. Conclusions

In the literature, detection of the B-ICG point seems to be the most difficult part of automatic analysis of ICG signals [13]. Surprisingly, in our study, the highest rate of false detection involved X-ICG. Incorrect B-ICG detection was a cause of artifacts in less than 50% of all artifacts. Other points (Q-ECG and C-ICG) were incorrect in about 25%.

The results are preliminary and we are aware of the study limitations. Firstly, the analyzed recordings came from a relatively small number of subjects. Moreover, young subjects usually present signals of higher quality than the overall population. However, the recordings were collected during relatively vigorous walking and stair climbing, which produce an increased number of artifacts. Secondly, the subjects were healthy, showing no signs of arrhythmia; arrhythmia usually increases the number of incorrect classifications. Thirdly, the analyzed segments were brief (100 s).

Despite these limitations, we may suppose that the main source of wrong detections of X-ICG was occurrence of a bimodal shape of the signal minimum around that point. The results gave sufficient justification to modify the part of the detection algorithm for recognition of X-ICG with the aim of decreasing the number of ambiguous identifications of the aortic valve closure.

Although the presented examination of artifact identification efficiency regards only our algorithm, it might be performed in similar way by other developers of ICG signal analysis software. We hope that the results of the present study, especially regarding the role of proper identification of the ET ending, might prove useful for ambulatory ICG development in general.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Statement of human rights and informed consent

This study, using noninvasive methods, was performed on human subjects (who gave their informed consent) in accordance with the ethical standards of the institutional ethical committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

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