Event Detection in ECG, Carotid Pulse, Phonocardiogram, and Detection of Consecutive Systolic Time Intervals

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Abstract:

We developed a program which allows measurement of consecutive time intervals between chosen events in ECG, carotid pulse, and phonocardiogram. Currently it is possible to determine following systolic time intervals (STI): PEP – pre-ejection period, Q-S2 – time between trough of Q wave and aortic valve closure, Q-D - time between trough of Q wave and dicrotic notch, S2-D - time between aortic valve closure and dicrotic notch, as well as QQ interval.

Measurements were performed on 30 young, healthy subjects. Subjects were supine, they performed two-minute isometric handgrip (HG) twice. First HG was followed by four-minute rest, second HG by two-minute occlusion of the working arm.

Preliminary analyses revealed: 1/ the QQ interval changes were reflected weakly or not at all in changes of STI, 2/ shortening of QQ during handgrip was paralleled by slight decrease of Q-D and Q-S2, 3/ during occlusion, when QQ intervals returned to baseline also Q-D and Q-S2 returned to baseline, despite sustained elevation of arterial pressure, 4/ there were distinct oscillation in the time course of Q-S2 intervals, time course of Q-D intervals was relatively smooth, thus S2 and D may reflect different events contrary to common notation.

Keywords: *systolic time intervals, ECG, polyphysiography, automatic signal analysis*

1. Introduction

It is believed that analyses of systolic time intervals (STI) may provide information on heart muscle contractility and sympathetic activity [1]-[8]. We undertook a study to verify reliability of STI as indices of SNS activity. Determination of STI requires combined analysis of few biological signals. We used following signals: ECG, carotid pulse, and phonocardiogram and performed 'manual' analysis of few chosen intervals which are believed reflect changes in sympathetic activity induced by experiment. We decided to replace cumbersome procedure with automated detection of key events, what in turn allowed determination of consecutive systolic time intervals in the whole period of observation.

2. Method

2.1. Events detection

Selected events were detected in the following order:

1) Q_i – trough of Q wave (ECG), local minimum preceding peak of R_i wave (Fig. 1),
2) S_i – trough of S wave (ECG), local minimum following peak of R_i wave (Fig. 2.),

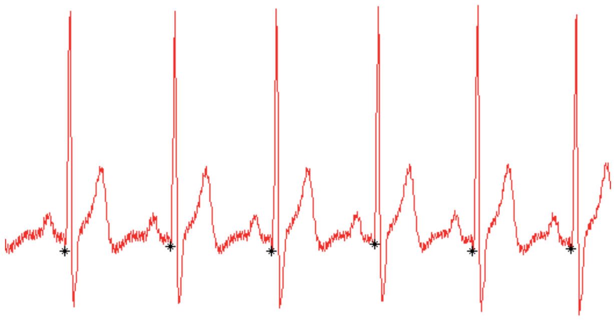

Fig. 1. Q – trough of Q wave; ECG

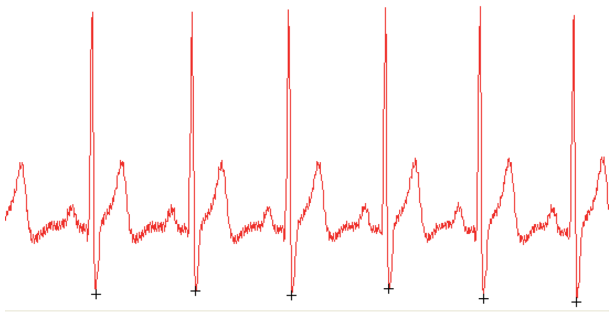

Fig. 2. S – trough of S wave; ECG

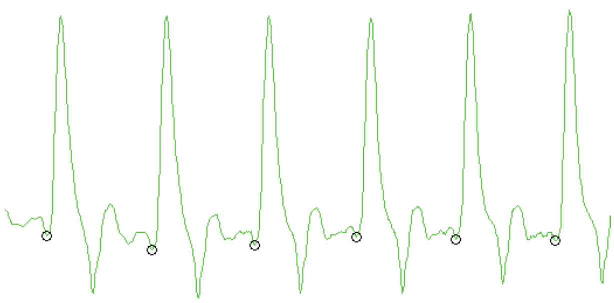

Fig. 3. E – beginning of blood ejection from left ventricle; carotid pulse

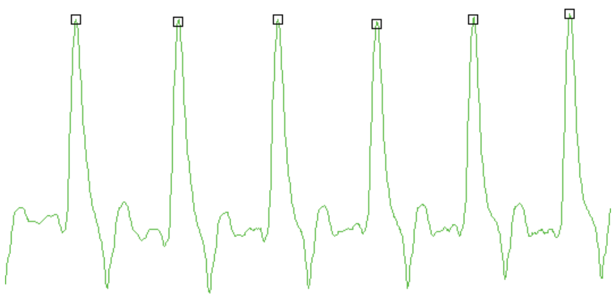

Fig. 4. M – local maximum in carotid pulse curve immediately following E

3) E_i – beginning of blood ejection from left ventricle (carotid pulse), local minimum of carotid pulse curve immediately following S_i (Fig. 3),
4) M_i – local maximum of carotid pulse curve immediately following E_i (Fig. 4),
5) D_i – dicrotic notch (carotid pulse), local minimum occurring during predetermined period (250 ms) after M_i (Fig. 5),
6) $S2_i$ – beginning of second heart tone caused by aortic valve closure (phonocardiogram), maximum peak of the first positive deflection of the S2 complex preceding dicrotic notch (Fig. 6).

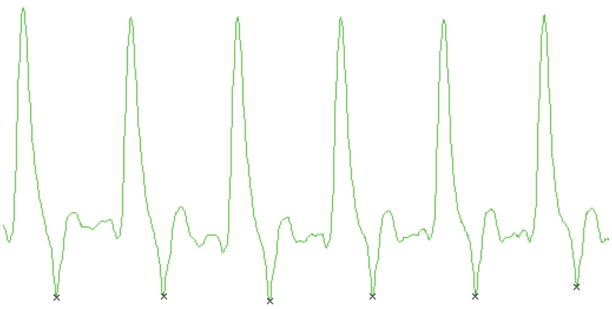

Fig. 5. D – dicrotic notch; carotid pulse

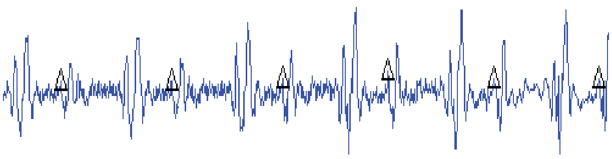

Fig. 6. S2 – beginning of second ton caused by aortic valve closure; phonocardiogram

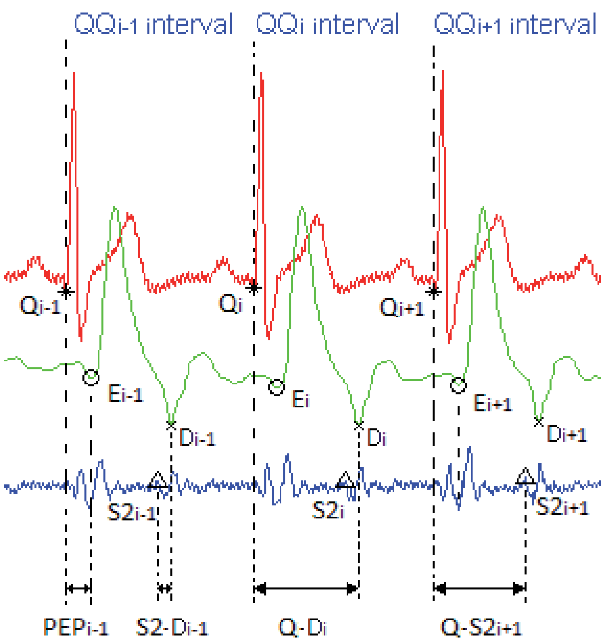

Fig. 7. Traces, events, time intervals. Traces: from the top: ECG, carotid pulse, phonocardiogram. Events: Q (trough of Q wave) – ''; E (beginning of blood ejection from left ventricular) – 'o'; D (dicrotic notch) – 'x'; S2 (beginning of second ton caused by aortic valve closure) – 'Δ'. Time intervals: PEP (pre-ejection time period); Q-S2 (interval between Q and S2); Q-D (interval between Q and D); S2-D (interval between event S2 and D); QQ (interval between consecutive Q).*

2.2. Determination of time intervals between chosen events

Time of event X_i appearance is denoted as $t(X_i)$. Following time intervals have been determined (Fig. 7.):

1. pre-ejection period: $PEP_i = t(E_i) - t(Q_i)$,
2. time between trough of Q wave and aortic valve closure: $Q\text{-}S2_i = t(S2_i) - t(Q_i)$,
3. time between trough of Q wave and dicrotic notch: $Q\text{-}D_i = t(D_i) - t(Q_i)$,
4. time between aortic valve closure and dicrotic notch: $S2\text{-}D_i = t(D_i) - t(S2_i)$,
5. QQ_i interval: $QQ_i = t(Q_{i+1}) - t(Q_i)$.

2.3. Experiment and case presentation

Thirty young, healthy subjects participated in the study. Subjects were supine, they performed two-minute isometric handgrip (HG) at 30% of the maximal voluntary contraction. First HG was followed by four-minute rest. After second HG, two-minute occlusion of the working arm was applied, followed by two-minute rest. The study was undertaken to verify reliability of some indices of SNS activity; among them PEP and PEP/LVET.

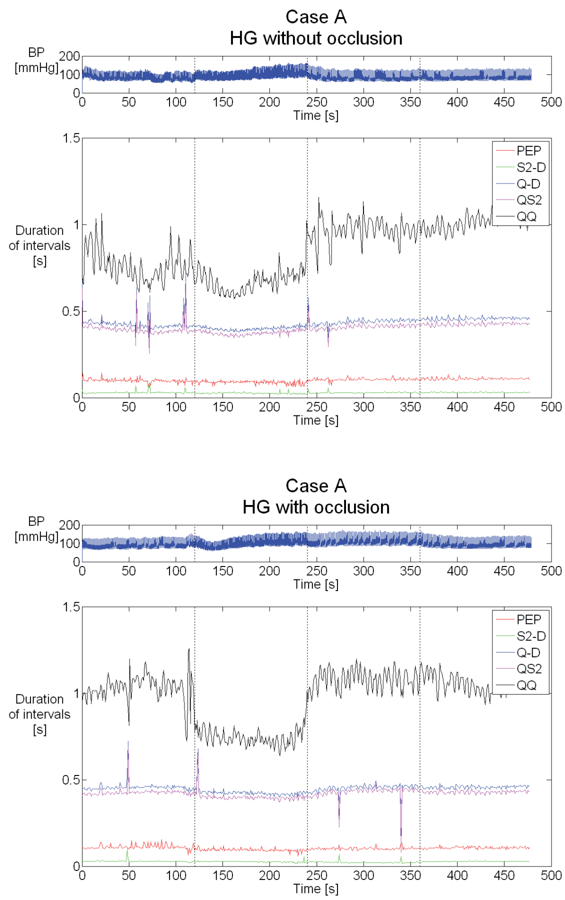

Fig. 8. Presentation of time courses of chosen time intervals for case A. S2–D curve remains almost flat through the experiment

2.3.1 Case presentation

Case A (Fig. 8)

One may see that changes of *Q-S2* curve are followed faithfully by changes of *Q-D* curve. The constant time lag between D_i (dicrotic notch) and $S2_i$ (aortic valve closure) may be interpreted as transition time from aortic valve to carotid artery; thus D_i and $S2_i$ are the same event observed in different places. Accordingly the constancy of time lag from D_i to $S2_i$ (ca. 30 ms) is evident in time course of *S2–D* curve; this curve remains almost flat through the experiment.

The presentation of continuous time courses of chosen time intervals reveals that 1/ the distinct oscillations of *QQ* seems to not influence strongly these intervals, 2/ shortening of *QQ* during handgrip is paralleled by slight decrease of *Q-D* and *Q-S2*, 3/ during occlusion, when *QQ* intervals return to baseline values also *Q-D* and *Q-S2* return to the baseline values, i.e. *Q-D* and *Q-S2* do not depend on arterial pressure which remains elevated.

Case B (Fig. 9)

It is evident that *Q-D* oscillate only slightly, the oscillations of *Q-S2* are much greater. This is also evident in *S2-D* interval (from 10 ms to 70 ms). Assuming that the detection of *S2* and *D* is correct it is rather impossible that the *S2* and *D* reflect the same event. The possible explanation may be given in the paper of M. F. O'Rourke, T. Yaginuma, and A. P. Avolio [9].

They stated that usually the beginning of the diastolic wave, termed dicrotic notch, occurs immediately after aortic valve closure. These two events are sometimes believed to be synonymous. However they may stem from different processes.

Closure of aortic valve is predominantly a cardiac phenomenon whereas dicrotic wave is predominantly a vascular one.

Is it possible that this explanation applies also to our results; thus *S2* reflects the cardiac event – valve closure, whereas *D* reflects beginning of the diastolic wave. If such hypothesis holds true next question arises: why *Q-D* interval is much more stable than *Q-S2*.

Case B demonstrates also the constancy of *PEP* which changes only slightly during handgrip despite considerable shortening of *QQ*.

Case C (Fig. 10)

Maybe case C provides proof that the *Q-S2* oscillations are not an artifact but true physiological phenomenon. It may be seen that characteristic of oscillation changes during handgrip and occlusion.

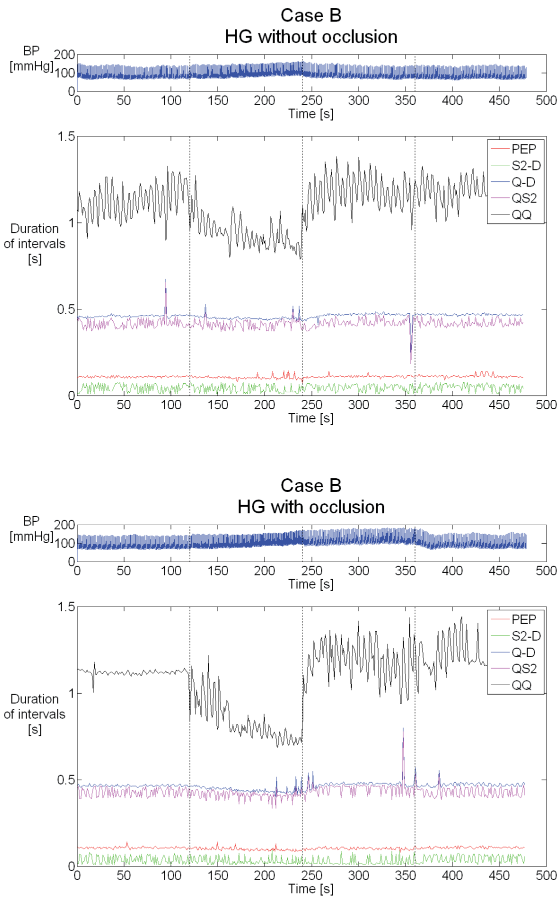

Fig. 9. Presentation of time courses of chosen time intervals for case B. Q-D curve oscillates only slightly, the oscillations of Q-S2 curve are much greater

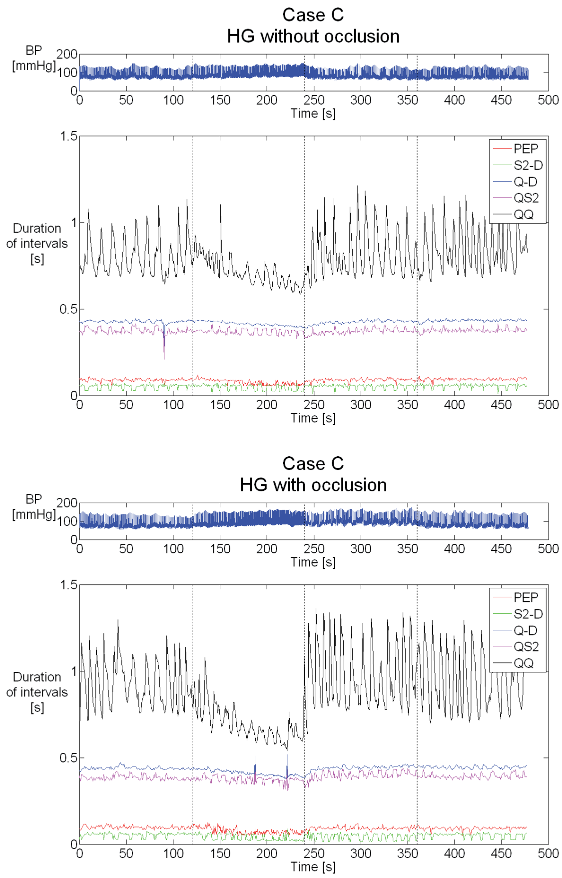

Fig. 10. Presentation of time courses of chosen time intervals for case C. This case may prove that the Q-S2 oscillations are not an artifact but true physiological phenomenon.

3. Conclusion

The automated beat-to-beat event detection and time intervals calculation allows to present continuous time course of systolic time intervals. Such presentation demonstrates oscillatory pattern of intervals changes, interdependence or lack of thereof between time intervals.

The time courses analysis of QQ, Q-D (time between trough of Q and dicrotic notch) and Q-S2 (time between trough of Q and aortic valve closure) time intervals demonstrated interesting features of relationships between these time intervals.

1/ The QQ duration influences weakly Q-D and Q-S2 intervals length, especially if the QQ variability is of respiratory origin.

2/ On the other hand the clear-cut shortening of Q-D and Q-S2 intervals seems to coincide with situation when increase of sympathetic activity is to be expected.

3/ Though, in some subjects S2 (aortic valve closure) precedes D (dictrotic notch) by constant time period, in others a delay between S2 and D was variable ranging-from 20 up to 70 ms. It shows that contrary to commonly held belief S2 and D do not reflect the same event.

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