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# Impedance Cardiography for Cuffless and Non-invasive Measurement of Systolic Blood Pressure

M. Y. M. Wong, E. Pickwell-MacPherson and Y. T. Zhang

*Abstract*— **In this study, we have used impedance cardiography to determine blood pressure (BP) cufflessly and non-invasively. We have devised a new parameter, QdZ [the duration measured from the foot of electrocardiogram (ECG) Q wave to the peak of impedance cardiogram (ICG)], for this purpose. Twenty-two subjects performed four minutes of treadmill exercise such that systolic BP (SBP) was increased significantly. We found that SBP was closely correlated with QdZ ($R^2$=0.65) demonstrating the potential application of ICG to cuffless and non-invasive BP measurement.**

## I. INTRODUCTION

Impedance cardiogram (ICG) has been commonly used for non-invasive measurements of stroke volume, cardiac output and systolic time intervals [1-3]. It is the derivative of the thorax impedance involving the measurement of cardiac-related impedance changes [4, 5]. To measure the impedance change in the thorax and ICG non-invasively, two pairs of electrodes are placed on the surface of the neck and thorax. One of the pairs of electrodes ejects sinusoidal low alternating current through the thorax while the other pair measures the resulting voltage between the electrodes to calculate the impedance change.

Several characteristic points on a typical ICG relate to the cardiac events. Figure 1 illustrates the waveforms of an electrocardiogram (ECG), thorax impedance change and ICG. The points A and C are associated with the contractions of the atria and ventricles respectively [6]. The points B and X in ICG coincide with the aortic valve opening and closure respectively [6]. These observations have been confirmed by several investigators using simultaneous recordings of phonocardiography, echocardiography and aortic pressure [7, 8].

Since these cardiac events are associated with the regulation of blood pressure (BP), these feature points are potentially able to reflect the level of BP. Among the feature points, point C (the peak of ICG) is selected in this study because of its ease of detection and the close relationship between ventricular contraction and systolic BP (SBP). Previous study reported the moderate correlation between the magnitude of point C in ICG and BP on over hundred healthy volunteers [9]. Thus, the objective of this study is to investigate the relationship between SBP and the proposed parameter. Parameter QdZ was defined as the time interval from the foot of ECG Q wave to the peak of ICG (point C) in Figure 1. As SBP increases, the arteries become stiffer and QdZ decreases.

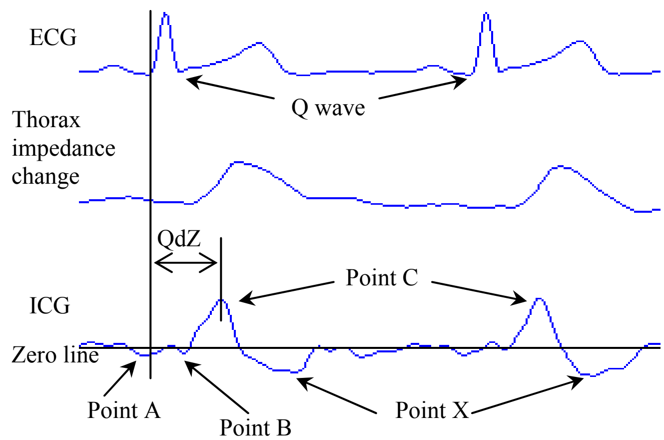


Figure 1. A graph to show the captured waveforms and the definition of the parameter QdZ.

## II. MATERIALS AND METHODS

The experiment has been described in previous literature [10, 11] but in this work we analyzed the data with a different objective. The experiment was conducted on twenty-two normotensive subjects, including eight females, aged 26±4 years (from 21 to 36 years). ECG (lead II) and thorax impedance change were detected by Physio Flow® (PF-05, Manatec Biomedical, France) simultaneously for one minute. Each signal was sampled at 1 kHz by an A-D converter. Arterial BP was measured by an automatic BP machine (HEM-907, OMRON, Japan) on a subject's left arm.

Before the experiment, each subject sat down and rested for five minutes. Then SBP, ECG and thorax impedance change were measured three times (Datasets 1-3). Next, the subject ran on the treadmill at 9km/h for four minutes and the signals were recorded again (Datasets 4-6). Finally, the subject then rested for five minutes before which the signals were recorded (Datasets 7-10).

## III. RESULTS

Table 1 summarizes the mean±SD of SBP and QdZ before and acutely after exercise. At the beginning of the experiment, the baseline SBP and QdZ (Datasets 1-3) were 111±12

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M. Y. M. Wong, E. Pickwell-MacPherson and Y. T. Zhang are with the Joint Research Centre for Biomedical Engineering, Department of Electronic Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong (corresponding author e-mail: ytzhang@ee.cuhk.edu.hk; phone: (852)2609-8459).
Y. T. Zhang is also with the SIAT Institute of Biomedical and Health Engineering, Chinese Academy of Sciences, China and Key Laboratory for Biomedical Informatics and Health Engineering, Chinese Academy of Sciences, China.

mmHg and 163±16 ms respectively. Acutely after exercise (Dataset 4), SBP increased and QdZ decreased significantly to 144±19 mmHg ($p$<0.001) and 128±21 ms ($p$<0.001) respectively. Both SBP and QdZ returned to their baseline values at the end of the experiment.

Table 1
The mean±SD of SBP and QdZ before (Datasets 1-3) and after exercise (Datasets 4-10).

| Dataset(s) | SBP (mmHg) | QdZ (ms) |
|---|---|---|
| 1-3 | 111±12 | 163±16 |
| 4 | 144±19 | 128±21 |
| 5 | 129±13 | 140±14 |
| 6 | 122±13 | 146±23 |
| 7 | 115±12 | 158±25 |
| 8 | 115±14 | 166±15 |
| 9 | 114±14 | 167±16 |
| 10 | 114±13 | 166±16 |

Figures 2 and 3 are the scatter plots of SBP versus QdZ over all subjects: a least squares regression line is fitted in each individual subject in the scatter plots. The subjects with minimum and maximum coefficient of determination are highlighted in bold coloured lines. The mean, median and variation of the coefficient of determination $R^2$, the slope and y-intercept of regression line are presented in Table 2. The slope of regression line varied from -1.19 to 0.17 mmHg/ms. The large variation of the slope and y-intercept of the regression lines indicated that the linear relationships between SBP and QdZ were subject-dependent. A positive slope was observed in only one subject in Figure 2. The relationship between SBP and QdZ in this subject was probably due to the much smaller variation of SBP (as shown in Figure 3).

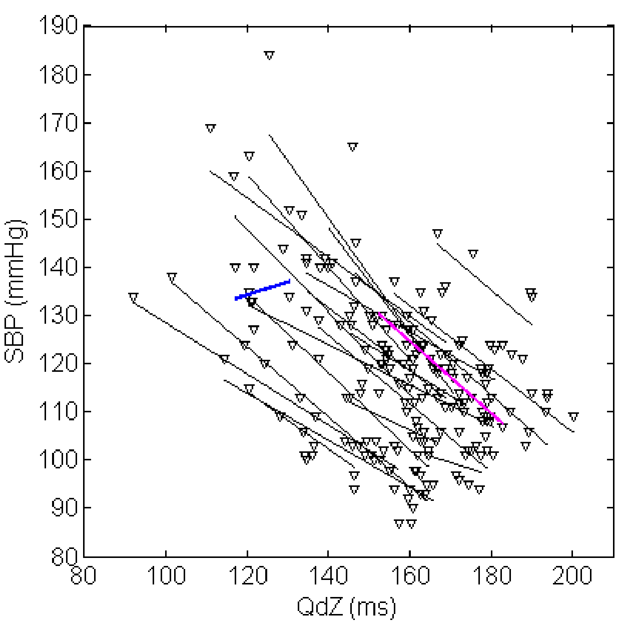


Figure 2. The scatter plot of SBP versus QdZ over all subjects. Least squares regression line is fitted for each individual subject. The bold blue and pink regression lines highlight the subjects with the minimum and maximum coefficient of determination $R^2$ respectively.

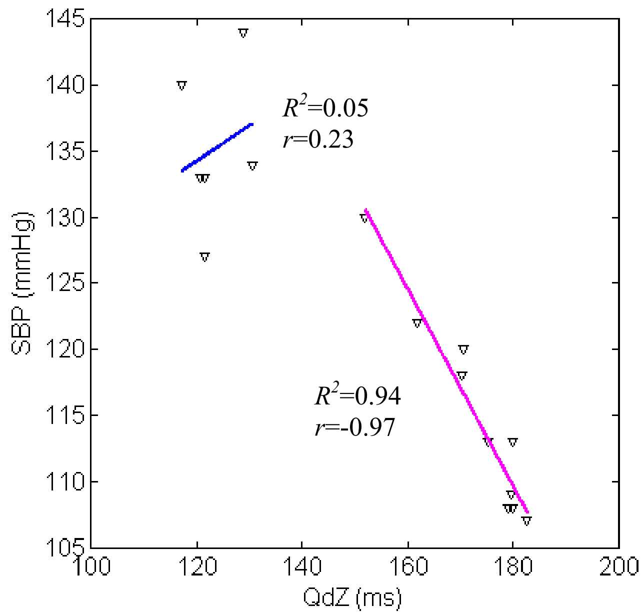


Figure 3. The scatter plot of SBP versus QdZ of subjects with the minimum (blue regression line) and maximum (pink regression line) coefficient of determination $R^2$. Correlation coefficient $r$ is also presented on the plot.

The mean and median $R^2$ were 0.65 and 0.73 respectively suggesting that SBP and QdZ were moderately correlated and therefore more than half of the subjects could be appropriately modelled by the linear regression between SBP and QdZ. When SBP was estimated by QdZ using the least squares method, the mean±SD difference between the prediction and measurement was 0.0±5.4 mmHg over all subjects.

Table 2
The coefficient of determination $R^2$, the slope and y-intercept of regression line in the scatter plot of SBP versus QdZ (Figure 2).

| | Mean | Median | Range |
|---|---|---|---|
| $R^2$ | 0.65 | 0.73 | 0.05 - 0.93 |
| slope (mmHg/ms) | -0.64 | -0.65 | -1.19 - 0.17 |
| y-intercept (mmHg) | 219 | 224 | 68 - 316 |

## IV. Discussion and Conclusion

Because of the prevalence of hypertension globally [12], frequent measurement of BP is advised to offer better control of hypertension. Thus, various technologies have been widely studied and investigated for cuffless and non-invasive monitoring of BP. Pulse transit time (PTT), the duration for a pressure pulse wave to propagate in a segment of arteries, has been considered as one of the potential parameters for this purpose. However, PTT-technique has several limitations: it is easily distorted by motion artifacts because of the necessity to attach a photoplethysmogram (PPG) at an extremity (fingertip, earlobe) and it loses accuracy when the extremity is exposed to the cold [13].

In this study, we proposed another cuffless technology for BP estimation. Instead of using PPG, ICG was used to predict BP without occlusive cuffs. Since ICG captures the impedance change in the thorax due to the change of blood flow, the signal is less distorted by the motion artifacts and cold temperatures. The close correlation between SBP and the proposed parameter QdZ was observed from twenty two subjects. Moreover, the mean±SD difference between the prediction and measurement was comparable to the difference when SBP was predicted by PTT-technique [11]. Thus, the results indicated the potential application of ICG to the cuffless and non-invasive SBP prediction.

Instead of the magnitude-derived parameter from ICG [9], we proposed a timing feature-derived parameter (QdZ) because it may be a more practical parameter for cuffless BP estimation. Because of the sensitivity of electrodes placement and skin conduction, the measurements of magnitude-derived parameters are difficult to reproduce. Thus QdZ was less affected by the aforementioned factors.

It should be noted that heart rate could affect QdZ and SBP. Close correlation between SBP and QdZ was observed in some subjects even though their heart rate did not change pronouncedly after exercise. The control of heart rate should be considered in the future experiment to demonstrate QdZ as an independent predictor of SBP. Moreover, the inclusion of a larger age range and participation of hypertensive subjects are necessary to confirm the relationship between QdZ and SBP in the future.

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