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Evaluation of Cardiovascular Stress Reaction Using HPCD Method on a Beat-by-beat Basis[1]

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Abstract: In order to establish a bionic model/system in cardiovascular fields, comprehension of hemodynamics is important. In this study, a novel beat-by-beat hemodynamic system evaluation method named "beat-by-beat HPCD method" is proposed and evaluated. Gregg's theoretically driven model of hemodynamics which was called "HPCD method" is improved by using non-invasive and beat-by-beat cardiovascular measurement of mean blood pressure and cardiac output.

Continuous beat-by-beat measurements of MBP and CO were done on three healthy male subjects during three hours. In the measurement, a five minutes cold pressor test was executed in each subject and also each subject did exercise using a bicycle ergometer in five minutes and walked during 15 minutes. Measured beat-by-beat MBP and CO can derive beat-by-beat HP (hemodynamic profile) and CO (compensation deficit). Then, beat-by-beat changes clearly observed from plots on HP axis and CD axis plane. More vascular response can be observed on cold pressor and more myocardial response can be observed on ergometer exercise. During walking period, the response is intermediate between cold pressor and ergometer exercise. Finally, the proposed method can be considered as applicable to evaluate cardiovascular bionic system especially on evaluation of a person being subjected to stress.

Keywords: hemodynamics; stress; cardiovascular system; hemodynamic profile and compensation deficit model

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INTRODUCTION

In order to establish a bionic model/system in cardiovascular fields, comprehension of hemodynamics should be considered as important. In this study, a novel beat-by-beat hemodynamic system evaluation method named “beat-by-beat HPCD method” is proposed and evaluations of human hemodynamic status in three different stress loading status were attempted using the method.

MATERIALS AND METHODS

As known, there have been many attempts of measurement and/or estimating for hemodynamic parameters. Among them, Gregg et al. recently proposed a new theoretically driven model of hemodynamics and demonstrated its application for hemodynamic parameters (Gregg et al., 2002) which were called “HPCD method.” The “HPCD method” is based on cardiac output (CO) and total peripheral resistance (TPR). Though it is not possible to measure TPR directly, TPR can be estimated from CO and mean blood pressure (MBP) as Eq. (1), as shown in Fig. 1.

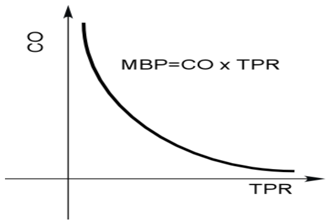

Figure 1: Three hemodymanic parameters; mean blood pressure (MBP), cardiac output (CO) and total peripheral resistance (TPR)

$$MBP = TPR * CO \tag{1}$$

The baseline measurement gives MBP and CO on baseline MBPb and COb, giving TPR on baseline TPRb as Eq. (2).

$$MBPb = TPRb * COb \tag{2}$$

Dividing Eq. (1) by Eq. (2) gives Eq. (3a) as below.

$$MBP/MBPb = TPR/TPRb * CO/COb \tag{3a}$$

Eq. (3a) means relative reactivity of three homodynamic parameters, then the three terms of Eq. (3a) are expressed as MBPr, TPRr and COr (shown as Eq.(3b)).

$$MBPr = TPRr * COr \tag{3b}$$

Then, logarithm of Eq. (3a) gives Eq. (4) of additive synthesis.

$$log(MBPr) = log(TPRr) + log(Cor) \tag{4}$$

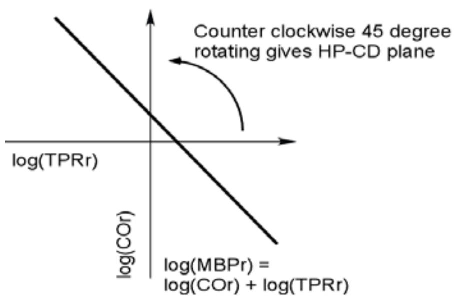

Figure 2: Hemodinamic parameters on orthogonal dimension consisted of logarithm of TPR and CO

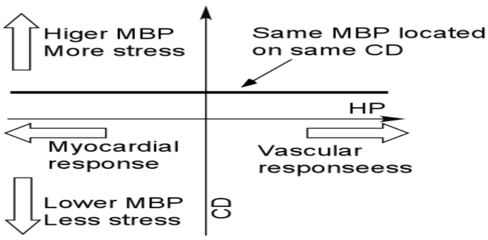

Figure 3: HP-CD plane: HP means "hemodynamic profile" and CD means "compensation deficit"

Now, Eq. (4) means orthogonal dimensions consisted of logarithm of TPR and CO as shown in Fig. 2. Finally, counter clockwise 45 degree rotating of this log-TPR axis and log-CO axis plane gives a new orthogonal dimensions consisted of logarithm of TPR and CO "hemodynamic profile (HP)" axis and "compensation deficit (CD)" axis, and the HP-CD plane can have information relating reactivity of hemodynamic parameters. In the HP-CD plane, CD axis gives relative stress reaction information and HP axis gives information of relative myocardial-and-vascular balance, as shown in Fig. 3.

Gregg et al. applied their method to evaluate hemodynamic status of human only intermittently. Consequently, their method remained one-shot evaluation and comparison of different hemodynamic statuses; i.e. comparison of before and after a stress loading. Meanwhile, we have been developed beat-by-beat continuous and non-invasive measurement methods and systems of cardiovascular/hemodynamic parameters that can measure blood pressure and cardiac output continuously (Nakagawara & Yamakoshi, 2000) whose measurement methodologies are based on volume-compensation method (Yamakoshi et al., 1979 & 1980) and transthoracic admittance plethysmograph method (Ito et al., 1976). Here, we thought inevitably that Gregg's HPCD method can be enhanced to beat-by-beat evaluation of hemodynamic by combining with our beat-by-beat measurement system.

Continuous beat-by-beat measurements of MBP and CO were done on three healthy male subjects (yrs. 21-23) during three hours. In the measurement, a five minutes cold pressor test was executed in each subject and also each subject done exercise using a bicycle ergometer in five minutes and walked during 15 minutes. For obtaining a baseline of the physilogogcal measurement, each subject was placed supine position in the first 5 minutes of the measurement. The cold pressor test is considered inducing mainly myocardial response and exercise using an ergometer is considered inducing mainly vascular response.

Continuous beat-by-beat hemodynamic measurement provides continuous plots on HP-CD plane. For evaluate distribution of those plots, principal component analysis (PCA) based evaluation is applied. In this paper, representative parameter of distributed plots is defined as an ellipse that drawn with PCA: That representative ellipse is drawn as follows (illustrated as Fig. 4):

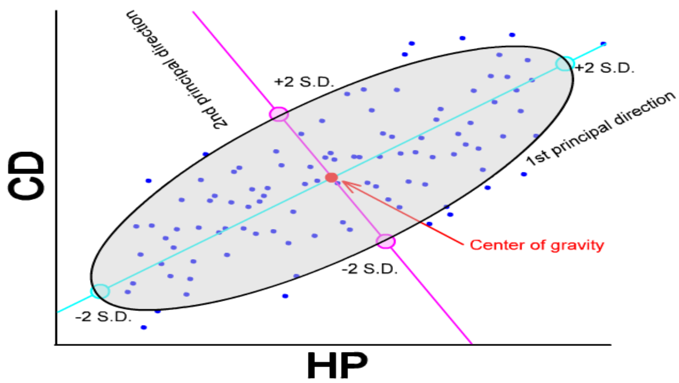

Figure 4: How to draw representative ellipse of plots on HP-CD plane

1. PCA is applied the plots then obtaining the 1st and 2nd principal direction.
2. The center of the ellipse is defined as the center of gravity the plot.
3. The long axis of the ellipse is defined as ±2 S.D. of the 1st principal component score.
4. The short axis of the ellipse is defined as ±2 S.D. of the 2nd principal component score.

RESULTS AND DISCUSSION

Measured beat-by-beat MBP and CO can derive beat-by-beat HP (hemodynamic profile) and CO (compensation deficit). Then, beat-by-beat changes clearly observed from plots on HP axis and CD axis plane. In cold pressor phase, the plots on HP-CD plane move to more vascular direction. In contrast, the plots move to more myocardial direction in ergometer exercise. In waking period, the plots distributed on the area between cold pressor phase and ergometer exercise phase. An example of the plots and representative ellipses of each status are shown in Fig. 5. This suggests that cardiovascular reactions of stress on daily living as walking should be considered as mixed myocardial and vascular response. This must mean that same blood pressure response can be originated from different hemodynamic status. Then, the proposed method can be considered as applicable to evaluate cardiovascular bionic system in a dynamic sense, on a beat-by-beat base. For a future cardiovascular bionic system analysis/synthesis, the view of myocardial-and-vascular balance should be important.

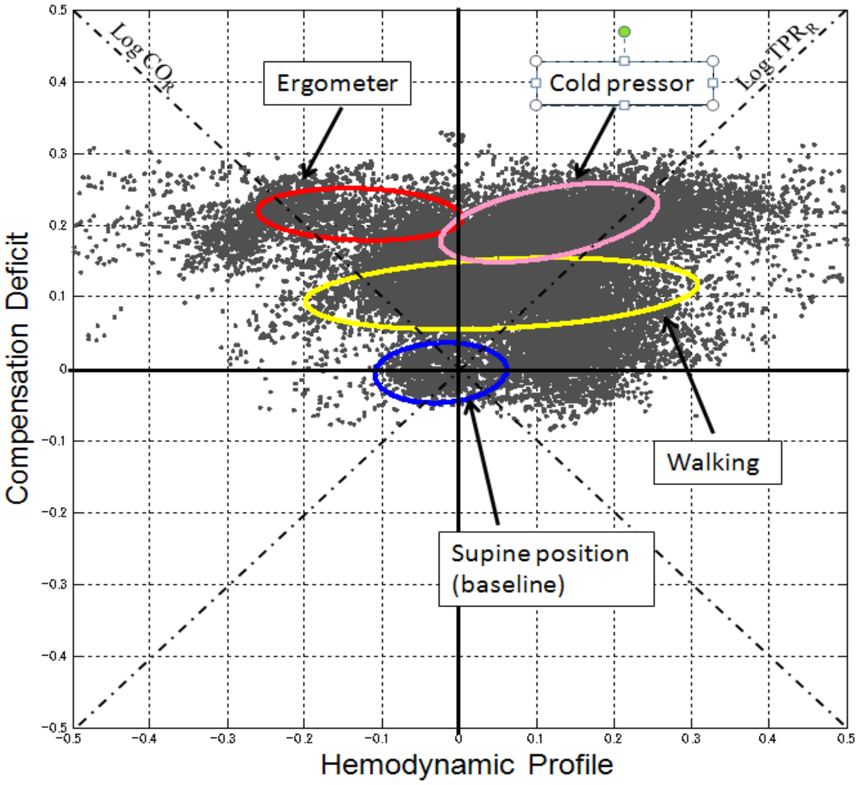

Figure 5: An example of beat-by-beat measurement based HP-CD plot and its evaluation. Gray dots are beat-by-beat plot of hemodynamic parameter, HP and CD. The blue ellipse shows distribution on supine position. The red, pink and yellow ellipses show cold pressor, ergometer exercise and walking respectively

CONCLUSION

Beat-by-beat HPCD hemodynamic evaluation method that was combination of Gregg's HPCD method and our beat-by-beat cardiovascular measurement was proposed and attempted. By the method, stress reactions can be observed clearly.

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