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Relationship Between Hemodynamic Parameters During Exercise and Cardiac Function

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ABSTRACT

In order to determine what parameter is useful for the prediction of cardiac function prior to exercise cardionuclear examination, the relation between hemodynamic parameters during exercise and cardiac function was studied in 56 patients who underwent both gated blood pool scintigraphy and exercise myocardial perfusion imaging. Patients were divided into three groups. Group 1 consisted of 11 patients who were suspected to have angina pectoris, but no exercise-induced ischemia. Group 2 consisted of 23 patients who had a history of angina pectoris and apparent exercise-induced ischemia. Group 3 consisted of 22 patients who had a history of myocardial infarction. Cardiac performance was evaluated using parameters of ejection fraction (EF), end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), and cardiac output (CO) at rest. The changes of systolic blood pressure (SBP), heart rate (HR), and pressure rate product (PRP) during exercise were recorded at 30-sec intervals and were used for analysis. HR was negatively correlated with EF in group 3 ($r=-0.476$, $P<0.05$), whereas HR was not correlated with EF in group 1 and group 2. HR was negatively correlated with SV. There was no correlation between HR and CO, whereas there was a weak positive correlation between EF and CO ($r=0.301$, $p<0.05$). The ascending slope of time-heart rate curve increased with increasing EF. The segmental defect score in group 3 patients was negatively correlated with the EF (%) ($r=-0.743$, $p<0.05$). In patients with cardiac dysfunction the increase in EDV and/or HR compensates for the decrease in EF to keep constant CO. Thus, the monitoring of hemodynamic parameter may be useful for the prediction of cardiac function.

KEY WORDS

Ischemic heart disease, Exercise, Cardiac function, Cardionuclear examination, Heart rate.

INTRODUCTION

Radioisotope studies including electrocardiography (ECG) gated blood pool imagings, and myocardial SPECT imagings have been widely used for the noninvasive evaluation of cardiac function and myocardial perfusion[1)-5)]. Although these examinations are often performed at rest, they are also performed during exercise to enhance the sensitivity of detecting ischemic heart disease. Hemodynamic parameters during exercise myocardial imagings provide valuable information on cardiac performance. Furthermore, cardiac performance provides the valid information on the selec-

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tion of therapeutic procedure, management, and the judgement of prognosis in patients with ischemic heart disease. Cardiac performance is maintained by a balance of heart rate (HR), preload, afterload and contractility. Since the disturbance of this balance causes heart failure, the severity of heart failure can be evaluated using these parameters. Contractility representing cardiac muscle function, consequently ventricular pump function is easily evaluated using the left ventricular ejection fraction (LVEF). As it is affected by changes in HR, preload and afterload[6)-8)], it is important to understand the relationship between these parameters at rest and during exercise.

In order to enhance the sensitivity of detecting myocardial ischemia, it is desirable to give more exertional load. However, excessive exertional load also enhances the possibility of inducing ischemic attack, or myocardial infarction. One of the means to avoid such a trouble is to obtain detailed information on the patient. Unfortunately we sometimes meet with the opportunity to perform exercise cardionuclear examinations without detailed imformation on the patients. Therefore, it is important to predict the cardiac function from the data at rest prior to the examination and to finish the exercise examination with safety by giving appropriate level of exercise. The purpose of this study was to determine what parameter is useful for the prediction of cardiac function prior to exercise examination.

MATERIALS AND METHODS

Patient population

Fifty-six patients (39 males, 17 females) who underwent both gated blood pool scintigraphy and exercise myocardial SPECT imaging were studied retrospectively. The mean±S.D. age was 65.8±8.8 years (range 40-79 years). Patients were divided into three groups. Group 1 consisted of 11 patients who were suspected to have angina pectoris, but no exercise-induced ischemia on exercise myocardial SPECT imaging. Group 2 consisted of 23 patients who had a history of angina pectoris and apparent exercise-induced ischemia. Group 3 consisted of 22 patients who had a history of old myocardial infarction (OMI) (7 anterior wall infarction, 6 inferior wall infarction, 1 lateral wall infarction, 4 inferior and lateral infarction, 2 anterior and inferior infarction, 1 anterior and lateral infarction, and 1 anterior, lateral and inferior infarction). Group 3 included six who had undergone coronary artery bypass grafting (CABG) surgery and four, percutaneous transluminal coronary angioplasty (PTCA). The mean±S.D. age in group 1, group 2, and group 3 were 68.7±6.6, 65.5±8.9, and 64.8±9.2, respectively. There was no significant difference for age among these groups. Patients with severe arrhythmia or cardiomyopathy were excluded from this study. Medications including beta blockers and antihypertensives were continued during the examination period.

Gated blood pool scintigraphy

Gated blood pool scintigraphy was performed using 740 MBq of in vivo ^{99m}Tc red blood cell labeling. A gamma camera (GCA901A/SB, Toshiba) with a low-energy, general-purpose collimator was used, which was interfaced to a nuclear medicine computer (GMS-550, Toshiba). The energy discrimination was centered on 140 keV with a 25% window. A 60s first pass radionuclide angiogram was acquired with 64×64 matrix in list mode, and equilibrium data were added. A left ventricular time-activity curve was generated. The cardiac index was computed using this curve fitted by an exponential function. In a gated blood pool study, a cardiac cycle was divided into 24 frames with 64×64 matrix. Gated images were obtained in three views (40° left anterior oblique, 10° right anterior oblique and left lateral). Ejection fraction (EF) was calculated from the stroke counts divided by end-diastolic counts. Other parameters including end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), and cardiac output (CO) were evaluated. Wall motion abnormality was assessed using end-diastolic and end-systolic contour display.

Exercise myocardial SPECT imaging

Exercise myocardial SPECT imaging was performed within 10 days of gated blood pool imaging. Using a supine bicycle ergometer, exercise was started at 25 watts and was increased by 25 watts every 2 min until the exercise end point was reached. Exercise was terminated when either severe chest pain, serious arrhythmia, ischemic ST segment depression with more than 0.2 mV, and fatigue occurred. At the maximum exercise, 111 MBq of ^{201}Tl was injected intravenously and the patient was encouraged to continue exercise for an additional 1 min. Within 10 min of ^{201}Tl injection, SPECT data acquisition was started using the same gamma camera with a single head SPECT system. The energy discrimination was centered on 70 keV with a 25% window. Data acquisition was performed with 60 projection images throughout 180° of rotation, rotating in an anterior direction from 45° right anterior oblique to 45° left posterior oblique. The sampling angle was 6° allowing 30 sec per projection. Projection data were transferred to the computer system used for the gated imaging and three SPECT images including transaxial, vertical long-axis and short-axis images were generated using a standard filtered back-projection algorithm supplied by the manufacturer. Attenuation correction was not performed. Systolic blood pressure (SBP), heart rate (HR), and pressure rate product (PRP) were recorded at 30-sec intervals during exercise and at least 5 min after the termination of exercise.

Two short-axis slices and a vertical long-axis slice were selected for interpretation of SPECT images. Two slices from near the cardiac base and mid-to-apical portion were used, and each slice was divided into eight segments. The apical portion of the long-axis image was divided into two segments. Thus there were 18 segments in each myocardium. The reduction in concentration was evaluated using a 5-point scale (normal=0, 1=slight reduction, 2=moderate reduction, 3=severe reduction, 4=complete defect)[9].

Table 1 Means±SD of hemodynamic parameters in each group.

	Group 1	Group 2	Group 3
HR(1/min)	64.5±9.9	71.1±10.4	68.3±11.7
EF (%)	61.5±4.2	64.8±8.4	54.5±11.7*
EDV (ml)	99.8±13.3	91.1±24.1	110.2±26.8*
ESV (ml)	38.5±7.0	32.8±13.7	52.2±24.5*
SV (ml)	61.3±8.6	58.2±14.6	58.0±11.7
CO (ml)	3807±327	4120±810	3917±621

Mean±S.D.
Statistical comparisons (G1 & 2 vs G3) : * $p<0.05$

Statistics

Least squares linear regression and linear correlation analyses were performed using Stat View (Abacus Concepts, Inc., Berkeley, USA). A p-value<0.05 was considered statistically significant. Standard deviation and mean were calculated using Microsoft Excel (Microsoft, Inc., Redmond, USA). Data were expressed as mean±standard deviation (S.D.).

RESULTS

1 Cardiac performance at rest

Table 1 shows cardiac performance in each group. Mean EF in group 3 was significantly lower than those in the other groups. Mean EDV and ESV in group 3 were significantly greater than those in the other groups. HR was negatively correlated with EF in group 3 ($r=-0.476$, $P<0.05$), whereas HR was not correlated with EF in the other groups (Fig. 1). HR was negatively correlated with SV in group 1 and group 2 (Fig. 2). There was no correlation between HR and CO (Fig. 3), whereas there was a weak positive correlation between EF and CO ($r=0.301$, $p<0.05$; Fig. 4).

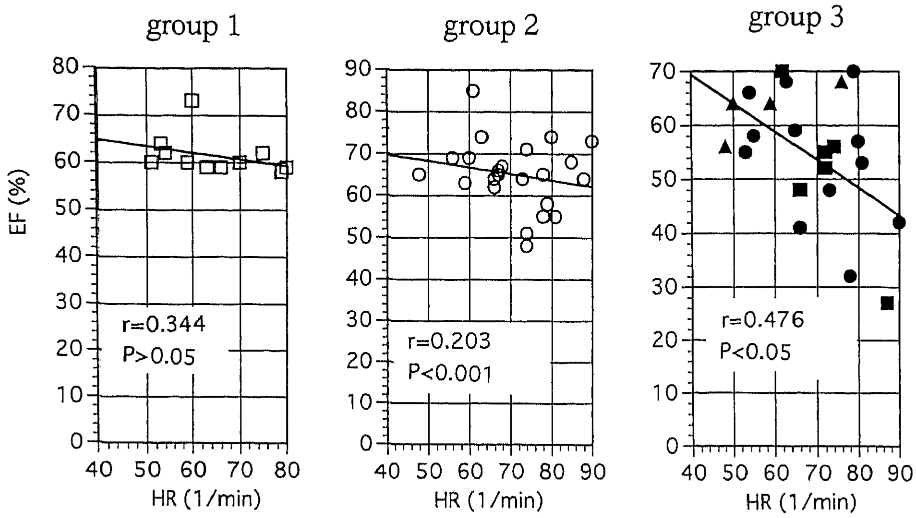

Fig. 1 Correlation between HR and EF

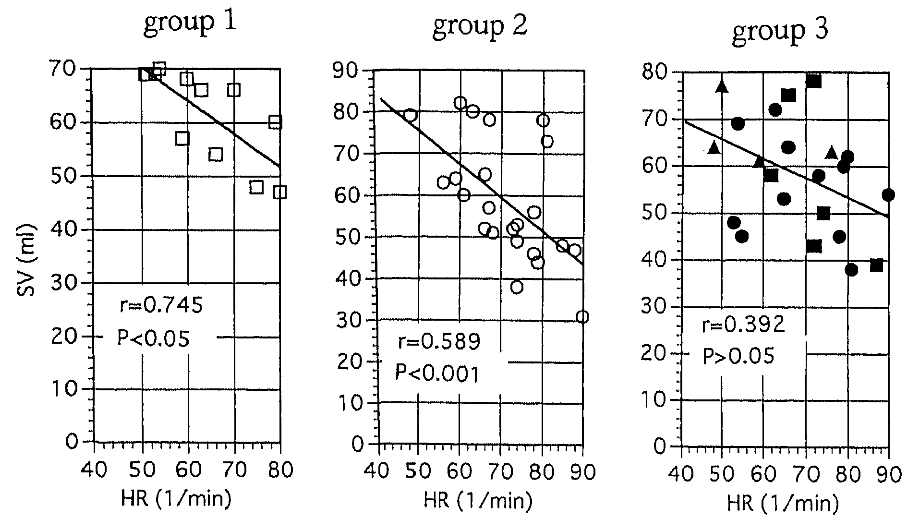

Fig. 2 Correlation between HR and SV

2 Hemodynamics during exercise

Figure 5 shows relationship between patient characteristics and exercise achievement. Exercise was terminated because of chest oppression in 5 patients (4 in group 2 and 1 in group 3). All other patients stopped exercise because of leg fatigue. During exercise, 9 patients (5 in group 2 and 4 in group 3) showed an ST segment depression. Eleven of the 13 (84.6%) male patients in group 2 achieved an exercise level of more than 75 watts, whereas 12 of the 18 (66.7%) male patients in group 3 achieved an exercise level of less than 50watts. Figure 6 shows a relationship between age and maximum HR. Maximum HR was represented by the formula : (Maximum HR)= (200-age). The ascending slope of time-heart rate curve during exercise increased with increasing EF (Fig. 7). It was demonstrated that patients with good contractility of the left ventricle showed rapid response of HR to exercise.

3 Exercise myocardial SPECT imaging

The segmental defect score was negatively correlated with the EF ($r=-0.743$, $p<0.05$; Fig. 8). Thus, it was demonstrated that patients who showed widely decreased perfusion on myocardial SPECT images had decreased contractility of the left ventricle.

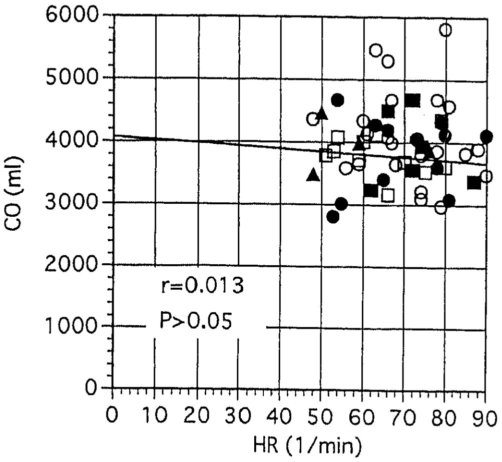

Fig. 3 Correlation between HR and CO (□ ; group 1, ○ ; group 2, ● ; OMI, ■ ; CABG,▲ ; PTCA)

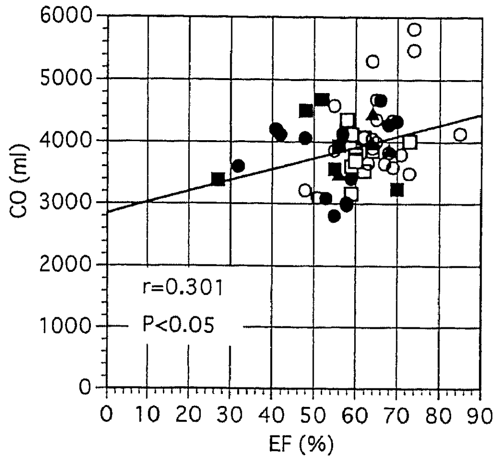

Fig. 4 Correlation between EF and CO (□ ; group 1, ○ ; group 2, ● ; OMI, ■ ; CABG,▲ ; PTCA).

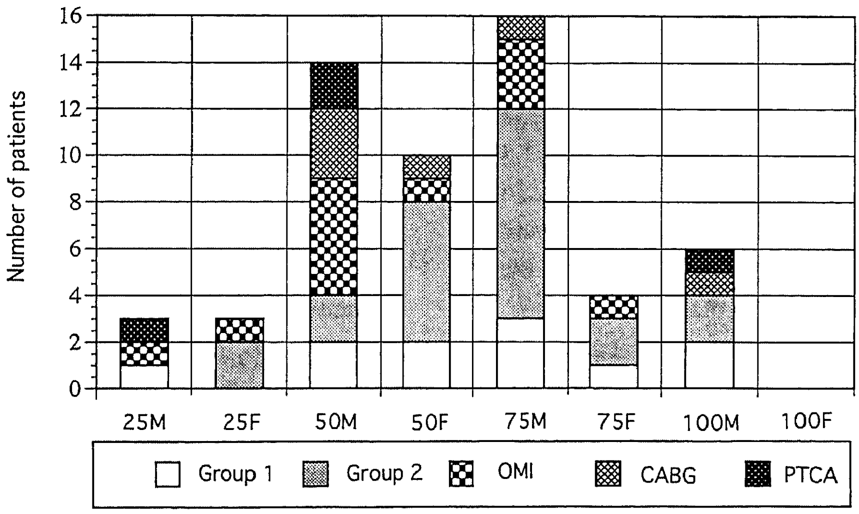

Fig. 5 Relationship between patient characteristics and exercise achievement. (M ; Male, F ; Female, A figure means a level of exercise).

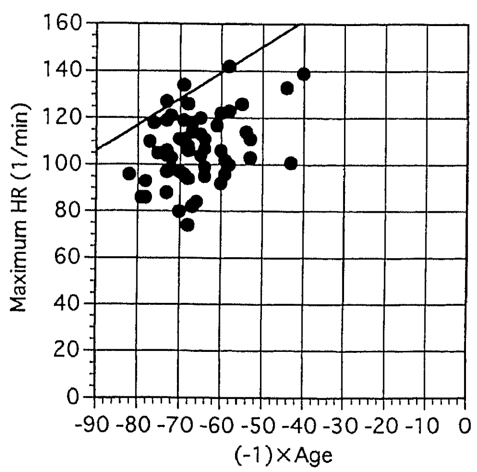

Fig. 6 Correlation between age and maximum HR during exercise (Line : Y=200−X).

DISCUSSION

Firstly we studied the relationship between the cardiac parameters at rest. The overall CO was 3948±599 ml (mean±SD, n=56). This value was not significantly different from the mean CO (3807±327 ml, n=11) in group 1. In addition, 51 of 56 (91.1%) patients were included within the range from 3000 ml to 5000 ml and the CO was almost constant independent of HR. Thus, our results confirmed the notion that CO is normally determined by the needs of the body, and not by the heart[7]. It is well-known that CO is proportional to body surface area (BSA). The effect of BSA on the CO is usually corrected

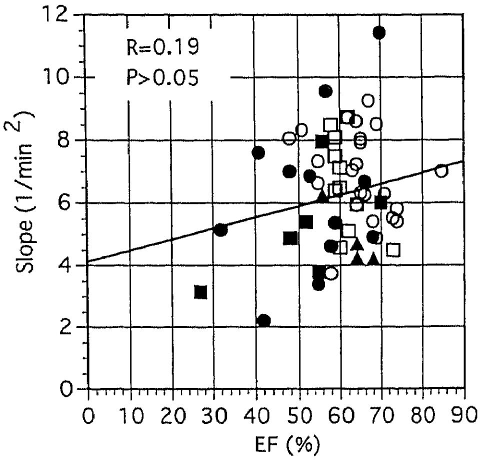

Fig. 7 Correlation between EF and the ascending slope of time-heart rate curve.
(□ ; group 1, ○ ; group 2, ● ; OMI, ■ ; CABG,▲ ; PTCA)

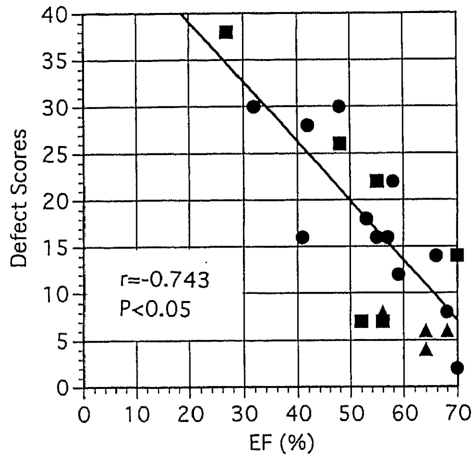

Fig. 8 Correlation between EF and defect scores in group 3.
(● ; OMI, ■ ; CABG,▲ ; PTCA)

using a parameter of cardiac index (CI) : CI=CO/BSA. However, no correction for BSA was performed in this study. The heart is constantly adjusting its performance to meet the immediate requirements of the body for blood flow. In the course of daily living, ventricular function varies on a beat-by-beat basis to meet tissue oxygen demands. Changes in position, psychological stress, physical exertion, and so on alter cardiac function.

The mechanism of cardiac performance is well explained by the Frank-Starling's law[7]. When venous return is kept constant, the operation of Starling's law of the heart causes EDV to fall when HR is increased, which decreases SV. Conversely, when slowing of the heart increases filling, Starling's law increases SV. Using the relationship of $CO=SV \times HR$ and $EF=SV/EDV$, CO is expressed as $CO=EF \times EDV \times HR$. Normal subjects meet changing demands with a range of changes in EDV, ESV and HR, to keep constant CO. During exercise, EF increases due to increasing EDV and decreasing ESV. As long as filling can increase to compensate for low HR, SV (=EDV-ESV) remains constant and diastole lasts long enough to allow adequate filling of the ventricle at rapid rates. At extremes of HR, however, changes in SV are no longer able to maintain CO at a level appropriate for the needs of the body. In the patients who showed decreased EF due to decreased contractility of the left ventricle, the increase of EDV and/or HR occurs to keep constant CO. In our results, HR was not correlated with EF in group 1 and group 2. Since patients in group 1 and 2 had good contractility of the left ventricle, their EF did not depend on the HR. On the contrary, since patients in group 3 had decreased cardiac function, their EF decreased with increasing HR. There was a negative correlation between EF and EDV ($r=-0.559$, $p<0.001$) or between EF and ESV ($r=-0.888$, $p<0.001$). On the other hand, there was a positive correlation between EF and SV ($r=0.303$, $p<0.05$). There was a negative correlation between HR and EDV or ESV (These figures were omitted). It was demonstrated that patients with cardiac dysfunction had the increase in ESV as well as the increase in EDV, consequently the decrease in SV.

HR plays an important role in adding computer quantification to the interpretation of exercise ^{201}Tl images. McLaughlin et al[10]. assessed the effect of varying the level of exercise on the results of ^{201}Tl myocardial imaging and concluded that significant coronary artery disease could be missed with less than maximum exercise, since ischemic defects developed in maximum exercise studies in segments that were normal with light exercise. Kaul et al[5]. also studied the relationship between the level of exercise and ^{201}Tl myocardial clearance and reported that ^{201}Tl clearance from the myocardium is influenced by maximum exercise HR. They used the formula of maximal predicted HR= (220-age). However, maximum HR in our study was represented with the formula : maximum HR= (200-age). The rate of increase in HR during exercise was very slow in the patients with decreased EF, whereas it was very rapid in the patient with normal EF. It appears that we can guess the decrease in EF from the rate of increase in HR. Since the monitoring of HR is easy even during exercise, this parameter may be helpful for the prediction of cardiac dysfunction in patients with ischemic heart disease. Because episodes of ischemia in these patients are associated with a transient decrease in contractile function. The segmental defect score in our study was negatively correlated with the EF. Thus, it was demonstrated that patients who showed widely decreased perfusion on myocardial SPECT images had decreased contractility of the left ventricle.

In conclusion, increased HR at rest, and the slow response of HR to exercise may represent cardiac dysfunction. When exercise cardionuclear examination is performed, careful attention should be payed to such patients.

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心機能と運動時の血行動態指標の関係

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要　旨

心臓核医学検査前に心機能を予測する上でどの指標が有効であるかを決めるために，心電図同期心プールシンチグラフィと運動負荷心筋シンチグラフィの両方の検査を施行した患者56人で，心機能と運動時の血行動態指標の関係について検討した。患者を３群に分類した：１群（運動による虚血なし，11人），２群（運動による虚血あり，23人），３群（陳旧性心筋梗塞，22人）。心機能の指標として，安静時の駆出率（EF），拡張期容積（EDV），収縮期容積（ESV），１回拍出量（SV），心拍出量（CO）を算出した。また運動時の収縮期血圧（SBP），心拍数（HR），両者の積（PRP）を30秒間隔で記録し，解析に用いた。１群と２群ではHRとEFの間に相関は認められなかったが，3群ではHRとEFは負で相関した。またHRはSVと負で相関した。COとHRに相関は認められなかったが，COとEFとは軽度相関した。最大運動量までの時間ー心拍数曲線における傾きは，EFの増加につれて増加した。３群で示された陳旧性心筋梗塞の患者では，心筋シンチグラフィにおける血流欠損の範囲とEFの間に明らかな負の相関が認められた。このような心機能の低下した患者では，EFの低下をHRの増加とEDVの増加によって代償することにより一定のCOを確保している。したがって安静時におけるHRが増加しており，運動負荷によるHRの増加も少ない。以上より，安静時の心拍数，および運動負荷に対する心拍数の変化は心機能を予測する上で役に立つと思われた。