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Effect of Arterial Baroreceptor on Cardiac Autonomic Nerve Activity during Head-up Tilting

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SUMMARY

To evaluate how the cardiac sympathetic and parasympathetic nerve activity response to the change of body axis component of gravity during head-up tilting, we examined the effects of decremental head-up tilting (90°, 64°, 53°, 44°, 37°, 30°, 24°, 17°, 12°, 6°, 0°) on heart rate variability using power spectral analysis in healthy young female.

Eight young female volunteers (age, 23.3±0.8 years ; mean±SD) were included in this study. The electrocardiogram (ECG) by bipolar chest leads was recorded continuously during procedures, and the bed was tilted at 0.1 interval of sine function of tilting angle from upright position (90°) to supine position (0°). The frequency domain measurements of low (0.08 to 0.15 Hz, LF) and high (0.15 to 0.40 Hz, HF) frequancy components were performed to assess the cardiac sympathetic and parasympathetic nerve activity.

The square root of high frequency power, specific index of cardiac parasympathetic tone, showed nearly linear increase between 90° and 17°, from 9.9ms to 28.5ms and tilting angle 17° and less, it remained unchanged. The ratio of low to high frequency power, marker of cardiac sympathetic tone, fell from 25.2 at 90° to 4.6 at 30°, and after from 30° to 0°, it remained unchanged. Although the direction was opposite, during high tilt angle range both cardiac sympathetic and parasympathetic tone showed close correlation to the sine of tilting angle. In contrast, during low tilt angle range, both cardiac autonomic nerve activity remained unchanged.

These findings gave us information concerning a relative high threshold characteristics of baroreflex which exerts a main influence on heart rate variability during head-up tilting, thus we conclude that arterial baroreceptors exert a major influence on the cardiac autonomic nervous response to postural adaptation.

KEY WORDS

head-up tilting, heart rate variability, power spectral analysis, cardiac sympathetic and parasympathetic nerve activity, arterial baroreflex.

INTRODUCTION

When we change our body position from supine to upright, increase of the body axis component of gravity causes a hydrostatic blood shift (ranging from 500 ml to 700 ml) from the upper to the lower body. This distribution of body fluid induces reduction of venous return, leading to reduce cardiac output and arterial hypotension. It was supposed that these conditions of body fluid sift and arterial hypotention might be compensated by reflex mechanisms depending on the sympathetic

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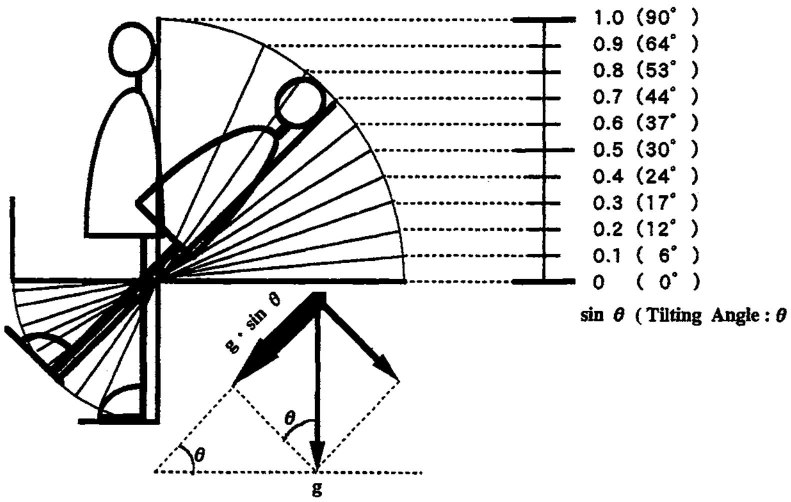

Fig. 1. Gradual decremental head-up tilting was performed at 0.1 interval of sine function of tilting angle from upright position (90°) to supine position (0°). Sine function of the tilting angle indicates the body axis component of gravity.

nerve activity[1-4] which is to increase in heart rate, stroke volume, and peripheral vasoconstriction. This assumption has proved quantitatively in vasoconstrictor responses in human by direct measurement of the peripheral sympathetic vasoconstrictor nerve activity which is called muscle sympathetic nerve activity (MSA)[1,2]. However, it has so far poorly proved quantitatively in the cardiac sympathetic and vagal nerve activity.

In the present study, we observe the cardiac sympathetic and parasympathetic tone through quantitative power spectral analysis of heart rate variability during head-up tilting.

SUBJECTS AND METHODS

1. Subjects. Eight healthy female volunteers aged from 20 to 24 were studied. All were normotensive (mean blood pressure 75.8±3.3 mmHg). None took any medication, or used tobacco products. All subjects were instructed not to ingest caffeine or alcohol for at least 12h prior. Informed consent was obtained from all subjects.

2. Protocol. All studies were carried out between 4 pm and 7 pm in a quiet warm room. Prior to the experiment, ECG electrodes were applied to the chest (lead CM5 and NASA) and continuous ECG signals were recorded on a Holter ECG recorder SM30 (Fukuda Denshi Co., Tokyo, Japan). After 15 minutes quiet period in the supine position, decremental head-up tilting was performed at 0.1 interval of sine function of tilting angle from upright position to supine position using an electrically driven tilt table (Fig. 1). In each position, initially subjects remained at rest for 3 minutes to permit their cardiovascular baroreflex mechanisms to achieve steady state[5]. For the next 5 minutes, subjects were asked to breath at a steady rate more than 0.2 Hz[6].

3. Data analysis. ECG signals were played back, and analog to digital conversion was performed at 8 bit 125 Hz, and R-R interval measurements were converted to a heart rate time series using data processa DMW-9000H (Fukuda Denshi Co., Tokyo, Japan). A artifact-free 256-sec series R-R segments during controlled respiratory periods in each position were selected for spectral analysis. The power spectrum of fluctuations in selected R-R segments was computed by means of the autoregressive model program[7] and was integrated into it's two major components ; a high frequency component (HF), from 0.15 to 0.40 Hz, and a low frequency component (LF), from 0.04

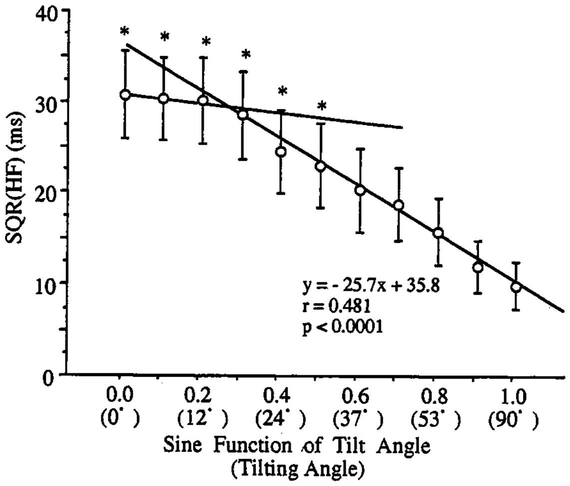

Fig. 2. Correlation between the sine of the tilting angle and the square root of high frequency power in 8 subjects

SQR (HF) = square root of high frequency power
Results are expressed as mean ± S.E.. The SQR (HF) showed linear correlation to the sine of tilting angle from 0.3 (17°) to 1.0 (90°). In the tilting angle 17° and less, it showed little decrements.
Asterisks denote significant increments above upright (90°) position.

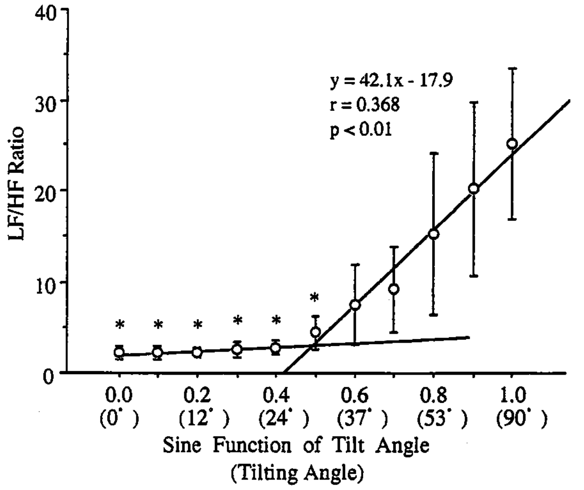

Fig. 3. Correlation between the sine of tilting angle and the ratio of low-to high-frequency power in 8 subjects

LF/HF ratio = ratio of low-to high-frequency power
Results are expressed as mean ± S.E.. The LF/HF ratio showed linear correlation to the sine of tilting angle from 0.5 (30°) to 1.0 (90°). In contrast, during low tilt angle range, it showed no correlation or remained unchanged.
Asterisks denote significant decrements under upright (90°) position.

to 0.15 Hz[8]. The square root of high frequency power (SQR (HF)), reflecting mostly cardiac vagal activity[6], and the ratio of low-to high-frequency power (LF/HF ratio), as a marker of sympathetic activity[9] were calculated.

4. Statistics. Results are expressed as mean ± S.E.M.. We used one-way analysis of variance to assess the differences among the tilting angles, and mean differences were assessed with Fisher's PLSD test. Correlations between the dependent and the independent variables were analyzed by simple linear regression. P values below 0.05 was assumed to indicate statistical significance.

RESULTS

1. Responses of the square root of high frequency power to the head-up tilting The SQR (HF) increase in a nearly linear fashion from 9.9±2.6 ms at 90° to 28.5±4.8 ms at 17°. Then, over high tilt angle between 90° and 17°, the SQR (HF) showed significant linear correlation to the sine of tilting angle. In contrast, in the tilting angle 17° and less, the SQR (HF) showed no significant change (Fig. 2). This two-phase response of the SQR (HF) was seen in the 7 of 8 subjects. However one exception showed nearly linear fashion in all tilt angle between 90° and 0°.

2. Responses of the low-to high-frequency power ratio to the head-up tilting The LF/HF ratio fell from 25.2±8.3 at 90° to 4.6±1.8 at 30°, and showed significant linear correlation to the sine of tilting angle at high tilt angle between 90° and 30°. In contrast, at the tilting angle less than 30°, the LF/HF ratio showed no significant change (Fig. 3). This two-phase response of the LF/HF ratio was seen in all subjects.

DISCUSSION

The gravity that works on the body on tilting bed can be divided into two components. The body axis component of gravity, which pull body fluid toward the foot direction, is indicated as a sine function of tilting angle (Fig. 1). So, we designed our tilt protocol of the same interval of sine function of tilt angle with the aim to elicit a number of consecutive increment in the circulatory load of about equal size[1,2].

Previous reports of Iwase et al[2]., concerning the relation between the MSA burst rate and the sine of tilting angle, have shown that the MSA has a linear function to the sine of tilting angle between 0° and 90°. These results suggested that the peripheral sympathetic vasoconstrictor nerve activity is activated proportionally to an increase in the body axis component of gravity from the small angle range of tilting. In addition, this may indicated that low pressure baroreceptors, a relative low threshold characteristics of baroreceptor, might play a role in vasoconstrictor which exerts a main influence on the MSA.

In the present study, both the SQR (HF), specific index of cardiac parasympathetic tone, and the LF/HF ratio, marker of cardiac sympathetic tone showed two-phase response to the sine of tilting angle. Although the direction was opposite, during high tilt angle, both cardiac sympathetic and parasympathetic tone showed close correlation between the sine of tilting angle. On the other hand, during low tilt angle, both cardiac autonomic nerve activity remained unchanged. These our findings gave us information concerning a relative high threshold characteristics of baroreceptor which exerts a main influence on heart rate variability during head-up tilting.

These different responses between vasoconstrictor nerve activity and cardiac autonomic nerve activity to the change in the body axis component of gravity might be originated in different baroreceptor reflex which exerts a major influence on each of them at least during low tilt angle. If low pressure baroreceptors also play a role in cardiac autonomic nerve activity responses to venous pooling from low tilt angle, the SQR (HF) and LF/HF ratio would show significant linear correlation to the sine of tilting angle from low tilting angle.

As a results of measurement by Izzo et al[3]., the change in carotid sinus mean arterial pressure from upright to supine is equal to 32 mmHg. This hydrostatic pressure change is nearly equivalent to 3.2 mmHg/0.1 (sine function of tilting angle) in our study. If we apply this manner to our results, the onset of close correlation between the sine of tilting angle and the LF/HF ratio corresponds to about 16 mmHg. Therefore, the threshold of baroreflexes which exert the cardiac sympathetic nerve activity corresponds to about 16 mmHg reduction of hydrostatic pressure at carotid sinus.

Zoller et al[10]. and Johnson et al[11]. found that low levels of lower body negative pressure (LBNP −5 and −10 mmHg) can significantly decrease forearm vascular conductance without significant change in aortic mean pressure and heart rate. However, in high level of venous pooling (LBNP −20 and −40 mmHg), significant decrease in arterial pressure and increase in heart rate accompanied the further reduction in central venous pressure and forearm blood flow.

It appears that mild reduction of venous return produced by LBNP at −5 and −10 mmHg can activate only cardiopulmonary baroreceptor reflex and increase the peripheral vasoconstriction without stimulation of arterial baroreceptor or enhancement of cardiac sympathetic tone. Whereas, high level reduction of venous return produced by LBNP at −20 and −40 mmHg can elicit both of the low and high pressure baroreceptor reflexes, and stimulation of not only the sympathetic vasoconstrictor nerve activity but cardiac sympathetic nerve activity. The findings of us agree with those of Zoller et al[10]. and Johnson et al[11]. It has been shown that aortic blood pressure began to fall at about −20 mmHg of lower body negative pressure[10,11], which support our results of a relative high threshold of arterial baroreceptors. Thus, our findings suggested quantitatively that aortic baroreceptor reflexes might play a major role in the cardiac sympathetic and vagal nerve activity during head-up tilting.

CONCLUSIONS

We have demonstrated biphasic responses of the cardiac sympathetic and vagal nerve activity to the change in the body axis component of gravity and suggested that the cardiac autonomic nervous response to postural adaptation is dependent more on the arterial baroreflexes than the cardiopulmonary baroreflex.

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Head-up Tiltingにおける心臓自律神経活動への動脈圧受容体の影響

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要　　旨

Head-up tilting時の体軸方向成分の重力変化に対して，心臓交感神経および副交感神経活動がどのように反応するかを，健常若年女性８名のdecremental head-up tilting (90°, 64°, 53°, 44°, 37°, 30°, 24°, 17°, 12°, 6°, 0°) 時の心拍変動パワースペクトル分析から評価した。

健常若年女性８名 (23.3±0.8歳，平均±標準偏差) を対象とした。心電図は，実験中胸部双極誘導を連続的に記録した。ベッドの傾斜は、$\Delta \sin\theta$が0.1きざみとなるようにし，立位 (90°) から臥位 (0°) まで倒していった。心臓交感神経および副交感神経活動の評価は，心拍変動周波数領域の低周波数 (0.08 Hzから0.15 Hz, LF) および高周波数 (0.15 Hzから0.40 Hz, HF) 帯域成分のパワースペクトル分析により行った。

心臓副交感神経活動の特異的指標である，高周波数成分パワーの平方根値は，傾斜角度が90°から17°の区間でほぼ直線的に9.9 msから28.5 msに増加を示し，17°以下ではほぼ一定値を示した。心臓交感神経活動指標である，低周波数成分パワーと高周波数成分パワーの比は，90°での25.2から30°での4.6へと低下し，その後30°から0°までは変化しなかった。方向性こそ逆向きではあるが，心臓交感神経および副交感神経活動は，高傾斜角区間では傾斜角の正弦値と有意の相関を示した。一方，低傾斜角区間では，両心臓自律神経活動ともほぼ一定で傾斜角の正弦値と相関しなかった。

以上から，Head-up tilting時に心拍変動への主な影響を及ぼす圧受容器反射は，相対的に高い閾値を持つことがわかり，それゆえ動脈圧受容器反射が体位変換時の心臓自律神経活動の適応反応に主に関与していることが示唆された。