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Left Recumbent Position Decreases Heart Rate without Alterations in Cardiac Autonomic Nervous System Activity in Healthy Young Adults

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Some studies have reported that recumbent position may have advantages in patients with heart disease and in pregnancy. However, it remains controversial whether recumbent position affects autonomic nervous system activity and hemodynamics in healthy adults. The aim of this study was to evaluate alterations in heart rate variability (HRV) and hemodynamics in the supine, left recumbent and right recumbent positions in healthy young adults. A total of 80 participants aged 22.8 ± 3.1 years were enrolled in this observational study. Fifty-eight volunteers (29 men and 29 women) maintained the supine position followed by the left and right recumbent positions, while electrocardiographic data were recorded for spectral analysis of HRV to assess cardiac vagal nerve and sympathetic nerve activities. The heart rate (HR) was significantly lower in the left recumbent position than in the other positions. There were no statistically significant differences in HRV among the three positions. Considering the possibility that the echographic procedure affects autonomic nervous system (ANS) activity, the other 22 participants (11 men and 11 women) underwent an echographic evaluation of hemodynamics in the heart and inferior vena cava (IVC) across the three positions. Although a low HR was also observed, there were no statistically significant differences in the IVC or the heart blood volume between the supine and the left recumbent positions. A postural change to the left recumbent position does not affect the cardiac blood circulation or ANS activity, though it does decrease HR in healthy young adults. This finding indicates that the lower HR in the left recumbent position is not attributable to the ANS activity.

Keywords: autonomic nervous system activity; heart rate; heart rate variability; hemodynamics; recumbent position
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Introduction

The cardiovascular system regulates the heart rate (HR) and arterial blood pressure in response to physiological and environmental changes, which involves regulation by the autonomic nervous system (ANS). To evaluate the ANS activity, spectral analysis of heart rate variability (HRV) has been used as a quantitative and noninvasive methodology since the 1990s (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology 1996). HRV represents the sequential fluctuations in the duration of R-R intervals on electrocardiogram (ECG) that are caused by the levels of autonomic neural input to the sinoatrial node on the right atrium (Xhyheri et al. 2012). HRV has two main components, namely low frequency (LF) and high frequency (HF) fluctuations. In particular, the HF component of HRV corresponds to cardiac vagal nerve activity at the sinus node, since atropine, a competitive muscarinic acetylcholine receptor antagonist, diminishes most of that component (Hayano et al. 1991; Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology 1996). The ratio of LF to HF (LF/HF) is associated with sympathetic nerve activity, as LF/HF increases in the standing position compared to the supine position (Pomeranz et al. 1985).

Using the above-mentioned method, some researchers have reported that the right recumbent position may enhance cardiac vagal nerve activity in patients with coronary artery disease or acute myocardial infarction (Kuo et al. 2000; Fujita et al. 2000; Miyamoto et al. 2001; Yang et al. 2008). This finding implies that lying on the right side may have advantages in patients with heart disease, because an increase in cardiac vagal nerve activity could lead to a reduction in myocardial oxygen consumption and a decrease in the possibility of serious ventricular arrhyth-

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mias (Grauer et al. 1973; Kuo et al. 2000). In addition, Miyamoto et al. (2002) found that plasma norepinephrine concentrations in patients with chronic congestive heart failure were lower in the right recumbent position than in the left recumbent and supine positions. They suggested that this finding may be related to a withdrawal of sympathetic stimulus from aortic baroreceptors in the right recumbent position, as a result of increased blood pressure following increased venous return. Preference for the right recumbent position has been empirically observed during sleep (Fujita et al. 2002; Leung et al. 2003), and is associated with predominant right-sided pleural effusion in patients with heart failure (De Araujo et al. 2012).

Other than patients with heart disease, laterality has also been recognized in late pregnancy (Kuo et al. 1997; Matsuo et al. 2007) and patients with systemic lupus erythematosus (Huang et al. 2008). In late pregnancy, cardiac sympathetic nerve activity is suppressed and cardiac vagal nerve activity is enhanced in the left recumbent position as a result of the release of aortocaval compression. In patients with systemic lupus erythematosus, the right recumbent position can lead to higher vagal modulation and lower sympathetic modulation, which is similar to some reports in patients with heart disease (Kuo et al. 2000; Fujita et al. 2000; Miyamoto et al. 2001; Yang et al. 2008).

However, whether the recumbent position affects cardiac ANS activity and hemodynamics in healthy adults is still controversial. In one study, cardiac vagal nerve activity in 28 healthy volunteers was found to be highest in the right recumbent position, lower in the left recumbent position, and lowest in the supine position (Chen and Kuo 1997), whereas in another, seven healthy adults did not exhibit higher vagal modulation when lying in the right recumbent position (Kalisnik et al. 2001). A large sample size may be required to fully elucidate the effect of the recumbent position on the ANS activity. Therefore, our aim in the present study was to investigate alterations in HRV and hemodynamics during the left and right recumbent positions compared to the supine position in healthy adults. If recumbent positions have beneficial effects on the ANS, the medical staff should apply the positions to postural change for patients who have an imbalance of ANS activity with an increased sympathetic nerve activity and reduced parasympathetic nerve activity in clinical practice.

Methods

Heart rate variability study of supine, left recumbent and right recumbent positions

Fifty-eight healthy young volunteers participated in the HRV study. All volunteers were recruited from a university and their medical condition was evaluated during an interview by a researcher. Twenty-nine of the 58 were women who had regular menstrual cycles. Exclusion criteria were as follows: past or current smoking, any history of respiratory or cardiovascular disease, hypertension, diabetes, dyslipidemia, neurological disorder, regular use of drugs that affect ANS regulation. Two volunteers who had a medical history of ventricular septal defect or congenital oligonephropathy were excluded from this study. Written informed consent was obtained from all participants, and the study was approved by the Ethics Committee of the Tohoku University Graduate School of Medicine (2010-173).

Experimental protocol

The ANS activity in the supine and recumbent positions was evaluated in all 58 volunteers. Data recordings were carried out in an air-conditioned quiet laboratory at an ambient temperature of 25 ± 2°C and humidity of 50 ± 5% between 10:00 and 17:00 on one day, to minimize the effect of the circadian rhythm on the ANS (Bilan et al. 2005). All 29 women were monitored once in the early follicular phase, defined as the first or second day after the menstrual phase based on the self-reported menstrual cycle, to avoid the influence of sex hormone levels on HRV (Tenan et al. 2014). All volunteers were asked to refrain from drinking alcohol and caffeinated beverages for at least 12 h prior to data collection. They were also required to have more than 7 h of sleep the night before and to fast for at least 2 h before the experiment (Lovallo et al. 2006).

The participants were fitted with four ECG electrodes in the anterior and lateral thoracic regions on both sides and lay quietly on a bed in the supine position for 5 min of rest for stabilization. They then were asked to maintain left or right recumbent positions at an angle of approximately 45° for 10 min, after remaining in the supine position for 10 min. The left and right recumbent positions were adopted in random order to exclude bias (Fig. 1). In healthy young adults, the lower limit of the 95% confidence interval of sleep latency is approximately 20 min (Littner et al. 2005), indicating that the maintenance of same position at rest for about 20 min could cause volunteers to fall asleep. The choice of 10 min of recording for each position was made to avoid the influence of sleep on the HRV (Tsunoda et al. 2001) while securing sufficient data for the analysis (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology 1996). Postural change was performed manually by two trained researchers. To maintain the recumbent positions, two pillows were inserted under the volunteer's back (Fig. 1). During the recording, they were asked to breathe spontaneously and to relax as much as possible with open eyes.

The ECG was recorded continuously using a portable ECG monitor (Radarcirc™; Sumitomo Dainippon Pharma Co., Ltd., Osaka, Japan) throughout the experiment. Since this monitor is not sensitive to various body movements or noise (Shimpuku et al. 2010), there was no risk of any artifact and it enabled us to measure ECG data precisely during the postural changes and in each position. The respiratory rate was measured visually across the three positions because a respiratory rate of < 9 cycles/min may lead to alterations in HRV (Patwardhan et al. 1995; Sasaki and Maruyama 2014).

Spectral analysis of heart rate variability

The sampling frequency for ECG signals was 1,000 Hz, and the data were stored on a personal computer after analog-to-digital conversion. The peak of the R wave in the recorded electrocardiographic signals was identified and the consecutive R-R intervals were measured. Sinus pause and atrial or ventricular arrhythmia were deleted. If the percentage of deletion was over 5%, the participant was excluded from further analysis. In addition, if a respiratory rate < 9 cycle/min was recognized, further analysis was not performed

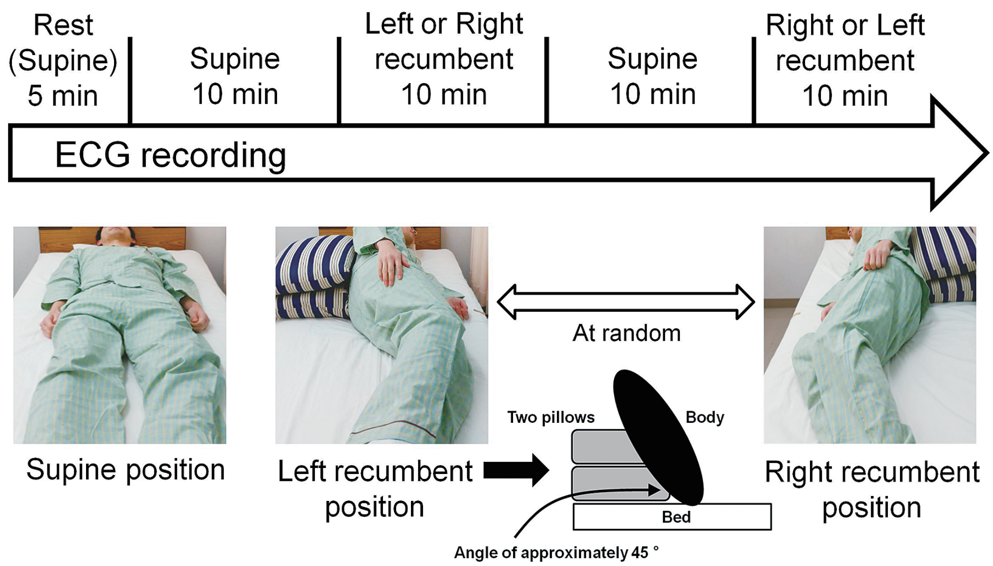

Fig. 1. Experimental protocol.
Body positioning in the left and right recumbent positions at an angle of approximately 45° was selected in random order after the subject had been in the supine position.

(Patwardhan et al. 1995; Sasaki and Maruyama 2014). The power spectral analysis was performed off-line with continuous wavelet transformation using Fluclet™ WT Ver. 4.0 (Dainippon Sumitomo Pharmaceutical Co., Ltd.). We obtained the LF and HF components as the area under the power spectral curve between 0.04 and 0.15 Hz and between 0.15 and 0.40 Hz, respectively. In general, the HF component represents cardiac parasympathetic nerve activity at the sinus node, while the LF component probably reflects both sympathetic and parasympathetic modulation of the R-R interval (Hayano et al. 1991; Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology 1996). In this study, to estimate the ANS activity in the heart, we used the HF component as an index of cardiac vagal nerve activity and the ratio of the LF component to the HF component (LF/HF) as an index of sympathetic nerve activity (Pomeranz et al. 1985). The reliability of HRV using spectral analysis has been described in a previous report (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology 1996).

Echographic study of supine, left recumbent and right recumbent positions

To investigate the cardiovascular alterations in three positions and eliminate the possibility that an echographic procedure could affect the ANS activity, another 22 healthy young participants were recruited for the echographic study. Exclusion criteria and the other experimental conditions were the same as described above in the HRV study. These participants underwent echographic evaluation of hemodynamics in the heart and the inferior vena cava (IVC), using an ultrasound device (iE33; Royal Philips, Amsterdam, Netherlands) with a 3.5 MHz probe, in the supine, left, and right recumbent positions, after 5 min of rest on a bed in the supine position for stabilization. The order of the recumbent positions was chosen at random. Two skilled sonographers of both sexes, who evaluated cardiac function especially in patients with cardiac diseases in clinical practice on a daily basis, measured all parameters including left ventricular end-systolic (LVDs) and end-diastolic (LVDd) dimensions, stroke volume (SV), cardiac output (CO), peak flow velocity during the rapid passive filling phase (E), peak flow velocity during atrial contraction (A), the ratio of E to A (E/A), and deceleration time using the parasternal or apical long-axis view and pulsed Doppler, according to the recommendations of the Japanese Society of Echocardiography. In particular, E and E/A appear to reflect left ventricular preload and diastolic function, respectively (Stoddard et al. 1989). Considering that a decrease in preload in the left ventricle has been observed in the right recumbent position in patients with congestive heart failure (Berensztein et al. 1996) and could be related to changes in the ANS activity with body positioning, it was considered to be important to assess the left ventricular preload and diastolic function in the supine, left recumbent and right recumbent positions in this echographic study.

Since venous return is associated with preload and its volume is largely due to blood volume from the lower limbs to the right atrium, we monitored the shape and hemodynamics in the IVC during expiration. The IVC diameter was determined in the long- and short-axis subxiphoid views 1 cm distal to the hepatic vein. The cross-sectional area of the IVC was calculated from the short and long axes. With regard to circulatory dynamics in the IVC, the following parameters were measured in each position with pulsed Doppler imaging in the long-axis view: mean blood flow velocity, maximal blood flow velocity, time velocity integral (TVI), and blood volume in the IVC, which was calculated as the product of the cross-sectional area and TVI. The values from at least three beats were averaged and recorded during expiration.

Statistical analysis

In the HRV study, to detect a 30 ms^2/Hz difference in HF between the supine and recumbent positions at an alpha error level of 0.05 and power of 80%, the power calculation indicated that the necessary sample size was at least 54 participants; the number of our volunteers who participated in the evaluation of the ANS activity was considered appropriate. For the echographic study, the necessary sample size was calculated to be at least 18 participants to detect a 3 beats per minute (bpm) difference in HR between the supine and recumbent positions at an alpha error level of 0.05 and power of 80%. All measurements, including HR, LF, HF, LF/HF, and circulatory parameters, were averaged for each position and are represented as mean ± standard error of the mean (SE). All data analysis was performed with SPSS 21.0 software (SPSS Inc., Chicago, IL, USA). All parameters of both sexes were combined, because there was no statistical significance in sex difference concerning alterations in HRV and hemodynamics among three positions. Normality was tested using the Kolmogorov-Smirnov test. A Friedman test was used to compare LF, HF, and LF/HF. All data except HRV were compared using repeated measures analysis of variance and the Bonferroni post hoc multiple comparison test. A value of $p < 0.05$ was considered to be statistically significant.

Results

A total of 80 healthy young adults aged 22.8 ± 3.1 years (mean ± standard deviation), 40 males and 40 females, were finally included in this study. The characteristics of the participants in the heart rate variability and echographic studies are depicted in Table 1. There was no significant difference between the two populations.

Heart rate, heart rate variability, and respiration in the supine and recumbent positions

HR in the supine, left recumbent, and right recumbent positions was 64.7 ± 1.1 bpm, 61.5 ± 0.9 bpm, and 63.1 ± 1.0 bpm, respectively. HR was significantly lower in the left recumbent position compared to the other positions (Fig. 2). As for temporal changes in HR, a low HR was maintained in the left recumbent position throughout the 10-min measurement (Fig. 3). Similarly, in the echographic evaluation, a statistically significant decrease in HR was observed in the left recumbent position (Table 3). Table 2 shows the effects of each position on HRV and respiratory rate in 58 healthy young volunteers. There were no significant changes in LF, HF, or LF/HF. No statistically significant difference was found in respiratory rate across the three positions.

Hemodynamics in the heart and inferior vena cava in the supine and recumbent positions

Table 3 shows the effects of each position on circulatory dynamics in the heart and IVC in 22 healthy young volunteers. LVDd was significantly higher in the left recumbent position than in the other positions and was accompanied by a decreased HR. Although a significant decline in HR and a significant increase in LVDd were observed, SV and CO were almost unchanged between the supine and the left recumbent positions. In contrast, SV and CO decreased significantly in the right recumbent position compared to the supine position, even though HR did not change.

To clarify the influence of the three positions on the venous return to the heart, we evaluated hemodynamics in the IVC. Compared to the supine position, the cross-sectional area of the IVC was significantly higher in the right recumbent position and significantly lower in the left recumbent position (Table 3). The shape of the IVC in the

Table 1. Characteristics of volunteers who participated in HRV and *echographic studies.*

	Total of 80 healthy adults		
	HRV study	Echographic study	p value
n	58	22	
Age (years)	23.0 ± 3.2 (20–39)	22.3 ± 3.0 (18–30)	0.38
Male / Female (n)	29 / 29	11 / 11	1.00
Height (cm)	166.3 ± 7.9	166.5 ± 8.6	0.91
Body weight (kg)	56.4 ± 8.7	55.5 ± 8.0	0.67
BMI (kg/m^2)	20.3 ± 2.1	19.9 ± 1.6	0.39
Systolic BP (mmHg)	111.5 ± 10.4	115.6 ± 12.0	0.17
Diastolic BP (mmHg)	61.3 ± 6.5	62.6 ± 9.7	0.57

Values are expressed as mean ± standard deviation (Minimum-Maximum).
Statistical analysis to compare the two populations was performed using Welch's t-test for basic characteristics.
BMI, body mass index; BP, blood pressure; HRV, heart rate variability.

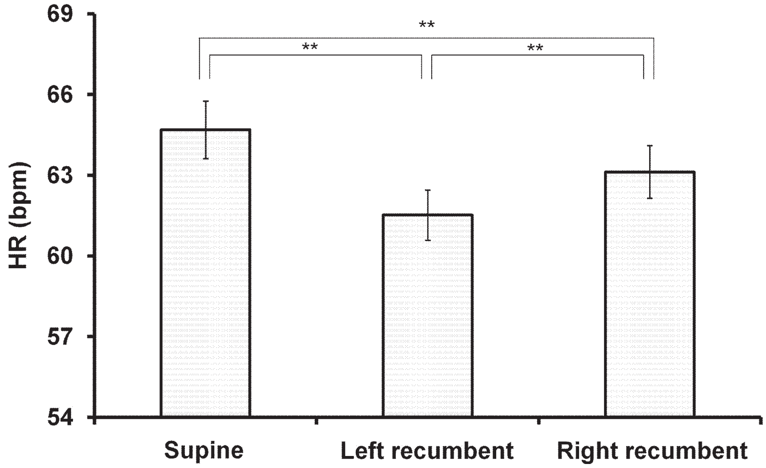

Fig. 2. Heart rate among three positions in 58 healthy young adults who participated in HRV study.
Mean ± standard error of the mean.
**$p < 0.01$, the position vs. the other positions using multiple comparisons, Bonferroni method.
HR, heart rate; bpm, beats per minute; Left recumbent, left recumbent position; Right recumbent, right recumbent position.

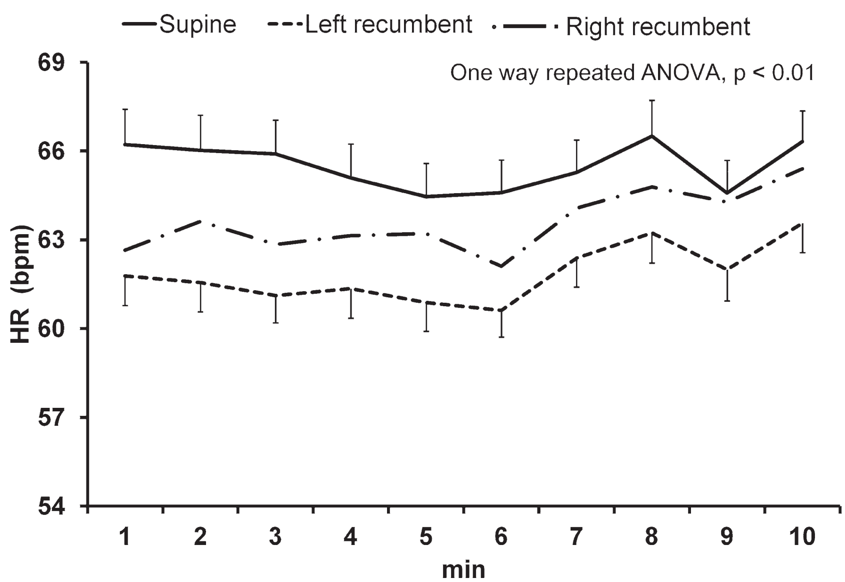

Fig. 3. Temporal changes in heart rate among three positions in 58 healthy young adults.
The upper, middle, and lower lines indicate the HR in the supine position, right recumbent position, and left recumbent position, respectively. Mean ± standard error of the mean.
HR, heart rate; bpm, beats per minute; Left recumbent, left recumbent position; Right recumbent, right recumbent position.
$p < 0.01$, using one-way repeated measures analysis of variance among three positions.

supine position appeared to be oval. In the left and right recumbent positions, it resembled a plane and a circle, respectively (Fig. 4). Mean and maximal blood flow velocity in the IVC was significantly faster in the left recumbent position and slower in the right recumbent position compared to the supine position, matching the variation in the shape of IVC. However, no statistically significant changes in blood volume in the IVC as venous return, E as preload or E/A as the diastolic function in the left ventricle were observed across the three positions.

Discussion

Recumbent positions may have beneficial effects in patients with heart disease, although the effects of the recumbent position on the ANS activity and hemodynamics have not yet been well clarified in healthy adults. We non-invasively evaluated alterations in HRV, using quantitative spectral analysis, and hemodynamics, using ultrasonography, in the supine, left recumbent and right recumbent positions in healthy young adults. To our knowledge, this study is the first to consider a relationship between the ANS activ-

Table 2. Heart rate variability and respiration among three positions in 58 young adults.

Young adults (n=58)	Supine	Left recumbent	Right recumbent
LF component (ms²/Hz)	193.7 ± 33.9	202.1 ± 26.7	168.8 ± 25.2
HF component (ms²/Hz)	203.5 ± 21.3	202.1 ± 22.8	183.0 ± 21.3
LF/HF ratio	1.03 ± 0.08	1.15 ± 0.10	1.14 ± 0.11
Respiratory rate (breaths/min)	15.6 ± 0.3	15.2 ± 0.3	15.6 ± 0.3

Values are expressed as mean ± standard error of the mean.
Statistical analysis across the three positions was performed using the Friedman test for heart rate variability or repeated measures analysis of variance for respiratory rate.
Left recumbent, left recumbent position; Right recumbent, right recumbent position; LF, low frequency; HF, high frequency; LF/HF ratio, the ratio of LF to HF.

Table 3. Hemodynamics in the heart and the inferior vena cava among three positions in 22 young adults.

Young adults (n=22)	Supine	Left recumbent	Right recumbent
In the heart			
HR (bpm)	64.1 ± 2.1	61.1 ± 2.0*	67.6 ± 2.4
LVDd (mm)	42.9 ± 1.0*	44.0 ± 1.0*	41.5 ± 1.1**
LVDs (mm)	28.5 ± 0.8	29.3 ± 0.9¶	28.0 ± 1.0
SV (ml)	59.1 ± 2.3	60.9 ± 2.3	50.0 ± 1.9**
CO (l/min)	3.8 ± 0.2	3.7 ± 0.2	3.3 ± 0.2*
DcT (msec)	179.2 ± 6.5	183.4 ± 4.1	176.7 ± 6.7
E (cm/sec)	85.1 ± 2.9	84.9 ± 3.2	83.8 ± 2.9
A (cm/sec)	40.2 ± 1.4	41.9 ± 1.9	45.1 ± 2.6
E/A	2.2 ± 0.1	2.1 ± 0.1	2.0 ± 0.1
In the inferior vena cava			
CSA (cm²)	2.55 ± 0.3**	1.59 ± 0.3**	4.02 ± 0.3**
Mean blood flow velocity (cm/s)	30.8 ± 2.7*	51.0 ± 6.3**	21.5 ± 1.2*
Max blood flow velocity (cm/s)	43.4 ± 4.0*	66.2 ± 6.7**	31.6 ± 1.4*
TVI (cm)	22.1 ± 2.9*	42.0 ± 6.2**	13.6 ± 1.1*
Blood volume (cm³)	55.5 ± 8.4	47.0 ± 5.4	53.3 ± 4.8

Values are expressed as mean ± standard error of the mean.
*$p < 0.05$ and **$p < 0.01$, the position vs. the other positions using multiple comparisons, Bonferroni method.
¶$p < 0.05$, the left recumbent position vs. the right recumbent position using multiple comparisons, Bonferroni method.
Left recumbent, left recumbent position; Right recumbent, right recumbent position; HR; heart rate; bpm, beats per minute; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; SV, stroke volume; CO, cardiac output; DcT, deceleration time of early mitral inflow; E, peak flow velocity during rapid passive filling phase; A, peak flow velocity during atrial contraction; E/A, the ratio of E to A; CSA, cross-sectional area; TVI, time velocity integral. Blood volume in the inferior vena cava was calculated as the product of CSA and TVI.

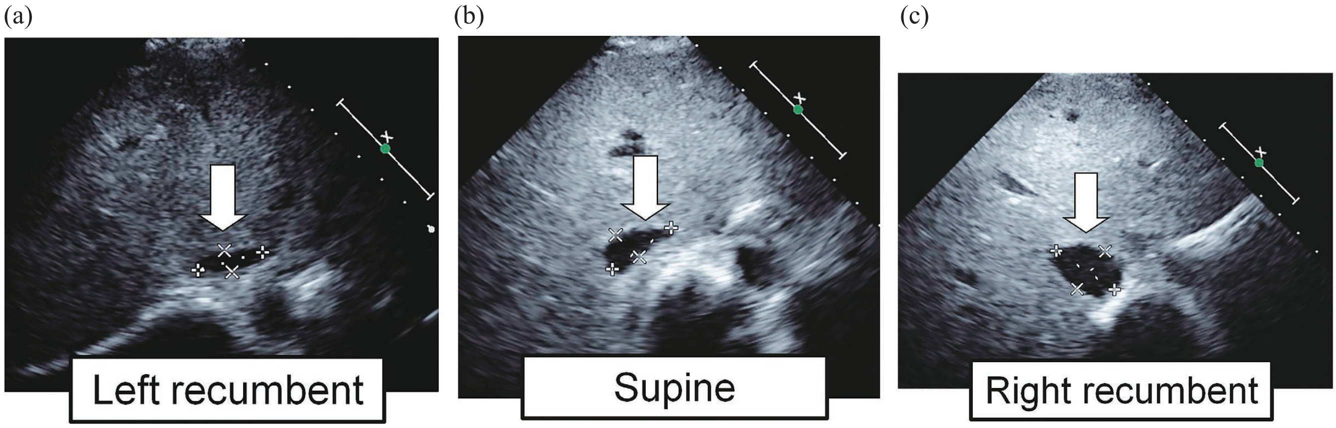

Fig. 4. Representative short-axis views of the shape of the inferior vena cava (IVC) among three positions in a 21-year-old man who participated in Echographic study.
The white arrow shows the site of IVC.
The shapes of the IVC in the supine, left recumbent and right recumbent positions appear to be oval, plane, and circle, respectively.
(a) Left recumbent position.
+-+ diameter: 2.05 cm
×-× diameter: 0.69 cm
(b) Supine position.
+-+ diameter: 2.23 cm
×-× diameter: 1.00 cm
(c) Right recumbent position.
+-+ diameter: 2.64 cm
×-× diameter: 1.76 cm

ity and circulatory dynamics across the three positions in a statistically valid healthy population.

Heart rate and heart rate variability in recumbent positions

In the present study, we demonstrated that HR decreased significantly in the left recumbent position compared to the supine and right recumbent positions. It has been well established that a brief response to changes in an internal or external environment correlates with neurogenic regulation, not hormonal regulation. Firstly, we assumed that autonomic neurogenic regulation could lead to a decline in HR when changing from the supine position to the left recumbent position since volunteers maintained the position for only 10 minutes. However, HRV between the supine and left recumbent positions was almost unchanged, which indicates that factors other than the ANS and neurohormones contribute to the phenomenon of decreased HR. Secondly, gravity may prevent the heart from enlarging in the diastolic phase. In the left recumbent position, the location of the heart within the mediastinal space is likely to be the lowest compared to the supine and right recumbent positions. In addition, compression of the lung against the heart is greater in the left recumbent position than in the supine and right recumbent positions because right lung volume is greater than left lung volume. Therefore, there is a possibility that a decrease in HR could be influenced by the anatomic position of organs, especially the positional relationship between the heart and the lung, in the left recumbent position.

The postural effect on the ANS activity in recumbent positions has been studied in patients with congestive heart failure. Some research has indicated that the right recumbent position could work as a cardiac vagal enhancer in these patients (Kuo et al. 2000; Fujita et al. 2000; Miyamoto et al. 2001; Yang et al. 2008). In addition, the lower the cardiac vagal nerve activity in the supine position, the higher the cardiac vagal nerve activity when the position was changed from the supine to the right recumbent position in patients with heart disease (Kuo et al. 2000; Yang et al. 2008). In this HRV study, we found no significant differences in HF or LF/HF between the supine position and either recumbent position in healthy young adults, which suggests that the recumbent positions have no impact on cardiac vagal or sympathetic nerve activity. The ANS activity, namely cardiac vagal nerve activity, in our healthy young volunteers could be active enough compared to that in patients with heart failure to account for these findings, since it has been well accepted that vagal nerve activity in patient with cardiac disease is depressed. Our findings are similar to the observation of Kalisnik and his associates, who reported no alteration in the ANS activity in four male and three female healthy adults aged 20 to 27 years (Kalisnik et al. 2001), although the number of participants was small.

In contrast, another report observed the highest HF and the lowest LF/HF in the right recumbent position in 28 healthy adults aged 24.7 ± 3.2 (Chen and Kuo 1997). The discrepancy between their findings and our present study might be attributed to a difference in sympathetic tone in the supine position. Sympathetic nerve activity in the previous study may have been more than in our study, since LF/HF was high: 2.80 ± 1.92 compared to 1.03 ± 0.08 in our study. During a recording period of 15 min, subjects in the previous study (Chen and Kuo 1997) were asked to relax as much as possible with closed eyes, which could lead them to fall asleep easily, calming the subject's excited sympathetic nerve activity with the progress of the experiment. In our study, to avoid drowsiness, the recording was performed with the subjects' eyes open.

In the spectral analysis of HRV, a decreased respiratory rate and/or increased tidal volume are likely to cause a rise in HF (Patwardhan et al. 1995; Sasaki and Maruyama 2014), since HF is synchronous with respiration (Badra et al. 2001). Moreover, respiratory rate probably has a greater effect than tidal volume (Hirsch and Bishop 1981). Therefore, we recorded respiratory rate across the three positions. It has been recognized that major complex changes in HRV, especially HF, occur at a rate of less than 9 breaths/min (Brown et al. 1993). In the HRV study, no change in respiratory rate across the three positions was seen and the respiratory rate was approximately 15 breaths/min; thus, we conclude that respiratory rate could not have had any abnormal effect on the spectral analysis of HRV.

Hemodynamics in the heart and inferior vena cava in recumbent positions

The cardiovascular system appropriately controls CO and arterial blood pressure. CO is not associated only with HR, myocardial contractility, peripheral vascular resistance, and blood pressure, but also with venous return. To investigate venous return in the supine, left recumbent and right recumbent positions, we recorded the circulatory dynamics in the IVC using echography in 22 healthy young adults. As far as we know, this was the first investigation of hemodynamics in the IVC during each position. Across the three positions, the shape and cross-sectional area of the IVC during expiration showed variations, such as an oval in the supine position, a plane in the left recumbent position and a circle in the right recumbent position. Compression and release of pressure by the liver against the IVC probably leads to these variations with body positioning (Nakao et al. 1987). In addition, a previous study using abdominal computed tomography in a 38-year-old man indicated that the differences in the cross-sectional area of the IVC across the three positions could be dependent on the positional relationship between the IVC and abdominal organs, especially the liver (Higashi 1988). For the blood flow velocity in the IVC, we demonstrated the fastest velocity in the left recumbent position and the slowest velocity in the right recumbent position; it is generally recognized that the blood flow velocity is inversely proportional to the cross-sectional area of the blood vessel.

Veins, also known as capacitance vessels, are able to hold about 60% of the total blood volume because their compliance is higher than that of arteries. We speculated that the compression of the IVC by the liver might be followed by a decreased venous return in the left recumbent position, although our results showed no effect of the position on blood volume in the IVC. In this study, the hemodynamics in the IVC were recorded at a site 1 cm distal to the hepatic vein, and Mookadam et al. (2011) found using echography that the blood volume returning from the liver to the heart between the supine and the left recumbent positions was almost unchanged. Therefore, these findings including our present study suggest that the left recumbent position has no influence on venous return as an index of preload. Besides, we demonstrated that there were no alterations in SV, CO, E, or E/A between the supine and the left recumbent positions. Our findings support Rossi's report, in which cardiovascular magnetic resonance failed to show any significant differences in left ventricular end-systolic or end-diastolic volumes in 5 non-pregnant women during the left recumbent position compared to the supine position (Rossi et al. 2011). Therefore, in healthy young adults, a decrease in HR in the left recumbent position could be a physiological phenomenon that is not accompanied by changes in the circulation of the blood.

There are some limitations in the present study. First, echocardiographic evaluation of circulatory dynamics in the heart during the right recumbent position is difficult. Echocardiography is usually performed in the left recumbent or supine positions. In right recumbent position, it may be difficult to show clear images of the left ventricular apex on a monitor because the left lung is pressing against the heart. Furthermore, there was potential error in the measurement of hemodynamics using echocardiography because two sonographers participated: A male and a female sonographer evaluated 11 men and the other 11 women, respectively. Inter-observer and intra-observer variability could not be investigated, although the each finding in men and women were similar. The greatest advantages to echocardiography are its noninvasiveness and safety, but its measurement depends on the skill of the sonographer. In this echographic study, both were proficient and knowledgeable concerning cardiovascular echocardiography, which should have minimized the error and the difficulty in measurement during the right recumbent position. Second, our findings should not be extrapolated to healthy elderly people because only healthy young adults were evaluated in the present study. It is well known that the ANS activity, and parasympathetic nerve activity in particular, decreases with increasing age (Antelmi et al. 2004). In addition, a preference for the right recumbent position has been observed in the elderly during their sleep (De Koninck et al. 1992). Thus, further investigation of ANS activity and cardiovascular hemodynamics during recumbent positions is required in different populations.

In conclusion, our study indicates that left and right recumbent positions have no beneficial effects on the ANS in healthy young adults, since HRV was almost unchanged between the supine and either recumbent position. Postural change from the supine to the left recumbent position does not affect the circulation of the blood in the heart, although it does decrease HR. This finding suggests that a decrease in HR in the left recumbent position is not caused by the ANS activity.

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Conflict of Interest

The authors declare no conflict of interest.

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