Comparison of Effect of 5 Recumbent Positions on Autonomic Nervous Modulation in Patients With Coronary Artery Disease

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Background This study compared the effect of 5 recumbent positions on cardiac autonomic nervous modulation in patients with coronary artery disease (CAD).

Methods and Results Spectral heart rate variability analysis was performed on 33 CAD patients and 17 patients with patent coronary arteries in random order in 5 positions; namely, supine, right lateral decubitus, left lateral decubitus, left prone and right prone positions. In the right lateral decubitus position, the vagal modulation was the highest and the sympathetic modulation was the lowest among the 5 recumbent positions in the control group. In the CAD patients, the vagal modulation in the supine position was significantly lower than that in the other 4 positions. The lower the normalized high-frequency power (nHFP) in the supine position, the larger the percent age increase in nHFP when the position was changed from supine to another recumbent position in both CAD patients and controls. There was no significant change in the respiratory rate when the position was changed from supine to any of the other 4 positions.

Conclusions Right lateral decubitus position leads to the highest vagal modulation in the controls, whereas the supine position leads to the lowest vagal modulation in the CAD patients. In addition to the right lateral decubitus position, both the right and left prone positions can be used as a vagal enhancer in patients with CAD as compared with supine, especially for those patients who have severely reduced cardiac vagal modulation while supine. (Circ J 2008; 72: 902–908)

Key Words: Autonomic nervous system; Coronary artery disease; Heart rate variability; Recumbence; Vagal modulation

It has been reported that cardiac vagal modulation is impaired in patients with coronary artery disease (CAD), and that the reduction in the cardiac vagal modulation correlates with the angiographic severity of the changes in the coronary arteries.^{1,2} In patients with CAD or congestive heart failure (CHF) or both, the short-term heart rate variability (HRV) is significantly lower in those with inducible ventricular tachycardia than in those without clinical or electrocardiographic (ECG) evidence of ventricular tachycardia; and the probability of developing sudden death increases substantially when short-term HRV decreases below 50 ms.³ It has also been shown that the very-low-frequency power (VLFP) of HRV is an independent risk predictor in patients with CHF.⁴ In addition, vagal enhancement has been shown to have an antiarrhythmic effect in acute ischemic animal

models,^{5,6} and can terminate ventricular tachycardia in humans.⁷ Therefore, any method that can increase cardiac vagal modulation may be beneficial to patients with CAD, and any factor that can lead to impaired cardiac vagal modulation is better avoided by patients with CAD.

Among the supine, left lateral or right lateral decubitus positions, the right lateral decubitus position leads to the highest vagal modulation in patients with CAD;^{8,9} and induces the greatest increase in the complexity of the human physiological system and the vagal modulation of the cardiac autonomic nervous system.¹⁰ Moreover, patients with chronic heart failure because of CAD prefer the right lateral decubitus position for significantly longer periods of time than either the left lateral decubitus or supine position, because the sympathetic nervous modulation is most attenuated in this position.^{11,12}

Modern medical research has found that the prone position can improve the arterial oxygen tension in acute lung injury (ALI) and acute respiratory distress syndrome (ARDS),^{13–18} and is one of the suitable positions used during general or spinal anesthesia.^{19,20} ALI and ARDS are severe clinical conditions that are associated with severe oxygenation failure and very high mortality rate. If the prone position can be used to treat the hypoxemia in ALI and ARDS, it may also be used to improve body function in other kinds of diseases and even in healthy people.

Because the prone position may be taken by CAD patients during sleep, it is necessary to include it in a comparison of the effect of recumbent positions on the cardiac autonomic nervous modulation of these patients. Thus, the aim of this study was to compare the effect of 5 recumbent posi-

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Table 1 Baseline Characteristics of the Control and CAD Groups

	Control group (n=17)	CAD group (n=33)	p value
<i>Baseline</i>			
Age (years)	61.8 (12.0)	67.0 (10.8)	0.132
Height (cm)	160.9 (8.0)	161.8 (8.6)	0.854
Weight (kg)	65.1 (12.4)	66.6 (10.7)	0.937
Gender (M/F)	9/8	25/8	0.187
<i>History</i>			
Previous MI	0	17	NA
Hypertension	12	18	0.428
Diabetes mellitus	2	9	0.292
Hyperlipidemia	9	13	0.540
<i>Medications</i>			
-blockers	12	14	0.112
Calcium-channel blocker	6	14	0.855
ACE inhibitors	2	12	0.099
Angiotensin II antagonists	6	4	0.070
Digitalis	1	5	0.650
Aspirin	17	21	0.004
Nitrates	15	29	1.000
<i>No. of diseased coronary arteries</i>			
1	0	10	NA
2	0	4	NA
3	0	19	NA
Left main disease	0	2	NA
Serum potassium	4.1 (0.4)	4.2 (0.5)	0.915

Data are no. of patients and continuous variables are mean (SD); p-values were obtained by chi-square test.

CAD, coronary artery disease; MI, myocardial infarction; NA, not assessed; ACE, angiotensin-converting enzyme.

tions on cardiac autonomic nervous modulation in patients with CAD.

Methods

Subjects

Coronary arteriography was performed in patients with angina pectoris, unstable angina, previous myocardial infarction (MI), or other evidence of myocardial ischemia, and from these we recruited patients for spectral HRV analysis. Patients who had atrial fibrillation, coexisting valvular heart diseases, or were using class I anti-arrhythmic medication were excluded.

The angiograms were interpreted by a panel of cardiologists who were unaware of the results of spectral HRV analysis. The coronary arteries and branches were divided into 15 segments according to the Ad Hoc Committee for Grading of Coronary Artery Disease of the American Heart Association.²¹ Only luminal narrowing in the following segments was used in the final assessment: segments 1–3 for the right coronary artery, segments 6 and 7 for the left anterior descending branch, segments 11 and 12 for the circumflex branch, and segment 5 for the left main coronary artery. By confining the analysis to these segments, only those patients who had significant obstruction in the main epicardial coronary arteries were included in the study. Stenosis was considered to be significant if luminal narrowing >50% was present.^{22,23} Patients without stenosis or with luminal narrowing <30% were classified as the angiographically patent coronary artery group. The experiments were conducted with the understanding and consent of each subject, after the institutional review board of the hospital had approved the experiment. The study protocol also conformed to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in the a priori approval by the institution's human research committee.

Spectral HRV Analysis

All subjects were instructed not to drink caffeinated or alcoholic beverages for at least 24 h before ECG recording. The patients were requested to assume 5 recumbent positions in random order; namely, the supine, right lateral decubitus, left lateral decubitus, right prone (right flank against the bed with the head turned to the left), and left prone (left flank against the bed with the head turned to the right) positions. After resting for 5 min in each position, the bedside ECG monitor (Model 9062 IA, Spacelabs Inc, Redmond, WA, USA) recorded the trend of ECG signals for 15 min. The signals were simultaneously transmitted to a personal computer for storage and later analysis. The sampling frequency for the ECG signals was 200 Hz. If the patients had chest discomfort or hemodynamic instability, the ECG recording was discontinued.

Consecutive RR intervals were measured using the software for the detection of R waves. Sinus pause and atrial or ventricular arrhythmias were deleted, and the last 512 stationary RR intervals in each recumbent position were obtained for spectral HRV analysis. If the percentage of deletion was ≥5%, the patient was excluded from the study.

The power spectra of the last 512 RR intervals were obtained by means of fast Fourier transformation (Mathcad 11, Mathsoft Inc, Cambridge, MA, USA). The direct current component was excluded before the calculation of the power spectrum in order to remove the non-harmonic components in the VLFP region.²⁴ The area under the spectral peaks within the range of 0.01–0.40 Hz, 0.01–0.04 Hz, 0.04–0.15 Hz, and 0.15–0.40 Hz was defined as the total power (TP), VLFP, low-frequency power (LFP), and high-frequency power (HFP), respectively. The normalized HFP (nHFP=100×HFP/TP) was used as the index of vagal modulation; the normalized LFP (nLFP=100×LFP/TP) as the index of vagal and sympathetic modulation;²⁵ the low-/high-frequency power ratio (=LFP/HFP) as the index of sympathovagal balance;²⁶ and the normalized VLFP (nVLFP=

Table 2 Effect of Position on Spectral Heart Rate Variability Measures

	Supine	Right lateral	Left lateral	Right prone	Left prone
<i>Control group (n=17)</i>					
TP (ms ²)	266.1 (101.5–579.8)	247.6 (158.8–430.9)	347.9 (109.8–714.7)	325.8 (144.1–545.4)	228.4 (111.1–654.9)
VLFP (ms ²)	126.4 (58.0–184.2)	103.9 (65.6–147.1)	154.2 (59.1–241.8)	133.2 (56.9–279.6)	136.6 (73.7–241.6)
LFP (ms ²)	50.4 (18.3–160.7)	40.2 (20.9–136.4)	57.6 (19.4–168.0)	53.0 (24.2–153.7)	35.3 (16.7–154.2)
HFP (ms ²)	48.5 (11.1–182.2)	87.8 (50.0–165.3)	66.2 (19.0–142.1)	71.2 (13.0–133.5)	56.1 (11.8–186.4)
nVLFP (nu)	56.3 (37.5–73.3)*	44.8 (29.2–56.8)	54.8 (42.4–67.8)*	54.0 (43.9–62.1)*	56.3 (49.1–72.1)*
nLFP (nu)	21.6 (15.3–27.4)	19.8 (14.2–29.5)	19.7 (15.2–29.8)	20.1 (16.8–27.7)	18.0 (14.4–27.1)
nHFP (nu)	18.2 (12.3–32.5)*	34.5 (26.4–41.4)	19.1 (11.9–30.3)*	23.4 (20.4–26.6)*	19.6 (11.3–33.0)*
LFP/HFP	1.2 (0.7–1.8)*	0.6 (0.4–0.9)	0.9 (0.6–1.6)*	0.9 (0.7–1.3)*	1.0 (0.6–1.7)*
RF	0.29 (0.21–0.33)	0.30 (0.25–0.32)	0.30 (0.24–0.34)	0.28 (0.24–0.32)	0.30 (0.20–0.32)
<i>CAD group (n=33)</i>					
TP (ms ²) [#]	191.6 (104.9–472.0)	242.7 (95.3–376.9)	261.1 (137.6–500.8)	189.0 (113.4–259.3)	223.2 (104.4–360.0)
VLFP (ms ²)	146.7 (42.9–284.8)	102.8 (48.1–245.5)	150.3 (85.8–219.5)	87.9 (41.2–168.1)*,†,‡	109.3 (54.2–176.6)*,†,‡
LFP (ms ²)	53.8 (18.7–94.2)	46.7 (19.7–73.3)	56.0 (28.4–88.2)	35.7 (18.3–58.9)	44.5 (25.1–63.7)
HFP (ms ²)	30.7 (11.2–73.5)	25.4 (12.6–85.9) [§]	38.6 (11.4–72.7)	23.1 (12.5–89.8)	25.8 (11.7–73.3)
nVLFP (nu)	61.3 (49.2–72.2)	55.6 (41.3–70.1) [§]	64.0 (47.7–75.8)	55.0 (43.5–66.8)	58.0 (46.7–67.8)
nLFP (nu)	18.8 (12.5–33.0)	19.1 (14.6–30.0)	18.5 (15.6–26.2)	20.7 (13.7–27.4)	19.8 (13.6–25.6)
nHFP (nu)	14.0 (9.0–27.1)	18.2 (9.7–33.3) [§] , [¶]	15.1 (6.8–24.0) [†]	18.3 (11.5–32.7) [†]	20.9 (11.6–31.6) [†]
LFP/HFP	1.6 (0.6–3.3)	1.4 (0.4–2.0) [§]	1.6 (0.8–2.7)	1.3 (0.6–1.9)	1.1 (0.6–1.8)
RF	0.30 (0.26–0.38)	0.31 (0.27–0.35)	0.29 (0.27–0.39)	0.29 (0.25–0.33)	0.34 (0.28–0.41)

Values are median and interquartile range (25–75th percentile).

TP, total power; VLFP, very-low-frequency power; LFP, low-frequency power; HFP, high-frequency power; nVLFP, normalized very-low-frequency power; nLFP, normalized low-frequency power; nHFP, normalized high-frequency power; LFP/HFP, low-/high-frequency power ratio; RF, respiratory frequency. Other abbreviation see in Table 1.

*Significant difference compared with right lateral decubitus position; †significant difference compared with supine position; ‡significant difference compared with left lateral decubitus position; §significant difference among 5 recumbent positions; ¶significant difference vs control group for the same HRV measure at the same position.

100×VLFP/TP) as the index of the renin–angiotensin–aldosterone system and vagal withdrawal.²⁷ The frequency at which the central peak of HFP located was identified as the respiratory frequency (RF) of the subject.²⁸

Statistical Analysis

The data of HRV measures are presented as median and interquartile range. A Friedman repeated measures analysis of variance on ranks (SigmaStat statistical software, SPSS Inc, Chicago, IL, USA) was used to compare the HRV measures among the 5 recumbent positions. The Student-Newman-Keuls test for multiple comparisons was used to isolate the groups that differed from the others. The Mann-Whitney rank sum test was used to compare the HRV measures between the CAD group and the control group. The chi-square test was used to compare categorical data. If more than 20% of the expected values in the contingency table were less than 5, then the Fisher exact test was used. A value of $p < 0.05$ was considered statistically significant.

To assess the effect of changing position on autonomic nervous modulation, the $nHFP_{RL/S}$ ($=100\% \times [nHFP \text{ in the right lateral decubitus position} - nHFP \text{ in the supine position}] / [nHFPs]$) was used as the indicator of the effect on nHFP of changing position from the supine to right lateral decubitus. The $nHFP_{LL/S}$, $nHFP_{RP/S}$, $nHFP_{LP/S}$ were defined similarly as the indicators of the effect on nHFP of changing position from supine to the left lateral, right prone or left prone position, respectively. The relationship between $nHFP_{RL/S}$, $nHFP_{LL/S}$, $nHFP_{RP/S}$, or $nHFP_{LP/S}$ and nHFPs was assessed by linear regression analysis. The effect of changing position from supine to lateral decubitus or prone on other HRV measures and RF was also assessed by the same statistical method as that for nHFP.

Results

Baseline Characteristics of the Subjects

The clinical characteristics of the control subjects and CAD patients are shown in Table 1, where hypertension is defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg, and hyperlipidemia is defined as total cholesterol >200 mg/dl and/or low-density lipoprotein cholesterol >130 mg/dl. The percentage of deletion of ectopic beats because of atrial or ventricular arrhythmia was $>5\%$ in 3 patients. Thus, 33 of 36 CAD patients and 17 control subjects were included in the final spectral HRV analysis.

Twelve of the CAD patients did not use aspirin: 5 because of a forthcoming operation, 3 because of peptic ulcer, and 4 were using ticlopidine instead. Although 17 of the 33 CAD patients had a history of MI, none of them developed chest discomfort or hemodynamic instability during ECG recording. The mean time since MI was 14.9 ± 32.3 months ($\pm$ SD; range: 1 day to 10 years). Of these 17 patients with history of MI, 8 had inferoposterior MI, 6 had anterolateral MI, and 3 had non-Q MI. There were no significant differences in other baseline characteristics.

Comparison of CAD Patients and Controls

In the right lateral decubitus position, the HFP and nHFP of CAD patients were significantly lower than those of the controls, whereas the LFP/HFP and nVLFP were significantly higher (Table 2). In the other recumbent positions, however, no significant difference in HRV measures was found between CAD patients and the controls.

Effect of Position on HRV Measures

In the control group, the nHFP in the right lateral decubitus position was the highest while the LFP/HFP and nVLFP were the lowest among the 5 recumbent positions (Table 2).

Fig 1. Linear regression between the percentage change in normalized high-frequency power (nHFP) and nHFPs (nHFP in the supine position) in (Left) controls and (Right) coronary artery disease (CAD) patients when the position was changed from supine to the other recumbent positions.

Table 3 Percentage Change in Heart Rate Variability Measures After Changing Position From Supine to Other Recumbent Positions

	RL/S	LL/S	RP/S	LP/S
Control group (n=17)				
nVLFP (%)	-23.8 (-36.8–-7.3)	-4.6 (-22.7–9.1)*	-8.0 (-22.4–20.5)*	-6.7 (-19.2–28.2)*
nLFP (%)	1.9 (-20.2–24.4)	4.4 (-19.6–17.2)	5.5 (-13.7–37.9)	-7.6 (-27.3–42.4)
nHFP (%)	83.5 (0.4–175.2)	10.6 (-36.5–39.6)*	19.9 (-37.0–75.8)*	18.1 (-30.7–65.8)*
LFP/HFP (%)#	-45.7 (-53.3–-6.6)	-19.8 (-31.0–54.6)	0.1 (-37.2–19.9)	-1.8 (-27.2–18.4)
RF (%)	0.31 (-6.39–5.58)	1.82 (-12.69–12.96)	-2.81 (-7.22–1.61)	-1.26 (-7.07–15.58)
CAD group (n=33)				
nVLFP (%)	-18.0 (-35.0–23.9)	-5.9 (-26.1–22.1)	-12.5 (-29.6–10.1)	-6.9 (-24.7–9.1)
nLFP (%)	-2.3 (-34.6–69.9)	-2.7 (-38.6–44.2)	10.1 (-23.5–71.6)	18.1 (-30.1–41.6)
nHFP (%)	43.2 (-31.1–109.1)	23.4 (-45.6–69.8)	36.4 (0.8–98.4)	42.5 (-13.1–133.5)
LFP/HFP (%)	-20.8 (-47.5–10.8)	-5.6 (-43.8–56.2)	-19.0 (-54.7–27.1)	-21.0 (-52.6–35.2)
RF (%)	-0.33 (-9.06–12.66)	-0.46 (-8.37–14.56)	-7.99 (-18.87–3.57)	1.16 (-6.69–23.03)

Values are median and interquartile range (25–75th percentile).

RL/S, from supine to right lateral decubitus position; LL/S, from supine to left lateral decubitus position; RP/S, from supine to right prone position; LP/S, from supine to left prone position. Other abbreviations see in Tables 1, 2.

* $p < 0.05$ vs RL/S; # $p < 0.05$ among RL/S, LL/S, RP/S, and LP/S.

No significant differences in the other HRV measures were found among the 5 recumbent positions in the control group.

In patients with CAD, the nHFPs was significantly lower than that in the other 4 recumbent positions, and the VLFP in the right prone and left prone positions was lower than that of the supine, right lateral, and left lateral positions.

Effect of Changing Position on HRV Measures

In the control group, when the position was changed from supine to the right prone, left prone or right lateral decubitus position, the percentage increase in nHFP correlated significantly and negatively with nHFPs (Fig 1, Right). In the CAD group, only the change in position from supine to

left prone or right lateral decubitus position resulted in a negative significant correlation between the percentage increase in nHFP and nHFPs (Fig 1, Left). In the CAD patients and the controls, the lower the nHFPs, the larger the percentage increase in nHFP when the position was changed from supine to another recumbent position.

Table 3 shows the percentage change in the HRV measures when the position was changed from supine to the other recumbent positions. In the control group, the percentage increase in the nHFP and the percentage decrease in nVLFP when the position was changed from supine to the right lateral decubitus were the greatest among the position changes from supine to the other 4 recumbent positions. In the CAD group, the percentage increase in nHFP and the percentage decrease in nVLFP when the position was changed from supine to the right lateral decubitus was still the greatest, though not statistically significant, among the position changes from supine to the other 4 recumbent positions. There was no significant difference in the percentage change in HRV measures for the same position change between control subjects and CAD patients.

Discussion

Position as a Vagal Enhancer

Compared with the supine position, the right lateral decubitus position can increase vagal modulation in both healthy subjects and patients with severe CAD and/or acute myocardial infarction (AMI).^{8,9} The present study also showed that the right lateral decubitus position increased vagal modulation in both the control group and in patients with CAD. Moreover, the right prone, left prone and left lateral decubitus positions could also be used as vagal enhancers in patients with CAD. In other words, though the vagal-enhancing effect of the prone position was not significant in the control group, it was quite significant in patients with CAD.

Effect of Changing Position

It has been shown previously that the percentage increase in vagal modulation when the position was changed from supine to right lateral decubitus position was greater when the vagal modulation was lower while supine; the lower the vagal modulation in the supine position, the higher the percentage increase in vagal modulation when the position was changed from supine to right lateral decubitus.⁸ Similar phenomena were found in the present study for changing position from supine to the prone or lateral positions in both CAD patients and controls. The negative significant correlation between the percentage increase in vagal modulation when the position was changed from supine to the other recumbent positions and the nHFP in the supine position suggests that those subjects who have lower vagal modulation while supine could benefit more from assuming either the prone or lateral decubitus position. In other words, those subjects who have lower vagal modulation in the supine position better assume either a prone or lateral decubitus position, especially the right lateral decubitus position.

Table 3 shows that in the control group the percentage increase in vagal modulation and the percentage decrease in sympathetic modulation were the greatest when the position was changed from supine to the right lateral decubitus position. In CAD patients, the percentage increase in vagal modulation was still the highest, though not statistically significant, when the position was changed from supine to right

lateral decubitus position, which suggests that the right lateral decubitus position is still the best position for both control subjects and CAD patients in terms of vagal modulation. Alternatively, the right prone, left prone and left lateral decubitus positions can also lead to increased vagal modulation, as compared with the supine position, in both controls and CAD patients.

Clinical Implications

Experimental and clinical studies have shown that decreased vagal and increased sympathetic activity favors the development of ventricular tachyarrhythmias, especially in the presence of acute ischemia or remote infarction.^{29,30} Increased vagal modulation can reduce myocardial oxygen consumption and decrease the likelihood of serious ventricular arrhythmias.³¹ Thus, vagal enhancement might be beneficial for patients with depressed vagal activity, such as those with CAD and/or AMI. The finding that the right and left prone positions can enhance vagal modulation in patients with CAD suggests that both positions have therapeutic potential. In addition to the right lateral decubitus position, both the right and left prone positions were shown in the present study to be better than the supine position, as far as cardiac vagal modulation was concerned, in both groups.

Speculated Mechanism for Benefit of Prone Position

Generally, the power of the spectral components is frequency-dependent, increasing in an exponential fashion as RF decreases and tidal volume increases. These spectral characteristics also raise a crucial question as to whether a larger nHFP in the prone position is caused by an increase in intrinsic vagal tone or by enhanced gating effects through an increased tidal volume. Because the RF was not significantly different among the 5 recumbent positions compared in the present study and did not change significantly when the position was changed from supine to other recumbent positions (Tables 2,3), the larger nHFP in the prone position might not be caused by enhanced gating effects; that is, the larger nHFP in the prone position was indeed caused by an increase in the intrinsic vagal tone.

Several mechanisms might be involved in the beneficial effect of the prone position on autonomic nervous modulation. When the relative volume of lung located directly under the heart was measured in the supine and prone positions by 4 axial tomographic sections between the carina and the diaphragm, it was found that although a large fraction of the lung, particularly on the left, is located directly under the heart in supine patients, and therefore would be subject to the compressive force resulting from heart weight, almost no lung is located under the heart when patient is prone and the compressive force of the heart is directed towards the sternum.³² The compressive force of the heart on the dorsal lung regions can be eliminated by turning from the supine to the prone position, which would lead to lower inspiratory pressure required to obtain maximal air space recruitment and lower end-expiratory pressure required to maintain maximal air space recruitment.³² Thus, lessening the compression of the lungs by the heart is the first possible mechanism of the improvement in cardiac vagal modulation when the prone position, rather than the supine position, is assumed by the patient.

Arterial blood oxygen tension is increased in the prone position in animals and humans because of an improvement in ventilation and perfusion matching,^{33,34} which is

secondary to increased homogeneity of the ventilation distribution and increased correlation of regional ventilation and perfusion.³⁵ Therefore, the improvement in oxygenation secondary to more uniform ventilation–perfusion distribution in the prone position might be another possible mechanism for the enhancement of cardiac vagal modulation in that position.

Atrial stretch reflex might also play a role because the volume load on atrial stretch receptors is greater when prone than when supine,³⁶ and the effect of atrial stretch reflex is conveyed from the right atrium via inhibitory vagal afferents, directly to the neurons of the noradrenergic general activation system of the locus ceruleus in the pontine region. Because increased volume load of the right atrium can induce an instant suppression of noradrenergic cell discharges,³⁶ the noradrenergic neuronal complex might be involved in the change in autonomic nervous modulation during the change in body position. Further studies are needed to understand the underlying mechanism of increased vagal modulation in the prone position as compared with the supine position.

Table 3 shows that in the control subjects the percentage increase in nHFP when the position was changed from supine to the right lateral decubitus, nHFP_{RL/S}, was the greatest among 4 kinds of position changes from supine to the other recumbent positions, whereas the same nHFP_{RL/S} was not statistically significant in the CAD patients. The obvious increase in nHFP_{RL/S} in the control subjects might be explained by the smaller lung compression and the greater atrial stretch reflex in the right lateral decubitus position than in either the left lateral decubitus or prone position, and the absence of a significant increase in nHFP_{RL/S} in the patients with CAD might be a saturation effect. That is, the relatively larger increase in the levels of atrial natriuretic peptides because of increased atrial wall tension caused by increased venous return might be saturated in the right lateral decubitus position in comparison with the other recumbent positions, as it has been demonstrated that atrial or cardiac natriuretic peptide levels increase in patients with MI and stable CAD.^{37–39}

Although the increase in nHFP_{RL/S} in the control subjects seemed to be greater than that of the CAD patients (83.5% vs 43.2% for the median values, $p=0.140$, Table 3), the comparison of the increase in nHFP_{RL/S} in the 2 groups of subjects did not reach statistical significance for this position change. It seems that the right lateral decubitus position can lead to a similar degree of vagal enhancement in the control subjects and in the CAD patients.

Clinical Significance of the Supine Position

In this study we found that in CAD patients the supine position can lead to the lowest vagal modulation among the 5 recumbent positions, which has important clinical implication because most CAD patients assume the supine position when they rest in bed. It seems that CAD patients should assume the right or left decubitus or prone position when they lie in bed, especially those patients who have severely reduced cardiac vagal modulation while supine.

Conclusion

Among 5 recumbent positions, the right lateral decubitus position is the best for patients in terms of enhancing vagal modulation. In addition to the right lateral decubitus position, either the right or left prone position can also be used

as a vagal enhancer in patients with CAD as compared with the supine position, especially for those patients who have severely reduced cardiac vagal modulation in the supine position. The supine position appears to be the worst recumbent position and is best avoided by CAD patients as far as cardiac vagal modulation is concerned.

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References

1. Airaksinen KEJ, Ikaheimo MJ, Linnaluoto MK, Niemelä M, Takkunen JT. Impaired vagal heart rate control in coronary artery disease. *Br Heart J* 1987; **58**: 592–597.
2. Hayano J, Sakakibara Y, Yamada M, Ohte N, Fujinami T, Yokoyama K, et al. Decreased magnitude of heart rate spectral components in coronary artery disease: Its relation to angiographic severity. *Circulation* 1990; **81**: 1217–1224.
3. Bikkina M, Alpert MA, Mukerji R, Mulekar M, Cheng BY, Mukerji V. Diminished short-term heart rate variability predicts inducible ventricular tachycardia. *Chest* 1998; **113**: 312–316.
4. Hadase M, Azuma A, Zen K, Asada S, Kawasaki T, Kamitani T, et al. Very low frequency power of heart rate variability is a powerful predictor of clinical prognosis in patients with congestive heart failure. *Circ J* 2004; **68**: 343–347.
5. Kent KM, Smith ER, Redwood DR, Epstein SE. Electrical stability of acutely ischemic myocardium: Influences of heart rate and vagal stimulation. *Circulation* 1973; **47**: 291–298.
6. Vanoli E, De Ferrari GM, Stramba-Badiale M, Hull SS Jr, Foreman RD, Schwartz PJ. Vagal stimulation and prevention of sudden death in conscious dogs with a healed myocardial infarction. *Circ Res* 1991; **68**: 1471–1481.
7. Waxman MB, Wald RW. Termination of ventricular tachycardia by an increase in cardiac vagal drive. *Circulation* 1977; **56**: 385–391.
8. Kuo CD, Chen GY. Comparison of three recumbent positions on vagal and sympathetic modulation using spectral heart rate variability in patients with coronary artery disease. *Am J Cardiol* 1998; **81**: 392–396.
9. Kuo CD, Chen GY, Lo HM. Effect of different recumbent positions on spectral indices of autonomic modulation of the heart during the acute phase of myocardial infarction. *Crit Care Med* 2000; **28**: 1283–1289.
10. Kim WS, Yoon YZ, Bae JH, Soh KS. Nonlinear characteristics of heart rate time series: Influence of three recumbent positions in patients with mild or severe coronary artery disease. *Physiol Measur* 2005; **26**: 517–529.
11. Fujita M, Miyamoto S, Sekiguchi H, Eiho S, Sasayama S. Effects of posture on sympathetic nervous modulation in patients with chronic heart failure. *Lancet* 2000; **356**: 1822–1823.
12. Miyamoto S, Fujita M, Sekiguchi H, Okano Y, Nagaya N, Ueda K, et al. Effects of posture on cardiac autonomic nervous activity in patients with congestive heart failure. *J Am Coll Cardiol* 2001; **37**: 1788–1793.
13. Douglas WW, Rheder K, Kroukje MB, Sessler AD, Marsh HM. Improved oxygenation in patients with acute respiratory failure: The prone position. *Am Rev Respir Dis* 1974; **115**: 559–566.
14. Langer M, Mascheroni D, Marcolin R, Gattinoni L. The prone position in ARDS patients: A clinical study. *Chest* 1988; **94**: 103–107.
15. Blanch L, Mancebo J, Perez M, Martinez M, Mas A, Bethese AJ, et al. Short-term effects of prone position in critically ill patients with acute respiratory distress syndrome. *Intens Care Med* 1997; **23**: 1033–1039.
16. Chatte G, Sab JM, Dubois JM, Sirodot M, Gaussorgues P, Robert D. Prone position in mechanically ventilated patients with severe acute respiratory failure. *Am J Respir Crit Care Med* 1997; **155**: 473–478.
17. Mure M, Martling CR, Lindahl SG. Dramatic effect on oxygenation in patients with severe acute lung insufficiency treated in the prone position. *Crit Care Med* 1997; **25**: 1539–1544.
18. Voggenreiter G, Neudeck F, Aufmkolk M, Fassbinder J, Hirche H, Obertacke U, et al. Intermittent prone positioning in the treatment of severe and moderate post-traumatic lung injury. *Crit Care Med* 1999; **27**: 2375–2382.
19. Lumb AB, Nunn JF. Respiratory function and rib cage contribution

- to ventilation in body positions commonly used during anesthesia. *Anesth Analg* 1991; **73**: 422–426.
20. Pelosi P, Croci M, Calappi E, Cerisara M, Mulazzi D, Vicardi P, et al. The prone positioning during general anesthesia minimally affects respiratory mechanics while improving functional residual capacity and increasing oxygen tension. *Anesth Analg* 1995; **80**: 955–960.
 21. Austen WG, Edwards JE, Frye RL, Gensini GG, Gott VL, Griffith LS, et al. A reporting system on patients evaluated for coronary artery disease: Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. *Circulation* 1975; **51**(Suppl): 5–40.
 22. Crouse JR III, Craven TE, Hagaman AP, Bond MG. Association of coronary disease with segment-specific intimal–medial thickening of the extracranial carotid artery. *Circulation* 1995; **92**: 1141–1147.
 23. Nygard O, Nordrehaug JE, Refsum H, Ueland PM, Farstad M, Vollset SE. Plasma homocysteine levels and mortality in patients with coronary artery disease. *N Engl J Med* 1997; **337**: 230–237.
 24. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation* 1996; **93**: 1043–1065.
 25. Koizumi K, Terui N, Kollai M. Effect of cardiac vagal and sympathetic nerve activity on heart rate in rhythmic fluctuations. *J Auton Nerv Syst* 1985; **12**: 251–259.
 26. Pagani M, Lombardi F, Guzzetti S, Rimoldi O, Furlan R, Pizzinelli P, et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circ Res* 1986; **59**: 178–193.
 27. Taylor JA, Carr DL, Myers CW, Eckberg DL. Mechanisms underlying very-low-frequency RR-interval oscillations in humans. *Circulation* 1998; **98**: 547–555.
 28. Van Ravenswaaij-Arts CMA, Kollée LAA, Hopman JCW, Stoeltinga GBA, van Geijn HP. Heart rate variability. *Ann Intern Med* 1993; **118**: 436–447.
 29. Schwartz PJ, La Rovere MT, Vanoli E. Autonomic nervous system and sudden cardiac death: Experimental basis and clinical observations for post-myocardial infarction risk stratification. *Circulation* 1992; **85**(Suppl): 177–191.
 30. Schwartz PJ. The autonomic nervous system and sudden death. *Eur Heart J* 1998; **19**(Suppl F): F72–F80.
 31. Grauer LE, Gershen BJ, Orlando MM, Epstein SE. Bradycardia and its complications in the pre-hospital phase of acute myocardial infarction. *Am J Cardiol* 1973; **32**: 607–611.
 32. Albert RK, Hubmayr RD. The prone position eliminates compression of the lungs by the heart. *Am J Respir Crit Care Med* 2000; **161**: 1660–1665.
 33. Beck KC, Vettermann J, Rehder K. Gas exchange in dogs in the prone and supine positions. *J Appl Physiol* 1992; **72**: 2292–2297.
 34. Lamm WJE, Graham MM, Albert RK. Mechanism by which the prone position improves oxygenation in acute lung injury. *Am J Respir Crit Care Med* 1994; **150**: 184–193.
 35. Mure M, Domino KB, Lindahl SGE, Hlastala MP, Altemeier WA, Glenny RW. Regional ventilation-perfusion distribution is more uniform in the prone position. *J Appl Physiol* 2000; **88**: 1076–1083.
 36. Kaada B. Why is there an increased risk for sudden infant death in prone sleeping?: Fear paralysis and atrial stretch reflexes implicated? *Acta Paediatr* 1994; **83**: 548–557.
 37. Sagnella GA. Measurement and significance of circulating natriuretic peptides in cardiovascular disease. *Clin Sci* 1998; **95**: 519–529.
 38. Weber M, Dill T, Arnold R, Rau M, Ekinici O, Muller KD, et al. N terminal BNP predicts extent of coronary artery disease and ischemia in patients with stable angina pectoris. *Am Heart J* 2004; **148**: 612–620.
 39. Kragelund C, Grønning B, Køber L, Hildebrandt P, Steffensen R. N-terminal pro-B-type natriuretic peptide and long-term mortality in stable coronary heart disease. *N Engl J Med* 2005; **352**: 666–675.