Impaired autonomic nervous activity has been recognized as a crucial component of congestive heart failure (CHF) (1), and increased sympathetic activity has been reported as a marker of poor prognosis of patients with CHF (2). The spectral analysis of heart rate variability (HRV) has provided much information on cardiac autonomic nervous activity. Earlier studies have revealed an augmentation of sympathetic drive and a withdrawal of parasympathetic tone in patients with CHF (3–5). A decrease in HRV has also been shown to be an independent predictor of arrhythmic events and sudden death in CHF (6).

Patients with mild or moderate CHF may become uncomfortable if they lie in the supine position without elevation of the head. Therefore, these patients may prefer other recumbent positions (i.e., trepopnea). In addition, we have frequently observed that patients with CHF were apt to be in the right lateral decubitus position. However, it remains unclear whether cardiac autonomic nervous activity is different among three recumbent positions in patients with CHF. To elucidate these issues, we developed a small-sized detector (3.2 cm × 3.2 cm) for accurately recording the postures under physiologic conditions during daily life. It simultaneously assesses each patient’s posture and cardiac autonomic nervous activity in combination with Holter electrocardiographic (ECG) monitor recording.

Thus, the purpose of the present study was twofold: to clarify which recumbent position is preferred by patients with CHF, and to evaluate whether cardiac autonomic nervous activity is affected by the various recumbent positions in patients with CHF during daily life.

METHODS

Study subjects. The study population consisted of 17 male patients (mean age 66 ± 7 years) with compensated CHF due to coronary artery disease (CAD). Four patients had three-vessel CAD, seven had two-vessel CAD, and six had one-vessel CAD. Four patients had New York Heart Association (NYHA) functional class I, eight had functional class II, and five had functional class III. The mean left ventricular ejection fraction was 32 ± 6%. Only beta-blocking therapy had been withdrawn at least seven days earlier in all the patients. A constant diuretic (53%), digitalis (12%), calcium antagonist (53%), nitrate (82%), and angiotensin-converting enzyme inhibitor (65%) dosing regimen was continued during the 24-h Holter monitoring. Seven patients with diabetes mellitus were...
Patients having either atrial fibrillation (9 patients), paced rhythms (3 patients), or frequent ventricular ectopic rhythms (2 patients) were also excluded. A similar number of age-matched healthy male subjects (mean age 66 ± 7 years) were selected as the control group. All subjects provided informed consent to the protocol, which was approved by the human subjects review committee of Takeda Hospital.

**Holter monitoring.** Each subject underwent 24-h ambulatory ECG monitoring with the use of a Fukuda SM-26 two-channel recorder (Fukuda Denshi, Tokyo, Japan). Bipolar leads were attached to the electrodes at CM5 (standard V5 lead position). Another channel was used to record the signal of the position of each subject during usual daily activity. Monitoring tapes were analyzed with a Medilog OPTIMA EC2200 Holter tape analyzer (Oxford, London, United Kingdom). Two trained cardiologists (S.M. and Y.O.) made independent visual analyses of the records.

**Determination of upright and recumbent positions.** The device used for detecting the posture generates a consecutive pulse signal. Both the pulse and ECG signals are recorded with the portable two-channel ECG recorder. The device consists of two parts—the sensor unit, which is to be attached to the center of the chest, and the oscillator unit. The sensor unit is 32 mm in diameter and 9 mm in thickness. The oscillator unit is included in a rectangular plastic box. As shown in Figure 1 (upper panel), four tilt switches are placed inside the sensor unit. The two switches (H1 and Hr) are used to detect the recumbent position. When the body turns sideways more than 30 degrees, one of these switches turns on. Another pair of switches (Vl, Vr) can be used to detect whether the patient is standing or not. An example of the record is shown in Figure 1 (lower panel). The output voltage of the pulse is 3 mV peak-to-peak, with the frequency selectable among 0.5, 1, and 2 Hz depending on the combination of the status of the tilt switches.

**Spectral analysis of heart rate variability.** Tape-recorded ECGs were played back and digitized at a rate of 500 samples/s by an analog-to-digital converter during each 5-min period in the three different recumbent positions between 3:00 AM and 6:00 AM. The analysis of HRV was restricted to the time period, because both healthy subjects and patients with CHF slept well. We selected only Holter recordings consisting predominantly of sinus rhythm. Recordings with frequent supraventricular or ventricular ectopic rhythms or atrial fibrillation were excluded from subsequent analysis. Power spectral analysis was performed by means of fast Fourier transformation. The direct current component was excluded in the calculation of the power spectrum to remove the nonharmonic components in the very low-frequency region (<0.04 Hz) (7). The area of spectral peaks within the whole range of 0.04 to 0.40 Hz was defined as total power, the area of spectral peaks within the range of 0.04 to 0.15 Hz as low-frequency power, and the area of spectral peaks within the range of 0.15 to 0.40 Hz as high-frequency power.
high-frequency power. The normalized high-frequency power (=100 × high-frequency power/total power) was used as an index of modulation of vagal activity. The normalized low-frequency power (=100 × low-frequency power/total power) was used as an index of sympathetic modulation (8) and the low/high-frequency power ratio (= low-frequency power/high-frequency power) as the index of sympathovagal balance (9).

Statistical analysis. Data are expressed as mean values ± SD. Multiple comparisons were performed by two-way analysis of variance. Nine comparisons were then conducted by the Tukey-Kramer test for each parameter among the three recumbent positions of both groups of patients. Results were considered significant at p < 0.05.

RESULTS

Preferred sleep posture. There were no differences in the time [time (min) × 100%/180 (min)] in each recumbent position in healthy subjects from 3:00 AM to 6:00 AM (left lateral decubitus position = 31 ± 11%; supine position = 38 ± 17%; right lateral decubitus position = 31 ± 20%, p = NS). In contrast, in patients with CHF from 3:00 AM to 6:00 AM, the time for the right lateral decubitus position (54 ± 15%) was significantly longer than the time for the supine (29 ± 16%) and left lateral decubitus positions (17 ± 11%) in patients with CHF (both p < 0.01).

Posture and cardiac autonomic nervous activity. Figure 2 shows the RR interval power spectra in the supine, left, and right lateral decubitus positions in a representative normal control and a patient with CHF. In the normal subject (Fig. 2a), no significant differences were seen in the power spectra among the three recumbent positions. In contrast, in the patient with CHF (Fig. 2b), the normalized high-frequency power was highest (58.9%) when the right lateral decubitus position was obtained, followed in decreasing order by the supine (30.4%) and left lateral decubitus positions (14.5%).

Table 1 summarizes the effects of the three recumbent positions on vagal and cardiac sympathetic modulation in the normal subjects and patients with CHF. The absolute values of the total and each frequency power in three recumbent positions were higher in normal subjects than those in patients with CHF except in the left lateral decubitus position. With regard to the normalized powers, significant changes were observed in the left decubitus position between normal subjects and patients with CHF. In normal subjects, no significant differences existed in the normalized low-frequency power among the three recumbent positions, whereas in patients with CHF the normalized low-frequency power was lowest in the right lateral decubitus position (0.3 ± 0.2) compared with the left lateral decubitus (0.7 ± 0.2) and supine (0.3 ± 0.2) positions.

In normal subjects, again, no significant differences were seen in the low-frequency power/high-frequency power ratio among the three recumbent positions, whereas the low-frequency power/high-frequency power ratio in patients with CHF had a reverse trend against the normalized high-frequency power (Table 1). Thus, no differences existed in the frequency domain measurements among the three recumbent positions in normal subjects. In contrast, in patients with CHF, the parameters for the right lateral decubitus position were significantly different from those for the left lateral decubitus and supine positions. As a result, the normalized high-frequency power and the low-frequency power/high-frequency power in the right lateral decubitus position were quite comparable between normal subjects and CHF patients (Table 1).

Effects of the severity of CHF. There were no differences between patients with NYHA functional class I and those with NYHA functional class II/III with regard to the time for the preferred sleep posture and the results of ECG spectral analysis.

DISCUSSION

The findings of the present study demonstrate that patients with CHF preferred the right lateral decubitus position, in which the imbalance of cardiac autonomic nervous activity was attenuated. The right lateral decubitus position can lead to the highest vagal modulation and the lowest sympathetic modulation among the three recumbent positions in patients with CHF, resulting in the same sympathovagal balance as normal subjects. This outcome, however, was not generic for healthy subjects, in whom there were no differences in preferred sleep posture. In addition, cardiac autonomic nervous activity was similar among the three recumbent positions.

Circadian rhythm of HRV. Our findings that cardiac autonomic nervous activity is largely different among the three recumbent positions in patients with CHF shed light on the interpretation of the circadian variation in cardiac autonomic nervous activity in patients with CHF (10–13). Although a clear circadian rhythm of the sympathovagal activity in normal subjects has been confirmed in several studies (14,15), a similar diurnal pattern of autonomic neural function was or was not observed in patients with CHF (10–13). Casolo et al. (10) demonstrated that none of the measures of HRV significantly changed over a 24-h period in patients with CHF. Soejima et al. (16) found that HRV and its circadian changes decreased in patients with left ventricular dysfunction.

In contrast to these reports, Adamopoulos et al. (17) concluded that the circadian variation in the high- and low-frequency components of HRV in patients with CHF followed a pattern similar to that seen in normal subjects,
Figure 2. (a) Representative power spectra of RR intervals during various recumbent positions in a normal subject and (b) a patient with CHF. In the normal subject, there were no significant differences in the normalized high-frequency power among the three recumbent positions. In contrast, in the patient with CHF, normalized high-frequency power was highest when the right lateral decubitus position was obtained, followed in decreasing order by the supine and left lateral decubitus positions. HF/total power = normalized high-frequency power; LF/total power = normalized low-frequency power; LF/HF = low-frequency/high-frequency power.
Study limitations.

Although at a significantly lower power throughout the 24 h. Because cardiac autonomic nervous function in these studies was assessed irrespective of patient’s sleep posture, significant changes in autonomic nervous activity by the posture may have altered the circadian variation of autonomic tone in patients with CHF. The simultaneous recording of ECG and patient’s posture will allow better assessment of the circadian rhythm of autonomic nervous function in patients with CHF.

Possible mechanisms for posture effects. It is tempting to speculate that the underlying mechanisms of the enhancement of vagal activity and attenuation of sympathetic activity in patients in the right lateral decubitus position. First, the position of the heart is higher in the right lateral decubitus position, which results in decreased venous return. Consequently, pulmonary congestion may be attenuated as the patient sits upright. Second, pleural effusion accumulates more prominently in the right pleural cavity compared with the left cavity in patients with CHF. When the patient assumes the right lateral decubitus position, the left pleural cavity becomes free of effusion at the sacrifice of the right lung. This may lead to a smaller workload on respiratory function. Finally, the right lateral decubitus position may facilitate gastric emptying, resulting in an increase in the vagal activity. Although all three of these mechanisms might be responsible for the increased vagal activity and decreased sympathetic activity in the right lateral decubitus position, further studies will be needed to assess the mechanisms of vagal activation and sympathetic suppression in the right lateral decubitus position.

Study limitations. First, the fact that respiration rate was not monitored in the present study may make the interpretation difficult when assessing the HRV. Because it is well-known that the respiration state largely influences the HRV (18,19), the effect of respiration should be tested in another study with a simultaneous recording of ECG, patient’s posture, and respiration. Second, we could not differentiate the standing position from the sitting position, and we also could not differentiate the supine position from the prone position. This may be a limitation of our new device for detecting posture. However, because we focused on sleep posture, differentiation of the three above-mentioned recumbent positions appears to serve the purpose of the present study. Third, we did not examine factors such as rapid eye movement (REM) or non-REM sleep other than position, which also possibly influence the HRV (20). Further studies about the simultaneous measurements of electroencephalography may be appropriate to assess the HRV in patients with CHF. Fourth, because in the present study only men with CHF due to ischemic etiology were studied, these results should not be extrapolated to women or nonischemic cardiomyopathy. Finally, some measures of reproducibility of these results need to be performed.

Conclusions. The present study found that CHF patients prefer the right lateral decubitus position, which leads to the highest vagal activity and the lowest sympathetic tone among the three recumbent positions. This may be a self-protecting mechanism of correcting the disturbed cardiac autonomic nervous activity in patients with CHF.

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