

Determining optimal sleep position in patients with positional sleep-disordered breathing using response surface analysis

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SUMMARY A lateral position (LP) during sleep is effective in reducing sleep disorder symptoms in mild or moderate sleep apnea patients. However, the effect of head and shoulder posture in LP on reducing sleep disorders has not been reported. In this study, effective sleeping positions and a combination of sleep position determinants were evaluated with respect to their ability to reduce snoring and apnea. The positions evaluated included the following: cervical vertebrae support with head tilting (CVS-HT), scapula support (SS), and LP. A central composite design was applied for response surface analysis (RSA). Sixteen patients with mild or moderate positional sleep apnea and snoring who underwent polysomnography for two nights were evaluated. Based on an estimated RSA equation, LP (with a rotation of at least 30°) had the most dominant effect [$P = 0.0057$ for snoring rate, $P = 0.0319$ for apnea–hypopnea index (AHI)]. In addition, the LP was found to interact with CVS-HT ($P = 0.0423$) for snoring rate and CVS-HT ($P = 0.0310$) and SS ($P = 0.0265$) for AHI. The optimal sleep position reduced mild snoring by more than 80% (i.e. snoring rate in the supine position was <20%) and the snoring rate was approximately zero with a 40° rotation. To achieve at least 80% reduction of AHI, LP and SS should be >30° and/or 20 mm respectively. To determine an effective sleep position, CVS-HT and SS, as well as the degree of the LP, should be concurrently considered in patients with positional sleep apnea or snoring.

KEYWORDS positional sleep apnea and snoring, positional therapy, response surface analysis

INTRODUCTION

Body position shifting during sleep is a conservative therapy for addressing snoring or sleep apnea. Reportedly, body position changes are effective for many non-obese patients with sleep apnea and/or snoring. Body position during sleep influences the frequency of apneas and hypopneas in 50–60% of individuals with obstructive sleep apnea (OSA) (Mador *et al.*, 2005; Oksenberg *et al.*, 1997). In such cases,

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the apnea–hypopnea index (AHI) increases in the supine posture and decreases in the lateral posture. Positional sleep apnea is defined as a 50% reduction or greater in the AHI during non-supine sleep (Cartwright, 1984; Jokic *et al.*, 1999). Continuous positive airway pressure (CPAP) is a highly effective form of therapy for OSA. However, poor acceptance and low compliance with CPAP indicate that it is not the best treatment for sleep apnea or snoring (Jokic *et al.*, 1999; Oksenberg *et al.*, 2000). As an alternative to CPAP treatment, patients with positional sleep-disordered breathing (SDB) may be candidates for therapies designed to prevent the supine posture during sleep, such as positional therapy. However, positional therapy is not likely to relieve

symptoms if the AHI in the non-supine position remains elevated. A more clinically appropriate definition would define positional sleep apnea when the AHI falls below the diagnostic threshold during sleep in the non-supine posture (Oksenberg *et al.*, 1997; Oksenberg *et al.*, 2000). Then, **positional therapy alone could be useful to treat patients with SDB** when positional therapy is entirely effective in eliminating sleep apnea and/or snoring in the supine position.

Many researchers have investigated SDB such as OSA and snoring, where collapse of the upper airway is the primary event in OSA (Choi *et al.*, 2000; Hiyama *et al.*, 2000). To eliminate SDB symptoms, numerous medical devices have been developed (Cartwright, 1984; Kavey *et al.*, 1985; Kushida *et al.*, 2001; Zuberi *et al.*, 2004) and appropriate sleeping positions for improvement of OSA symptoms have been proposed (Bliwise *et al.*, 2004; Geer *et al.*, 2006). However, there have been few studies that have investigated the optimal position with respect to reduction of the upper airway to decrease sleep apnea and/or snoring symptoms. There are several reasons why sleep position is difficult to study. In the natural sleeping position, patients can unconsciously rotate approximately 90° in the LP without awareness of their degree of rotation during sleep. Several studies that have investigated the association between sleep posture and the collapsibility of the upper airway have reported a 20° head extension cervical support (Kushida *et al.*, 2001), a 45° incline on both sides (Zuberi *et al.*, 2004), and an elevation of body position (Skinner *et al.*, 2004) are effective in reducing sleep apnea and/or snoring. However, few studies have theoretically evaluated several characteristics of the body position that play key roles in determining the parameters of positional therapy.

In this study, effective sleep positions and a combination of sleep position determinants were evaluated to examine their effect on reducing snoring and/or apnea, including cervical vertebrae support with head tilting (CVS-HT), scapula support (SS; that is, upper trunk), and lateral position (LP). Unlike conventional clinical trials to evaluate the efficacy of positional therapy, the current study focused on determining the potential optimal position in patients with snoring and sleep apnea. Thus, response surface analysis (RSA), a complex statistical method, was used for the following purposes: (i) to determine the factor levels that will simultaneously satisfy a set of desired specifications, (ii) to determine the optimum combination of factors that yield a desired response and describes the response near the optimum, and (iii) to achieve a quantitative understanding of snoring and sleep apnea behavior over the region evaluated.

MATERIALS AND METHODS

Experiment design

Unlike conventional clinical study designs, a RSA experimental design was applied in this study. The RSA experiment

is designed to allow estimation of interactions and even quadratic effects, and therefore gives an idea of the shape of the response investigated. A widely used central composite design of RSA is a response surface design, which consists of three different points and can fit a full quadratic model. These three points include cube points at the corners of a unit cube that is the product of the interval $[-1, 1]$, points along the axes at or outside the cube, and center points at the origin (Montgomery, 1997). Each point in the central composite design indicated each subject who takes a combination of sleep position factors; one of CVS-HT levels, one of SS levels and one of LP levels. All the subjects were randomly assigned to 16 combinations across levels of three factors. For the purpose of determining optimal sleep positions for a snorer with positional sleep apnea during this study, a response surface design with a 2^3 factorial design, including two central points, was utilized.

Establishment of a design matrix for 2^3 factorial design

Based on a literature search (Cartwright, 1984; Jokic *et al.*, 1999; Kushida *et al.*, 2001; Mador *et al.*, 2005; Oksenberg *et al.*, 2006) and a previous pilot study, several determinants of sleep positions to reduce snoring and apnea were selected. These determinants included CVS-HT, SS, and LP. For the position of CVS-HT, three levels were considered: normal, 30 mm (assuming an average cervical height with a conventional pillow in the supine position was 55 mm, then CVS-HT became 85 mm) elevation from a supine position, and 30 mm elevation from a supine position with 15° head tilting. The levels of SS consisted of a normal supine position as well as an elevation of 20 or 40 mm from the supine position. Finally, the LP levels were supine, a 20° rotation from the supine position, or a 40° rotation from the supine position.

Participants and assignment

The sleep records of subjects enrolled in the Korean Health and Genomic Study (Kim *et al.*, 2004) were evaluated for snoring and positional sleep apnea, as defined by a AHI ≥ 5 with $> 50\%$ reduction of AHI in the non-supine posture compared to AHI in the supine posture (Cartwright, 1984; Jokic *et al.*, 1999; Oksenberg and Silverberg, 1998). To screen position-dependent patients, each subject was required to satisfy the following criteria: ambulatory males 40–50 years of age; snorers with mild or moderate ($5 < \text{AHI} \leq 30$) positional sleep apnea; snoring for $\geq 10\%$ of total sleep time, and no history of musculoskeletal disease.

Twenty-five participants who gave their written informed consent underwent an overnight diagnostic polysomnography. When participants maintained the supine position longer than the first sleep cycle (approximately 2 h), including rapid eye movement (REM) sleep, during the diagnostic examination, a monitoring technician caused their sleep position to change to

the non-supine for the appropriate non-supine position sleep time and observed whether or not the non-supine position was maintained for more than 20 min.

In the experimental examination, all participants fell asleep in the supine position with a conventional pillow for the first cycle of total sleep time. After the first REM cycle occurred, the monitoring technician exchanged the pillow for a position support instrument. Sixteen of the 25 participants who satisfied the eligible criteria underwent polysomnography to measure AHI reduction during specific sleep positions. At the beginning of the second night examination, all the subjects fell asleep in the supine position with a conventional pillow for the first sleep cycle, and then were required to take position support device. After the second cycle, we switched to a conventional pillow again. To change the device, it takes < 1 min. Assuming that total sleep time is 8 h, and that average length of a sleep cycle was 1.5–2 h, the possible number of device changes was three. Actually, the subjects were required to change the device 2–3 times for the entire sleep. Thus, the participants were intermittently interrupted < 3 min in all the sleep time. Moreover, we excluded 5–10 min data from the interrupt to minimize artifacts.

Table 1 Sleep related characteristics of baseline polysomnography

	Total	Supine	Non-Supine
Total sleep time (mm)	432 ± 48	303 ± 35	128 ± 41
Snoring rate (%)	29.2 ± 13.5	36.2 ± 15.2	7.3 ± 13.2
Apnea–hypopnea index	15.2 ± 7.9	24.3 ± 8.1	5.2 ± 7.2
Arousal index	21.4 ± 7.3	23.5 ± 7.8	21.0 ± 8.2
Minimal saturation (%)	84.5 ± 9.2	80.2 ± 8.2	89.4 ± 5.2
Sleep efficiency (%)	87.3 ± 10.0	84.2 ± 9.3	89.1 ± 10.1

Polysomnography

Participants underwent polysomnography at the Sleep Disorder Center, Ansan Hospital, Korea University with Alice 5 (Respironics, Atlanta, GA, USA). Sixteen channels were used, and the polysomnography results were manually scored according to standard criteria (Rechtschaffen and Kales, 1968).

Instrument for supporting a specific sleep position

An instrument to set a specific sleep position during polysomnography was devised in this study (Fig. S1). The instrument was made with expanded polystyrene and covered with a latex-type pad, and was constructed to enable manual modulation of its height at the cervical vertebrae and scapula by insertion of layered polystyrene plates (10 mm/plate). In order to modulate angles of lateral position, we used another part which was made with the same plastic material (that is, polystyrene). When a participant needs to change to a lateral position, the part was inserted under a latex-type pad, which made it possible to maintain 20 and 40° of lateral position. The horizontal length of the part was 360 mm and we made two parts to modulate 20 and 40° so that the heights of two parts were 161 and 322 mm.

Statistical analyses

The central composite design data were analyzed with a polynomial second-order equation by the least-squares method (SAS 9.13, NC, USA). To adjust baseline values, a quadratic response surface regression model with a simple linear regressor for covariates was used. Optimization of RSA was conducted by minimizing snoring rate and AHI by fitting the following quadratic model:

Table 2 Estimated regression coefficients for snoring rate and AHI

	Snoring rate*		AHI†	
	$\beta \pm SE$	P-value	$\beta \pm SE$	P-value
Intercept	-0.016812 ± 0.063704	0.8024	6.454992 ± 2.591484	0.0471
CVS-HT	0.063123 ± 0.022364	0.0370	1.752126 ± 1.182849	0.1890
SS	-0.089298 ± 0.021992	0.0097	-1.425204 ± 1.182849	0.2736
LP	-0.102957 ± 0.022282	0.0057	-3.290255 ± 1.182849	0.0319
CVS-HT ²	0.041497 ± 0.039176	0.3380	-0.805003 ± 1.586961	0.6301
CVS-HT × SS	-0.075907 ± 0.030031	0.0527	2.212500 ± 1.448687	0.1776
SS ²	0.100885 ± 0.029172	0.0181	1.345008 ± 1.586961	0.4292
SS×LP	0.002958 ± 0.025622	0.9126	-4.237500 ± 1.448687	0.0265
CVS-HT × LP	-0.070476 ± 0.026007	0.0423	-4.062500 ± 1.448687	0.0310
LP ²	0.000002232 ± 0.028218	0.9999	1.720010 ± 1.586961	0.3201
Baseline value	0.607736 ± 0.234279	0.0486	0.108488 ± 0.221222	0.5058

The parameter estimates were based on coded factors.

CVS-HT, cervical vertebrae support with head tilting; SS, scapula support; LP, lateral position; AHI, apnea–hypopnea index.

*The P-value for the Goodness of Fit test for the regression model in the snoring rate was 0.0046 and the R² for the regression model was 0.9659.

†The P-value for the Goodness of Fit test for the regression model in AHI was 0.0264 and the R² for the regression model was 0.8438.

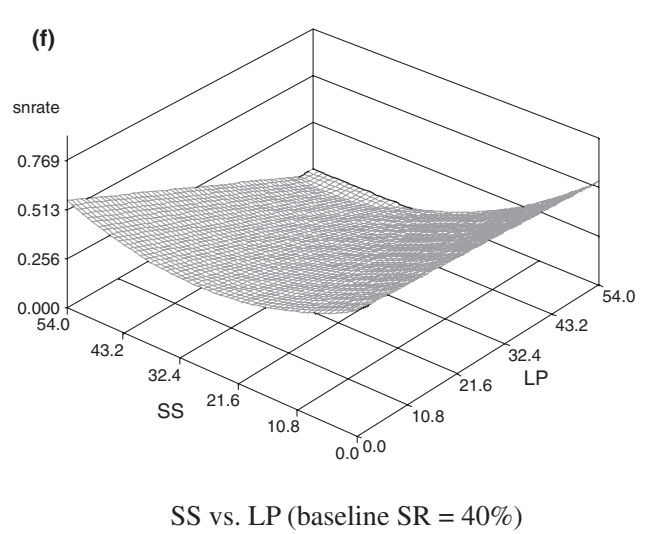
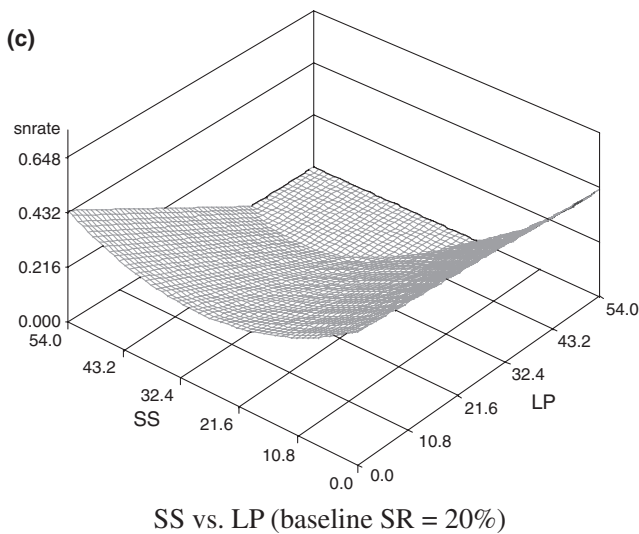
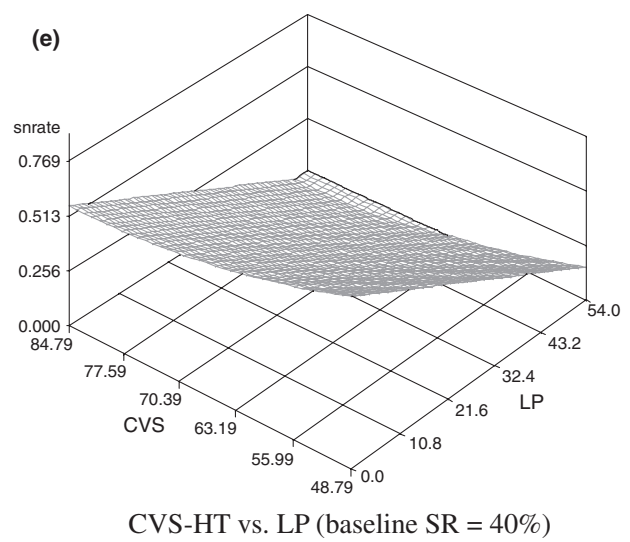
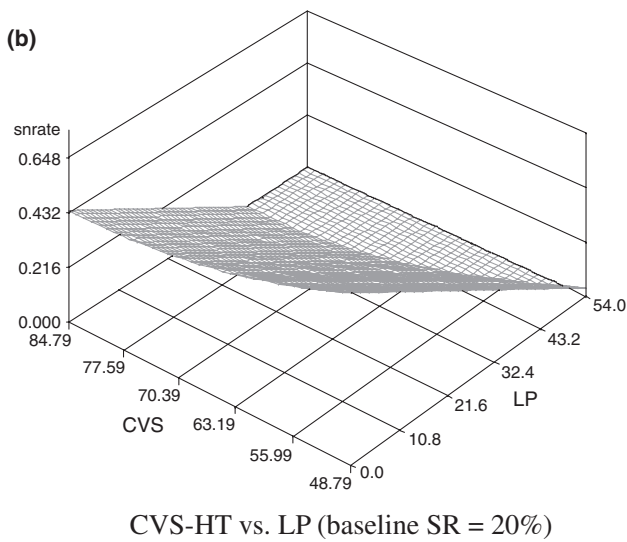
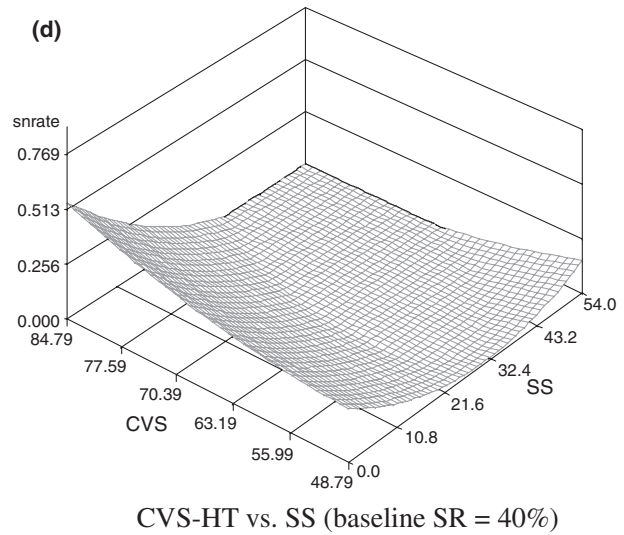
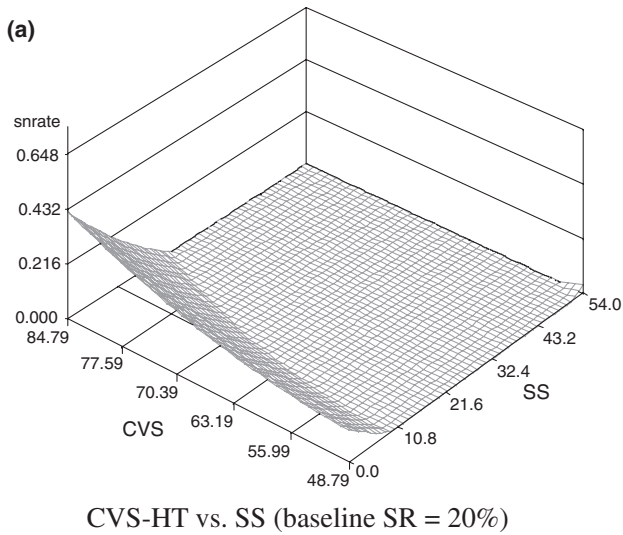


Figure 1. Response surface maps of snoring rate (baseline snoring rate (SR) = 20%, 40%). (a) cervical vertebrae support with head tilting (CVS-HT) versus scapula support (SS) (baseline SR = 20%) (d) CVS-HT versus SS (baseline SR = 40%). (b) CVS-HT versus LP (baseline SR = 20%) (e) CVS-HT versus LP (baseline SR = 40%). (c) SS versus LP (baseline SR = 20%) (f) SS versus LP (baseline SR = 40%).

$$y = \beta_0 + \gamma z + \sum_{i=1}^p \beta_i x_i + \sum_{i=1, j=1}^p \beta_{ij} x_i x_j + \sum_{i=1}^p \beta_{ii} x_i^2$$

where y is the calculated snoring rate or AHI, p ($P = 3$ in this study) is the number of variables in the model, β_0 , β_i , β_{ij} are coefficients determined by polynomial second-order regression, γ is a coefficient of a covariate, and z , x_i are the covariate and independent variables of the model respectively.

RESULTS

Out of 25 participants, 16 subjects satisfied the eligibility criteria. The mean age and BMI of the 16 subjects were 47.6 ± 3.29 years and 25.6 ± 2.18 kg/m² respectively. A summary of sleep-related characteristics is given in Table 1. Total sleep time of the 16 subjects was 432 ± 48 min (303 and 128 min at the supine and non-supine position, respectively) on the first night and 421 ± 40 min (219 and 202 min at the supine and non-supine positions, respectively) in the experiment. In the screening examination, the average snoring rate and AHI were $29.2 \pm 13.5\%$ and 15.2 ± 7.9 , respectively. The snoring rate and AHI in the supine position ($36.2 \pm 15.2\%$ and 24.3 ± 8.1 , respectively) were significantly higher than in the non-supine position ($7.3 \pm 13.2\%$ and 5.2 ± 7.2 , respectively). However, the Arousal Index and minimal saturation were similar between supine (23.5 ± 7.8 and $82.2 \pm 8.2\%$, respectively) and non-supine (21.0 ± 8.2 and $88.4 \pm 8.2\%$, respectively) positions. Also, sleep efficiency in non-supine position ($89.1 \pm 10.1\%$) was relatively higher than that in supine position ($84.2 \pm 9.3\%$).

Significant factors in snoring and sleep apnea based on RSA

A polynomial regression was performed to observe the effects of design parameter changes on snoring. The estimated regression equation for snoring rate is summarized in Table 2 (left side). Among the linear regressors, the estimated regression coefficients of LP were the most significant (-0.1030 , $P = 0.0057$). For the snoring rate, SS and CVS-HT were also significant. CVS-HT was negatively associated with a reduction of snoring rate. The cross product of CVS-HT and LP (-0.0705 , $P = 0.0423$) also contributed to snoring rate reduction. The fitted model revealed that the following factors reduce snoring: LP significantly affects the snoring rate; there was an interaction among CVS-HT and LP as well as LP and the quadratic effect of SS (0.1008 , $P = 0.018$). Moreover, CVS-HT and SS had a tendency to interact with each other.

Regarding model fitting for sleep apnea, the response surface regression model was used to observe the effects of design parameter changes on AHI. The estimated regression equation for AHI is summarized in Table 2 (right side). Among the main effects, the estimated LP regression coefficients were the only significant factors (-3.2903 , $P = 0.0319$) while an interaction with CVS-HT and SS (-4.0625 ,

$P = 0.0310$ and -4.2375 , $P = 0.0265$, respectively) also contributed to reduce AHI.

The estimated regression parameters indicated that AHI is mainly influenced by LP, and that the interactions of CVS-HT and LP, as well as SS and LP, are very significant at reducing snoring.

Optimal position for snoring reduction

Fig. 1 shows the response surface map when the baseline snoring rate was 20% (a–c) and 40% (d–f). In Fig. 1a, d, three-dimensional plots of CVS-HT and SS corresponding to snoring rate, shows that the snoring rate increased as the height of CVS-HT increased. These plots also show that there was an interaction between CVH-HT and SS, which implies that CVS-HT alone was not effective, but that CVS-HT and SS should be simultaneously increased to reduce the snoring rate. In Fig. 1b, e, three-dimensional plots of CVS-HT and LP corresponding to the snoring rate indicate that high CVS-HT

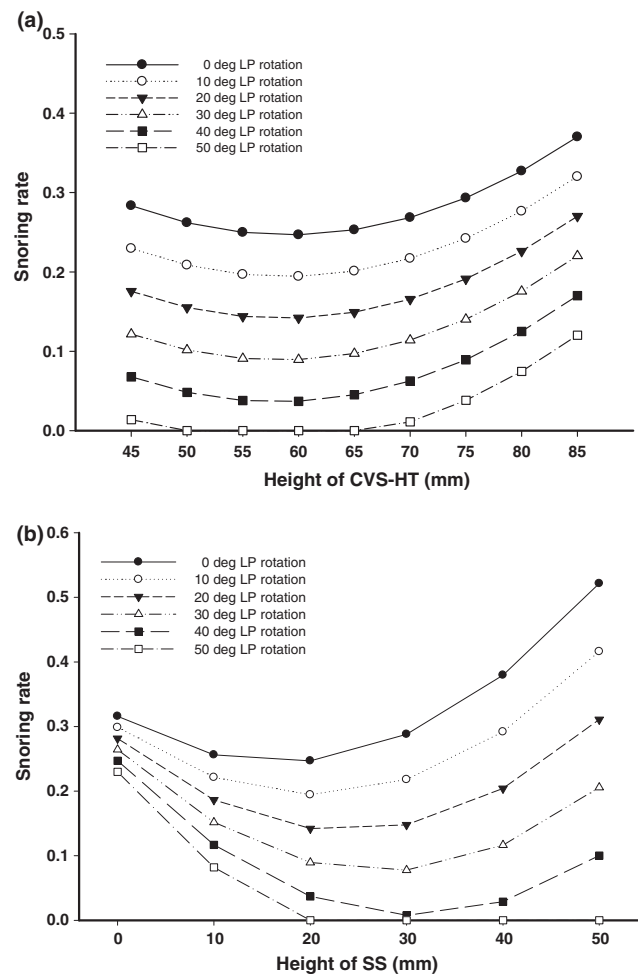


Figure 2. Comparison of snoring rates (baseline SR = 30%). (a) A comparison of snoring rates according to cervical vertebrae support with head tilting (CVS-HT) [scapula support (SS) = 20 mm]. (b) A comparison of snoring rates according to SS (CVS-HT = 60 mm).

levels in the supine position (that is LP = 0°) increased the snoring rate; the appropriate levels of CVS-HT should be maintained in the LP. Fig. 1e, f show that the quadratic effect of SS was dominant, as were the main effects of SS and LP.

Fig. 2a shows the snoring rates at 0–50° LP rotation when the baseline snoring rate and level of SS were 30% and 20 mm, respectively. In Fig. 2a, increasing degrees of LP rotation helped to eliminate snoring at moderate levels of CVS-HT (50–70 mm). In contrast, the snoring rate decreased in the LP with at least 20 mm SS, and 40–50° LP rotation made the snoring rate zero (Fig. 2b). Notably, a higher level of SS (> 20°) in the supine position increases the snoring rate. In summary, the model of snoring rate revealed that complex interactions among design parameters existed for the snoring rate. As shown in Figs 1 and 2, the important factors for eliminating snoring were LP and LP's interaction with CVS-HT.

In Table 3, the estimated snoring rate is enumerated with all possible combinations of the three factors when snoring rates in the supine position were 20, 30 and 40%. To achieve >80% reduction in snoring rate when the baseline snoring rate is 20%, LP and SS should be more than 30° and 20 mm, respectively, when CVS-HT is 60 mm. When the LP is 40° and SS is ≥20 mm, the snoring rate was reduced to zero. When the baseline snoring rate was > 30%, more than a 40° rotation was

required to achieve an 80% reduction of the snoring rate. When the snoring rate in the supine position was 40%, no combination of sleep positions could reduce the snoring rate by more than 5%.

Optimal position for reducing sleep apnea

Fig. 3, which is the response surface map when baseline AHI was 15 (a–c) and 30 (d–f), demonstrates the complicated relationship between the three sleep position factors. Contrary to the snoring rate, CVH-HT's interactions with SS and LP were inversely U-shaped, implying that moderate levels of position changes may not be effective in reducing sleep apnea.

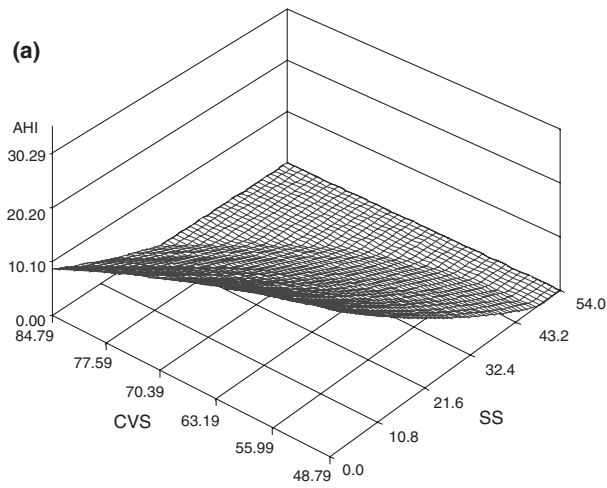
In Fig. 4a, when baseline AHI and level of SS were 20 and 20 mm, respectively, the AHI at 0–50° of LP rotation demonstrated that increasing degrees of CVS-HT was essential for LP's reduction of AHI. In Fig. 4a, the supine position (0° LP rotation) with a lower level of CVS-HT was also effective, but this position was uncomfortable. In agreement with Fig. 3c, f, AHI decreased to more than 50% in the LP (30–50°) with at least 20 mm SS (Fig. 4b).

Table 4 demonstrates the estimated AHI with possible combinations of the three factors when AHI in the supine position was 10, 20 and 30. To achieve >70% reduction of

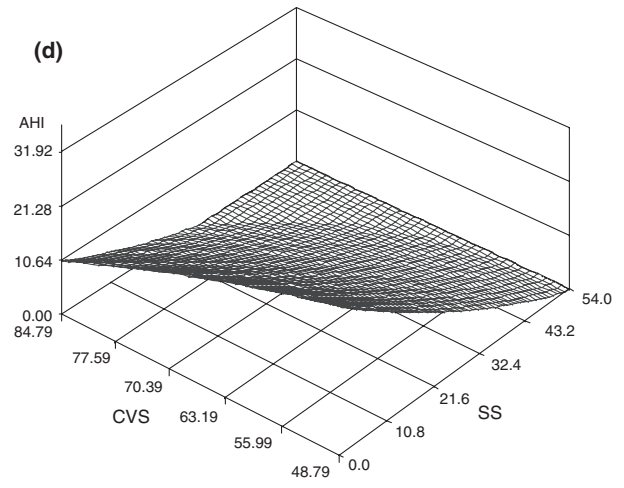
Table 3 Possible combinations for minimizing the snoring rate

Snoring rate = 20%		CVS-HT(mm)				Snoring rate = 30%		CVS-HT(mm)				Snoring rate = 40%		CVS-HT(mm)					
LP (°)	SS (mm)	50	60	70	80	LP (°)	SS (mm)	50	60	70	80	LP (°)	SS (mm)	50	60	70	80		
0	0	21.97	25.51	32.74	43.66	0	0	28.05	31.59	38.81	49.73	0	0	34.12	37.66	44.89	55.81		
	10	18.52	19.53	24.23	32.61		10	10	24.60	25.61	30.31		38.69	10	10	30.68	31.69	36.38	44.77
	20	20.12	18.60	20.76	26.62		20	20	26.20	24.68	26.84		32.70	20	20	32.27	30.75	32.92	38.77
	30	26.77	22.71	22.35	25.67		30	30	32.84	28.79	28.42		31.75	30	30	38.92	34.86	34.50	37.83
10	0	20.15	23.79	32.74	43.66	10	0	26.23	29.86	38.81	49.73	10	0	32.30	35.94	44.89	55.81		
	10	14.94	16.05	17.46	29.33		10	10	21.02	22.12	26.92		35.40	10	10	27.09	28.20	33.00	41.84
	20	14.78	13.35	20.76	26.62		20	20	20.85	19.43	26.84		32.70	20	20	26.93	25.51	32.92	38.77
	30	19.65	15.70	22.35	25.67		30	30	25.73	21.78	28.42		31.75	30	30	31.81	27.86	34.50	37.83
20	0	29.58	23.09	28.96	29.88	20	0	35.66	29.17	35.05	35.94	20	0	41.73	35.25	41.13	41.92		
	10	18.33	22.07	29.49	40.60		10	10	24.40	28.14	35.56		46.68	10	10	30.48	34.22	27.76	33.73
	20	11.36	12.56	20.30	26.04		20	20	17.43	18.63	23.53		32.12	20	20	23.51	24.72	29.61	38.19
	30	9.43	8.10	10.47	16.52		30	30	15.51	14.18	16.55		22.60	30	30	21.58	20.26	22.62	28.68
30	0	12.55	8.69	8.53	12.05	30	0	18.62	14.77	14.60	18.13	30	0	24.70	20.85	20.68	24.20		
	10	20.71	14.32	11.63	12.62		10	10	26.79	20.46	17.70		18.70	10	10	32.86	26.48	23.78	24.77
	20	16.51	20.34	27.86	39.07		20	20	22.58	26.42	33.94		45.16	20	20	28.66	32.49	40.02	51.23
	30	7.77	9.08	14.07	22.75		30	30	13.85	15.15	20.15		28.83	30	30	19.93	21.23	26.22	34.91
40	0	4.08	2.86	5.32	11.47	40	0	10.16	8.94	11.40	17.55	40	0	16.24	15.01	17.48	23.63		
	10	5.44	1.68	1.62	5.24		10	10	11.52	7.76	7.68		11.31	10	10	17.59	13.84	13.75	17.39
	20	11.84	5.55	2.96	4.05		20	20	17.92	11.63	9.03		10.12	20	20	23.99	17.71	15.15	16.20
	30	14.68	18.62	26.24	37.55		30	30	20.76	24.69	32.32		43.63	30	30	26.84	30.77	38.39	49.70
40	0	4.19	5.59	10.68	19.46	40	0	10.27	11.67	16.76	25.54	40	0	16.34	17.75	22.84	31.62		
	10	0	0	0.17	6.42		10	10	4.82	3.69	6.25		12.50	10	10	10.89	9.77	12.33	18.58
	20	0	0	0	0		20	20	4.41	0.75	0.78		4.51	20	20	10.49	6.83	6.86	10.58
	30	2.97	0	0	0		30	30	9.05	2.86	0.36		1.51	30	30	15.13	8.94	6.44	7.63

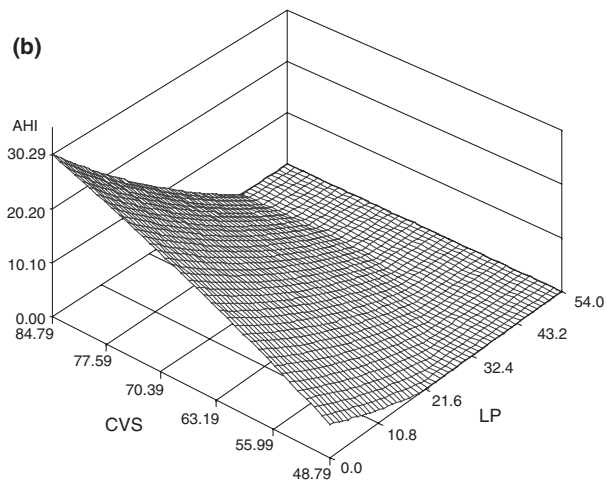
Bold characters indicate a >80% reduction in snoring rate compared with the baseline snoring rate.
 CVS-HT, cervical vertebrae support with head tilting; SS, scapula support; LP, lateral position.



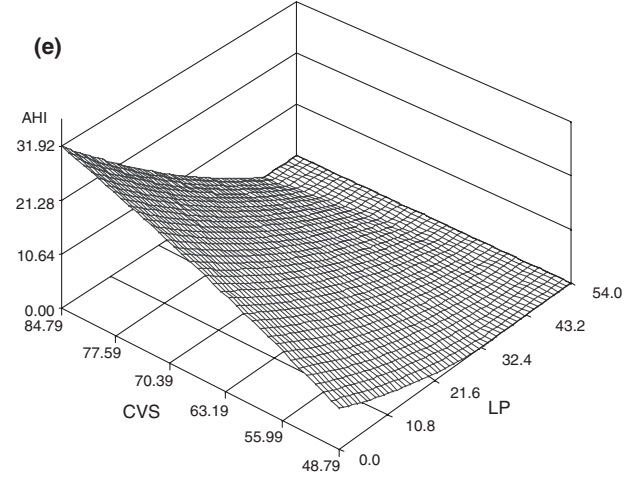
CVS-HT vs. SS (baseline AHI = 15)



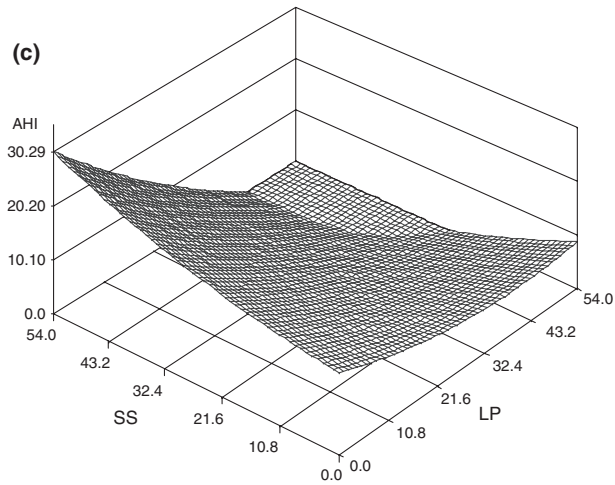
CVS-HT vs. SS (baseline AHI = 30)



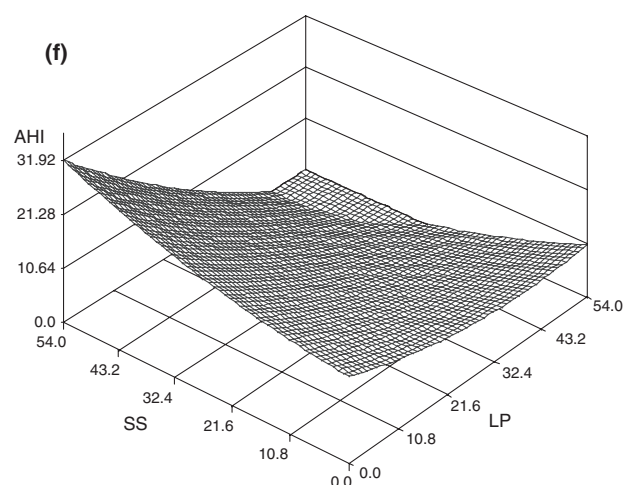
CVS-HT vs. LP (baseline AHI = 15)



CVS-HT vs. LP (baseline AHI = 30)



SS vs. LP (baseline AHI = 15)



SS vs. LP (baseline AHI = 30)

Figure 3. Response surface maps of apnea–hypopnea index (AHI) (baseline AHI = 15, 30). (a) cervical vertebrae support with head tilting (CVS-HT) versus SS (baseline AHI = 15) (d) CVS-HT versus SS (baseline AHI = 30). (b) CVS-HT versus LP (baseline AHI = 15) (e) CVS-HT versus LP (baseline AHI = 30). (c) SS versus LP (baseline AHI = 15) (f) SS versus LP (baseline AHI = 30).

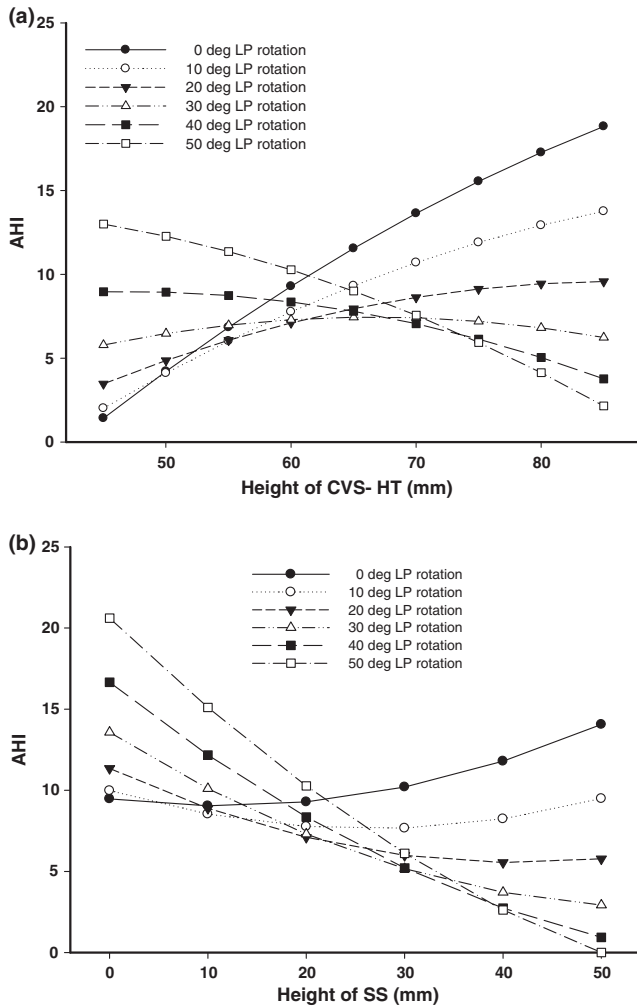


Figure 4. Comparison of apnea-hypopnea index (AHI) (baseline AHI = 20). (a) AHI comparison according to cervical vertebrae support with head tilting (CVS-HT) (scapula support = 20 mm). (b) AHI comparison according to CVS-HT (CVH-HT = 60 mm).

AHI at baseline when AHI is 10, LP and SS should be at least 40° and 30 mm, respectively. To achieve at least an 80% reduction of AHI, LP and SS should be > 30° and/or 20 mm, respectively.

DISCUSSION

The data from this study demonstrated that, by using RSA, the optimal sleeping position for eliminating snoring was highly associated with the LP and its interaction with CVH-HT. The results from this study also showed that the interaction of LP with CVS-HT and SS was effective in reducing sleep apnea. The principal conclusion of this study was that more than a 30° rotation and 20 mm elevation of the upper trunk with moderate support (60–70 mm) of the cervical vertebrae were effective at reducing snoring. For sleep apnea, a > 40° rotation with higher levels of CVS-HT (> 70 mm) and SS (30 mm) were recommended for an AHI reduction > 80%. Based on the

estimated regression equation, the optimal sleeping position could ideally reduce the snoring rate to 0% during the entire sleeping period when a $\geq 40^\circ$ lateral rotation and a ≥ 60 mm cervical vertebrae elevation in mild snoring patients (i.e. a snoring rate $\leq 20\%$) is employed. In addition, AHI could be decreased to < 80% in the case of a $\geq 40^\circ$ lateral rotation and a ≥ 30 mm SS with the appropriate CVS-HT in mild or moderate sleep apnea.

Several studies have investigated the effectiveness of positional therapy on snoring and sleep apnea, but they have reported inconsistent results (Braver and Block, 1994; Itasaka *et al.*, 2000; Mador *et al.*, 2005; Nagano *et al.*, 2003; Oksenberg *et al.*, 1997). Several researchers have reported that a backpack and ball, used as a positional device, significantly improved sleep apnea severity (Berger *et al.*, 1997; Zuberi *et al.*, 2004). Oksenberg and Silverberg (1998) and Itasaka *et al.* (2000) reported that obesity was negatively associated with the AHI. This result implied that weight loss was more effective for eliminating SDB in the lateral than in the supine position (Oksenberg *et al.*, 1997). Weight loss is a well known fundamental therapy in patients with sleep apnea. However, many patients experience difficulty with weight loss and fail to lose weight. In contrast, positional therapy is one of the easiest approaches in patients with mild or moderate patients to reduce SDB. In addition, practical applications of positional therapy should not be disregarded. However, few studies have been performed on the combined effect of positional therapy and weight loss.

Based on results from our present study, body position change may be a dominant factor for mild to moderate OSA. Oksenberg *et al.* (1997) suggested that positional therapy is important for treating upper airway resistance syndrome (UARS), which appears to be the mildest form of upper airway disturbance during sleep, occurring even in non-snoring patients; this syndrome may be caused mainly by sleeping in the supine position (Hiyama *et al.*, 2003). Thus, the non-supine position may be helpful in avoiding an increase in UARS, and as a consequence, CPAP treatment can be bypassed, which has been reported to be associated with very poor outcomes in UARS patients (Menn *et al.*, 1996; Rauscher *et al.*, 1995).

Initially, the tennis ball technique (Cartwright, 1984; Rauscher *et al.*, 1995), an alarm system to awake the patients (Cartwright *et al.*, 1985), and an alternative to the tennis ball technique (Freebeck and Stewart, 1995), were widely used in positional therapy. These devices benefited a small percentage of patients with positional snoring and apnea. However, because these devices caused patients' arousal by a pain stimulus or loud noise, acceptance of and compliance with these devices was problematic. Moreover, few studies have evaluated sleep quality while treatment modalities are being evaluated. Even though the anatomical and physiological mechanisms responsible for the breathing function in the supine position have not been well defined, the influence of gravity on the upper airways is regarded as the most dominant factor (Oksenberg and Silverberg, 1998; Penzel *et al.*, 2004).

Table 4 Possible combinations for minimizing AHI

<i>AHI</i> = 10		<i>AHI</i> = 20				<i>AHI</i> = 30		<i>AHI</i> = 30				<i>AHI</i> = 30					
		<i>CVS-HT(mm)</i>						<i>CVS-HT(mm)</i>						<i>CVS-HT(mm)</i>			
<i>LP</i> (°)	<i>SS</i> (mm)	50	60	70	80	<i>LP</i> (°)	<i>SS</i> (mm)	50	60	70	80	<i>LP</i> (°)	<i>SS</i> (mm)	50	60	70	80
0	0	8.38	11.25	13.41	14.86	0	0	14.84	19.35	22.74	25.00	0	0	21.25	27.02	31.37	34.29
	10	7.95	11.56	14.64	16.64	10	10	11.31	15.84	19.47	22.20	10	10	14.36	19.48	23.60	26.69
	20	8.19	12.55	16.18	19.10	20	20	10.78	15.84	20.06	23.46	20	20	13.08	18.58	23.17	26.86
	30	9.11	14.20	18.57	22.23	30	30	11.41	17.10	22.00	26.09	30	30	13.44	19.50	24.71	29.07
	40	10.70	16.53	21.64	26.03	40	40	12.90	19.27	24.86	29.73	40	40	14.80	21.51	27.39	32.44
10	0	8.89	11.25	13.41	11.13	10	0	10.75	13.30	15.63	13.16	10	0	12.43	15.08	17.51	14.95
	10	7.44	9.64	11.13	11.90	10	10	9.10	11.44	13.02	13.84	10	10	10.62	13.05	14.70	15.55
	20	6.67	12.55	16.18	13.34	20	20	8.21	14.42	18.27	15.25	20	20	9.65	16.06	20.03	16.93
	30	6.57	14.20	18.57	15.49	30	30	8.05	16.06	20.67	17.39	30	30	9.45	17.69	22.42	19.05
	40	7.15	16.53	21.64	18.24	40	40	8.61	18.42	23.77	20.22	40	40	10.00	20.06	25.54	21.89
20	0	10.25	10.31	9.64	8.26	20	0	11.81	11.87	11.18	9.74	20	0	13.24	13.29	12.59	11.12
	10	7.80	8.58	8.66	8.01	10	10	9.22	10.04	10.11	9.45	10	10	10.57	11.40	11.48	10.79
	20	6.01	7.53	8.35	8.44	20	20	7.34	8.92	9.76	9.86	20	20	8.63	10.24	11.09	11.20
	30	4.90	7.16	8.71	9.54	30	30	6.18	8.51	10.11	10.97	30	30	7.42	9.81	11.44	12.31
	40	4.45	7.45	9.74	11.31	40	40	5.71	8.80	11.15	12.77	40	40	6.94	10.08	12.48	14.12
30	0	12.48	11.12	9.04	6.25	30	0	13.96	12.56	10.42	7.55	30	0	15.31	13.88	11.71	8.80
	10	9.01	8.38	7.04	4.99	10	10	10.36	9.72	8.35	6.23	10	10	11.65	10.99	9.60	7.46
	20	6.21	6.32	5.72	4.40	20	20	7.47	7.59	6.97	5.62	20	20	8.71	8.83	8.20	6.83
	30	4.08	4.93	5.06	4.48	30	30	5.28	6.15	6.30	5.70	30	30	6.48	7.37	7.50	6.90
	40	2.62	4.21	5.08	5.24	40	40	3.78	5.41	6.31	6.46	40	40	4.96	6.61	7.51	7.67
40	0	15.57	12.80	9.31	5.10	40	0	17.02	14.18	10.62	6.32	40	0	18.34	15.48	11.87	7.52
	10	11.08	9.04	6.29	2.82	10	10	12.42	10.34	7.53	3.99	10	10	13.68	11.57	8.73	5.15
	20	7.26	5.96	3.95	1.22	20	20	8.51	7.19	5.13	2.35	20	20	9.72	8.38	6.31	3.49
	30	4.12	3.56	2.28	0.29	30	30	5.30	4.73	3.42	1.40	30	30	6.48	5.90	4.58	2.53
	40	1.65	1.80	1.28	0.03	40	40	2.78	2.96	2.41	1.13	40	40	3.93	4.10	3.55	2.26

Bold characters indicate >80% reduction in AHI compared with the baseline AHI.

CVS-HT, cervical vertebrae support with head tilting; SS, scapula support; LP, lateral position, AHI, apnea-hypopnea index.

Thus, recently developed devices for position therapy have focused on positional correction to enlarge the upper airway; these devices have maximized patients' acceptance and compliance (Bliwise *et al.*, 2004; Skinner *et al.*, 2004). However, these position correction approaches did not take the theoretical effects of the head, neck and shoulder position on the influence of gravity in the supine and non-supine positions into consideration. Specifically, the inlet of upper airway anatomy is known to vary according to the effect of gravity and the positions of the head and neck. Thus, exploring the optimal sleep position to prevent snoring and sleep apnea is vital for successful positional therapy.

This study has a few limitations. To determine the optimal position, only mild and moderate positional sleep apnea patients with snoring were included. In addition, RSA may not reflect the true snoring rate and AHI in the far outside range of each component. For example, setting the lateral rotation more than 60° is actually impossible with a manual position support device. Moreover, if patients were set to rotate more than 50°, they would be required to be placed in a complete LP by themselves during sleep. Most patients with positional sleep apnea and snoring were mild and moderate cases, and numerous studies have reported that severe patients are not affected by positional therapy

(Cartwright, 1984; Oksenberg and Silverberg, 1998; Oksenberg, 1997). Further limitations include the fact that the patients' comfort in the optimal sleeping position could not be measured and that some of the patients could not maintain some of the sleeping positions for extended periods of time. Thus, the optimal range of the three components was carefully applied, and development of an automatic device, which enables a slow positioning change without the patient's arousal and discomfort, is necessary. However, this study was the first trial to evaluate the effect of these three components and their interactions to determine optimal sleeping positions.

In summary, positional therapy was very effective in patients with mild or moderate sleep apnea and/or snoring, and the LP was the most effective of the three components. To determine the optimal sleeping position, patients with positional sleep apnea or snoring need to consider cervical vertebrae support and head and scapula tilting, as well as the degree of their LP.

CONFLICT OF INTEREST

None of the authors have a financial relationship with a commercial entity that has an interest in the subject of this manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Figure S1. Layout of instrument used for setting a specific sleep position (mm).

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