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Positional therapy in patients with residual positional obstructive sleep apnea after upper airway surgery

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Abstract
Purpose/background A considerable portion of patients has residual positional obstructive sleep apnea (POSA) after upper airway surgery. Those patients could benefit from additional treatment with positional therapy (PT). The objective of this prospective study was to assess the additional effect of PT in patients with residual POSA after upper airway surgery for sleep apnea.
Methods A polysomnography (PSG) was used to diagnose a patient with residual POSA after surgery. After informed consent, patients were treated with PT for 3 months and underwent a follow-up PSG while using the sleep position trainer (SPT). Changes in apnea-hypopnea index (AHI) and sleep position parameters were analyzed. Compliance rates and mean disease alleviation (MDA) were determined.
Results Thirty-three patients with a median postoperative AHI of 18.3/h sleep were included. With the SPT median AHI dropped to 12.5/h sleep and the Epworth Sleepiness Scale (ESS) improved from 10.0 to 7.0. After 3 months, 37.5 % patients were considered responders of whom 31.3 % had treatment success. The compliance rate with SPT was 89.0 %. MDA was 44.7 % for SPT alone. With the combination of both surgery and SPT, MDA was 65.6 %.
Conclusions The results of this study indicate that additional PT in a complex OSA patient population with residual POSA after surgery can increase overall therapeutic effectiveness by improving the median MDA from 39.5 % (effect of surgery alone) to 65.6 % (effect of combining surgery and PT).

Keywords Residual positional obstructive sleep apnea · Positional therapy · Upper airway surgery · Obstructive sleep apnea

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Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent episodes of partial or complete collapse of the upper airway during sleep, leading to decreased oxygen blood levels and microarousals. This results in fragmented sleep accompanied by symptoms such as snoring, observed apneas and excessive daytime sleepiness [1].

The obstruction in the upper airway is caused by muscle relaxation and is aggravated by the influence of gravity. It is hypothesized that in patients who snore but initially do not suffer from OSA, apneas start occurring in the supine position, since gravity can then exert its maximal effect [2]. When left untreated, apneas will eventually develop in all sleeping positions as severity increases. In line with this assumption, it is reported that a considerable number of patients with mild and moderate OSA have a higher apnea-hypopnea index (AHI) in supine sleeping position [3]. Several studies reported a prevalence of position dependency of approximately 56 % in patients with mild OSA. Patients with severe OSA often have a high AHI in all sleep positions [4–6]. Positional OSA (POSA)

is diagnosed when the AHI is at least twice as high in supine position compared to the non-supine sleeping position [4].

Since various therapeutic options for patients with POSA have been presented over the last years, measurement of sleep posture is one of the key parameters during a sleep registration. Besides conservative measures (e.g., weight reduction, abstinence from alcohol, smoking, and sedatives), promising results of positional therapy (PT) with new devices have recently been shown [7]. The sleep position trainer (SPT) is a chest-worn device that gives a subtle stimulus when supine sleeping position is detected. Studies suggest that the SPT successfully prevents patients from sleeping in supine position without disrupting their sleep and hereby improves sleep-related quality of life parameters with a reported long-term compliance of 64.4 % [8].

In patients with moderate and severe OSA, continuous positive airway pressure (CPAP) is still regarded as gold standard treatment, but its compliance is often disappointing [9, 10]. Oral appliance therapy (OAT) is an alternative treatment modality for patients with mild or moderate OSA. The therapy is generally well tolerated but one third of the patients experience no therapeutic benefit [11]. Some of the non-responders have a high residual AHI in supine position [12]. Surgery is a treatment option for well-selected patients when noninvasive treatments such as CPAP or OAT have been unsuccessful. A wide variety of interventions is available, both minimally invasive as well as more invasive such as tonsillectomy (TE), uvulopalatopharyngoplasty (UPPP), Z-palatoplasty (ZPP), hyoid suspension (HS), tongue base surgery, and upper airway stimulation [13–19]. In selected patients with severe OSA, maxillomandibular advancement (MMA) can be indicated, both as primary surgery and in case of treatment failure [20–22].

A recent study from Dieltjens et al. showed that 34 % of patients treated with OAT still has residual POSA while using oral appliances [12]. In another study, they showed that a combined therapeutic strategy of both OAT and PT with the SPT resulted in a higher therapeutic efficacy than treatment with OAT or PT alone [12].

Similarly to residual POSA under OA therapy, we observed that a number of patients who had undergone upper airway surgery for OSA had residual disease, mainly in supine position, i.e., the AHI in supine sleeping position remained high, whereas the AHI in other sleeping positions had improved considerably. A retrospective analysis by Van Maanen et al. showed that UPPP/ZPP with or without radiofrequency thermotherapy of the tongue base (RFTB) significantly reduced AHI, but the reduction was significantly higher in non-positional OSA than in POSA patients [23].

The effectiveness of combining different treatments for OSA has been little investigated. Since the effect of combining OSA surgery and PT still needs to be determined, the purpose of this prospective study was to assess the efficacy of additional PT with the SPT in patients with residual POSA after upper airway surgery for OSA.

Methods

Study design

We performed a prospective study, approved by the institution's ethical committee. The first patient was included in January 2014 and the last follow-up polysomnography (PSG) was performed in April 2015. After signing an informed consent form, patients received the SPT (NightBalance B.V., Delft, NL) and filled out the Epworth Sleepiness Scale (ESS) and the Functional Outcomes of Sleep Questionnaire (FOSQ) to assess their daytime sleepiness and quality of life [24, 25]. After 3 months of therapy, a follow-up PSG was performed while the patients used their SPT, and the patients filled out the questionnaires again.

Patients

Patients were recruited from the department of Otolaryngology, Head and Neck surgery of the OLVG West Hospital in Amsterdam, The Netherlands. All patients already had undergone (any combination of) surgical treatment for OSA or POSA, i.e., RFTB, TE, UPPP/ZPP, HS, or MMA.

Either after referral from another clinic because of persistent OSA, or as part of regular follow-up, a PSG was performed. Patients were asked to participate in this study when they met the following inclusion criteria: (1) age of 18 years or older, (2) previous upper airway surgery as treatment for POSA/OSA, (3) POSA at baseline PSG after surgery, (4) the percentage of total sleep time in supine position was between 10 and 90 %, and (5) ability to use the necessary SPT computer software. Main exclusion criteria were as follows: (1) shoulder or neck complaints, (2) working in changing or night shifts, (3) epilepsy, (4) simultaneous use of other treatment modalities for OSA, (5) other sleep-related disorders (i.e., severe restless leg syndrome).

Polysomnography

A PSG was performed during an overnight stay in the hospital, using a digital PSG system (Embla A10, Broomfield, CO, USA). This system recorded an electroencephalogram (EEG) (FP2-C4/C4-O2), electro-oculogram (EOG), electrocardiogram (ECG), and a submental and anterior tibial electromyogram (EMG). Nasal airflow was measured by a pressure sensor in a nasal cannula and blood oxygen saturation was measured by finger pulse oximetry. Straps containing piezoelectric transducers recorded thoracoabdominal motion and a position sensor (Sleepsense, St Charles, IL, USA) attached to the

midline of the abdominal wall was used to differentiate between supine, prone, right lateral, left lateral, and upright positions. The recorded data were analyzed using special software (*Somnologica*™, Broomfield, USA) and manually checked and scored by an employee of the clinical neurophysiology department of the OLVG West hospital Amsterdam.

Definitions

The sleep stages were scored manually in 30-s epochs according to American Academy of Sleep Medicine (AASM) criteria [1]. An apnea was defined as the cessation of nasal airflow of more than 90 % for a period of 10 s or longer in the presence of respiratory efforts. In accordance with the prevailing definition at that time, a hypopnea was scored whenever there was a greater than 30 % reduced oronasal airflow for at least 10 s, accompanied by ≥4 % oxygen desaturation from pre-event baseline. The AHI is defined as the mean number of apneas and hypopneas per hour during sleep. Oxygen desaturation index (ODI) was defined as the number of times per hour of sleep that the blood oxygen level drops by 4 % or more from baseline. POSA was diagnosed when the AHI in supine position was at least twice as high as in the non-supine position, and the percentage of total sleeping time in supine position was between 10 and 90. Similarly to the compliance definition used in CPAP, a patient was declared compliant to the SPT if the mean daily use of the SPT was ≥ 4 h per night, during ≥ 5 days per week [9]. Treatment response to SPT therapy was defined as a reduction in overall AHI of more than 50 % from baseline, whereas treatment success was defined as a reduction in overall AHI of more than 50 % from baseline combined with an AHI < 5/h [26]. The concept of calculating the mean disease alleviation (MDA) was introduced by Vanderveken et al. It reflects the overall therapeutic effectiveness of OSA therapy by measuring the efficacy of the therapy combined with the compliance. The MDA (%) is calculated by the product of the compliance, adjusted for total sleep time (TST) (i.e., adjusted compliances) (*X*-axis), combined with therapeutic efficacy (*Y*-axis), divided by 100 [26]. One should be aware of the fact that if the SPT has been switched on but the patient is still awake, the calculation will show that SPT usage will be longer than the TST. This could result in an adjusted compliance >100 % in fully compliant users. Average usage of the SPT per patient per night is calculated by the sum of total therapy time with a cutoff point of 9 h maximum per night, to overcome data errors (e.g., patient who forgot to turn/switch off their device) divided by the total nights slept with the SPT.

Sleep position trainer (SPT)

The SPT is a small device (72 × 35 × 10 mm; 25 g) that has to be worn across the chest using a neoprene torso strap and can vibrate in order to urge a patient to change body position (Fig. 1). The device uses a three-dimensional digital accelerometer to determine the body position. Treatment is divided into three phases. During the first two nights, the SPT analyses body position without giving active feedback to the patient. Then, during the following seven nights, the SPT gradually trains the patient by vibrating in an increasing percentage of episodes of supine sleeping position. Depending on reaction time, the vibration will be adapted automatically in strength, pattern, and duration, until body position will be changed. If the patient does not change position after the stimulus, the SPT will vibrate again after 2 min. At day 10, the so-called therapy phase begins, in which the SPT will vibrate every time the patient is in supine sleeping position, to urge the patient to change his or her sleeping position. The SPT has a USB port to recharge the internal battery and to upload data to an online self-monitoring system, which can also be accessed by the patient's physician.

Fig. 1 The sleep position trainer (SPT). The SPT is a small, lightweight device (72 × 35 × 10 mm; 25 g) that is worn across the chest using a neoprene torso strap

Statistical analysis

For analyses we used descriptive statistics and inferential statistics. All data were first tested for normality by a Kolmogorov-Smirnov test, a Q-Q plot, and Levene's test.

Categorical variables were expressed as *n* (%). Continuous normally distributed variables were expressed by their mean and standard deviation (SD), not normally distributed data by their median and interquartile range (IQR) for skewed distributions. To test groups, categorical variables were tested using the Pearson's chi-square test or Fisher's exact test, when appropriate. Normally distributed continuous data were tested with the independent samples Students *t* test and in case of skewed data, with the independent samples Mann-Whitney *U* test. Predictors were evaluated through univariate and multivariable logistic regression analysis. All independent variables counting more than ten events and showing *p* values <0.1 were eligible for multivariable analysis, which was achieved through backward selection. The optimal prediction model was evaluated with -2Log likelihood. Significance level for baseline variables and multivariable regression analysis was set at *p* value <0.05. Statistical analysis was performed using SPSS Statistical software (version 21.0, SPSS Inc., Chicago, IL).

Results

A group of 33 patients (mean age 52.3 ± 9.7 years; mean body mass index (BMI) 27.9 ± 2.8 kg/m2; male to female = 28: 5) met the inclusion criteria and were enrolled in this study. One patient withdrew, because he opted for alternative therapy. Patient demographics are shown in Table 1.

Pre-surgical evaluation

CPAP failure was noted in 76 % of the included patients (n = 25) and 48.5 % (n = 16) of the patients were failures of OAT prior to enrollment in this study. Some patients had upper airway surgery as first choice treatment. In Table 2 an overview is given of the different surgical procedures that have been performed before the patients started with the SPT.

Polysomnographic results

PSG data of the pre-surgical evaluation showed a median AHI of 28.5/h sleep [18.0–52.8]. Six patients were missing in this analysis since the PSG was performed in the center of referral elsewhere and data could not be retrieved. After surgery, median AHI dropped with 35.8 % to 18.3/h sleep [13.7–24.0]. Additionally, the median AHI significantly dropped further to 12.5/h sleep [4.5–21.8] after 3 months of treatment with the SPT (p = 0.034). All PSG parameters are shown in Table 3. AI, AHI, ODI, and percentage supine sleep all decreased significantly. The severity of daytime sleepiness scored with the ESS improved significantly from 10.0 [5.5–15.0] to 7.0 [5.0–12.0], p = 0.029. Treatment response was noted in 37.5 % of the patients (n = 12) and 20 patients were considered non-responders. From this last group an increase in AHI with the SPT was seen in seven patients (21.7 %). Treatment success was observed in 31.3 % (n = 10). There was no significant difference between the type of surgery performed (uni- or multilevel or MMA) in relation to treatment response. Clinical and polysomnographical characteristics between responders and non-responders are presented in Table 4. In the responder group, the AHI, AI, ODI, supine AHI, percentage supine sleep, percentage non-supine sleep, the arousal index, and the minimum saturation all significantly improved. In the non-responder group, a significant improvement was seen in percentage supine sleep, AHI non-supine, and the minimum saturation. Comparison of responders and non-responders showed that responders had a significantly lower AHI (p < 0.001), AI (p < 0.001), supine AHI (p = 0.015), non-supine AHI (p = 0.001), ODI (p = 0.021), arousal index (p = 0.009), and ESS score (p = 0.043). Time spent in the different sleep stages did not change significantly for both groups.

Table 1 Patient characteristics at baseline inclusion and after 3 months of SPT therapy

Characteristics	Baseline N = 33 Mean ± SD	+ SPT N = 32 Mean ± SD
Age, years	52.3 ± 9.7	
Gender, male no. (%)	28 (84.8)	
BMI, kg/m^2	27.9 ± 2.8	27.9 ± 2.6
Neck circumference, cm	39.6 ± 2.7	39.5 ± 2.7
Smoking, no. (%)	8 (24.2)	7 (21.2)
Alcohol, no. (%)		
<2 EH/day	26 (78.8)	26 (78.8)
2 EH/day	3 (12.1)	3 (9.1)
>2 EH/day	4 (9.1)	3 (9.1)

SPT sleep position trainer, *BMI* body mass index, *SD* standard deviation

Table 2 Sleep parameters before upper airway surgery for OSA and an overview of the surgeries performed

N = 33	Median [IQR]
AHI, /h*	28.5 [18.0–52.8]
AHI supine, /h[a]	54.9 [29.0–73.0]
AHI non-supine, /h[b]	25.5 [8.9–49.1]
Percentage supine sleep, %[b]	49.0 [14.1–64.8]
Surgery	Percentage, % (frequency, n)
UPPP/ZPP	30.3 (10)
UPPP/ZPP + RFTB	27.3 (9)
UPPP/ZPP + RFTB + HS	18.2 (6)
MMA	21.2 (7)
TE	3.0 (1)

IQR interquartile range, *AHI* apneu-hypopnea index, *UPPP* uvulopalatopharyngoplasty, *ZPP* Z-palatopharyngoplasty, *RFTB* radiofrequency thermotherapy of the tongue base, *HS* hyoid suspension, *MMA* maxillomandibular advancement, *TE* tonsillectomy

[a] missing data n = 6

[b] missing data n = 8

SPT compliance and mean disease alleviation (MDA)

The compliance rate (i.e., ≥4 h per night and ≥5 days of usage per week) with the SPT was 89.0 %. Average use per patient per night when the SPT was worn was 6.92 ± 0.75 h. Median percentage of sleep time in supine position with the SPT was 7.4 % [0.1–17.8]. Figure 2 additionally shows the median percentage supine sleep per night from the total group. The median MDA for surgery alone was 39.5 % [4.6–55.1], which consists of an adjusted median compliance of 100 % (all patients had the operation and were therefore adherent) and a median efficacy of 39.5 %. The adjusted median compliance after 3 months of SPT therapy was 107.5 % [95.9–116.8] (with a maximum of 9 h usage). Median therapeutic efficacy

Table 3 Comparison of sleep parameters between baseline inclusion and SPT. First and third quartiles (Q1; Q3)

Characteristics	Baseline Median [IQR] $N = 33$	With SPT Median [IQR] $N = 32$	Wilcoxon signed ranks p value
Total AHI, /h	18.3 [13.7–24.0]	12.5 [4.5–21.8]	*0.034*
Apnea index, /h	13.4 [6.3–18.9]	7.0 [1.6–18.7]	0.051
Obstructive	5.8 [3.0–13.4]	1.9 [0.4–12.6]	*0.030*
Central	0.4 [0.1–1.8]	0.4 [0.0–1.3]	0.204
Mixed	3.2 [0.7–7.2]	1.0 [0.0–2.2]	*0.009*
Total AHI supine, /h	43.0 [24.2–59.6]	32.4 [14.2–66.2]	*0.023*
Total AHI non-supine, /h	4.8 [2.3–8.6]	7.9 [3.3–16.3]	*0.002*
Percentage supine sleep, %	40.1 [32.0–50.0]	7.4 [0.1–17.8]	*<0.001*
Average SaO_2, %	95.0 [94.0–96.0]	95.0 [94.3–96.0]	0.434
Min. SaO_2, %	85.5 [82.3–87.0]	88.0 [86.0–90.0]	*<0.001*
ODI, /h	21.0 [14.7–29.2]	12.9 [5.5–23.3]	*0.011*
Total sleep time, hours	7.2 [6.3–7.8]	6.8 [6.1–8.0]	0.638
Sleep efficiency, %	90.8 [80.8–94.9]	89.5 [85.3–94.0]	0.896
N1 sleep/total sleep time, %	6.9 [3.9–12.4]	6.7 [3.8–12.3]	0.597
N2 sleep/total sleep time, %	50.6 [45.3–58.2]	52.8 [43.3–61.0]	0.556
N3 sleep/total sleep time, %	18.8 [11.0–24.8]	18.7 [13.9–27.4]	0.178
REM sleep/total sleep time, %	20.1 [15.8–24.4]	20.1 [16.0–24.6]	0.525
Positional change index, changes/h	.6 [1.7–3.8]	2.7 [1.6–4.4]	0.530
Questionnaires			
ESS score	10.0 [5.5–15.0]	7.0 [5.0–12.0][a]	*0.029*
FOSQ score	15.8 [10.5–17.0]	16.0 [10.8–18.2][a]	0.616

[a] $n = 31$

was 31.0 % [7.0–65.9], which led to an objective MDA with the SPT therapy of 41.3 % [10.4–70.9]. Combining the effectiveness of surgery with the SPT results led to an overall MDA (from pre-surgical evaluation until $T = 3$ months) of 65.6 % [28.2–87.6], as depicted in Fig. 3.

Discussion

The present study is the first to our knowledge to report on additional treatment with positional therapy in patients with residual POSA after partial effective upper airway surgery. Patients with good response to upper airway surgery were obviously not eligible for this study. The results demonstrate a positive effect of additional treatment with the SPT in about one third of the patients within this cohort. The overall treatment response was 37.5 % and the compliance rate with PT was 89.0 %. Effectiveness of the SPT has been previously evaluated by Van Maanen et al. [7]. They showed a significant reduction in median AHI (from 16.4 to 5.2/h sleep) after 1 month of therapy, with a compliance rate (>4 h per day during 7 days per week) of 92.9 %. The same authors reported on the long-term efficacy and compliance in a multicenter study, in which patients used the SPT for 6 months. Compliance (>4 h per day during 7 days per week) was 64.4 % [8]. Combination therapy of SPT and OAT was reported by Dieltjens et al. [12] They demonstrated that both therapies individually reduced the overall AHI, but with the combination of both the AHI was significantly lower than with monotherapy of each modality.

Despite the high compliance rate during this study period, the number of responders was lower than we had expected beforehand. We can conclude that more research is required to identify predictors of non-responsiveness to therapy, especially since our patient population involved complex cases and the design was a non-controlled selected cohort. Most patients were already failures of other OSA therapy. CPAP was already tried in 76 % of the patients, 48.5 % underwent OAT, and all patients had some type of upper airway surgery (mono- or multilevel) before they were included in this study. It is well-known that the prevalence of multilevel collapse increases with increasing severity of OSA, postoperative drug-induced sleep endoscopy (DISE) could have been performed to gain more detailed information on site (s), configuration, and severity of the upper airway collapse [27]. Another reason for the limited response might be due to involvement of head position, since percentage of supine TST significantly decreased in both groups, but the AHI remained high in

Table 4 Comparison of sleep parameters between responders and non-responders of SPT

Characteristics	Responders $N = 12$			Non-responders $N = 20$			
	$T = 0$	$T = 3$	p value*	$T = 0$	$T = 3$	p value*	p value**
Age, yrs.	52.5 [50.0–60.0]			51.5 [46.0–57.8]			
Male:female	9:3			18:2			
BMI, kg/m^2	27.6 [24.7–28.6]	27.3 [24.8–29.1]	0.799	27.7 [26.2–29.1]	28.0 [26.6–30.5]	0.062	0.136
Neck circumference, cm	39.0 [36.3–40.8]	38.0 [37.0–40.8]	0.317	40.0 [39.3–42.0]	41.0 [39.0–42.0]	0.611	0.076
Total AHI, /h	16.8 [11.6–24.0]	3.9 [1.9–7.3]	*0.002*	20.1 [14.9–24.1]	18.8 [12.1–32.7]	0.940	*<0.001*
Apnea index, /h	12.0 [7.1–19.9]	1.7 [0.3–5.3]	*0.002*	14.1 [7.4–18.6]	14.3 [5.4–27.6]	0.779	*<0.001*
Obstructive	6.0 [2.5–11.4]	0.4 [0.1–2.2]	*0.002*	7.1 [3.4–14.4]	8.3 [1.0–17.2]	0.765	*0.001*
Central	0.9 [0.1–2.7]	0.2 [0.0–1.0]	*0.025*	0.3 [0.0–1.3]	0.5 [0.0–1.8]	0.965	0.307
Mixed	3.2 [0.6–8.3]	0.3 [0.0–1.9]	*0.021*	3.5 [1.0–7.2]	1.1 [0.1–5.6]	0.126	0.366
Total AHI supine, /h	30.9 [20.8–42.4]	4.6 [1.5–29.9]	*0.043*	51.4 [29.8–65.9]	48.9 [22.5–68.4]	0.234	*0.015*
Total AHI non-supine, /h	4.1 [1.3–7.5]	3.3 [1.6–7.2]	0.155	6.4 [2.4–9.4]	13.3 [5.6–31.5]	*0.000*	*0.001*
Percentage supine sleep, %	43.4 [38.0–65.0]	0.2 [0.0–14.1]	*0.002*	37.1 [19.6–48.5]	11.3 [2.1–19.7]	*0.000*	0.070
Average SaO_2, %	94.5 [93.0–96.0]	95.0 [94.0–95.8]	0.196	95.0 [94.3–96.0]	95.0 [95.0–96.0]	0.813	0.431
Min. SaO_2, %	86.0 [82.0–88.0]	89.0 [85.0–90.0]	*0.014*	85.0 [82.3–87.0]	87.5 [86.0–89.8]	0.002	0.632
ODI, /h	18.7 [13.7–30.0]	7.1 [4.3–11.7]	*0.041*	22.3 [17.0–29.2]	17.4 [7.9–29.0]	0.113	*0.021*
Total sleep time, minutes	443 [416–484]	471 [410–514]	0.388	424 [370–471]	388 [368–456]	0.227	*0.044*
Sleep efficiency, %	91.2 [88.5–96.3]	89.9 [86.3–92.4]	0.480	89.0 [77.8–93.9]	89.3 [81.4–94.6]	0.538	1.000
N1 sleep/total sleep time, %	7.4 [3.9–13.3]	7.8 [3.4–12.2]	0.784	7.1 [3.9–11.9]	6.7 [3.8–12.7]	0.601	0.954
N2 sleep/total sleep time, %	48.4 [45.2–57.4]	47.4 [42.8–55.9]	0.158	51.8 [44.8–58.4]	55.5 [47.0–62.0]	0.867	0.146
N3 sleep/total sleep time, %	18.6 [12.6–22.9]	23.1 [13.9–27.6]	0.272	19.1 [9.1–25.8]	17.3 [13.9–25.8]	0.332	0.552
REM sleep/total sleep time, %	20.1 [16.4–24.5]	23.9 [17.5–26.8]	0.433	20.0 [14.1–25.0]	19.5 [13.7–22.2]	0.185	0.146
Positional change index, changes/h	2.1 [1.6–3.8]	2.5 [1.5–4.0]	0.814	2.9 [2.0–4.7]	2.7 [1.7–4.7]	0.573	0.366
Arousal index, /h	9.8 [7.7–13.1]	4.2 [3.3–9.3]	*0.008*	7.7 [3.9–13.0]	11.1 [5.8–14.5]	0.179	*0.009*
ESS score	11.0 [3.8–15.0]	5.0 [4.0–7.8]	0.056	10.0 [6.75–14.5]	9.0 [6.0–12.0]	0.213	*0.043*
FOSQ score	15.5 [10.0–16.9]	16.7 [12.4–18.5]	0.374	10.2 [16.1–17.3]	15.8 [9.8–18.2]	0.831	0.509

Median [IQR] *Wilcoxon signed rank; **Mann-Whitney U test with/after SPT

non-responders. This suggests that the trunk position might be lateral (due to an effective response on the SPT) but the head possibly remained in supine position.

Sleep position and surgical outcome The AHI in mild and moderate OSA patients is usually higher in the supine sleep position when compared to other sleeping positions, due to the

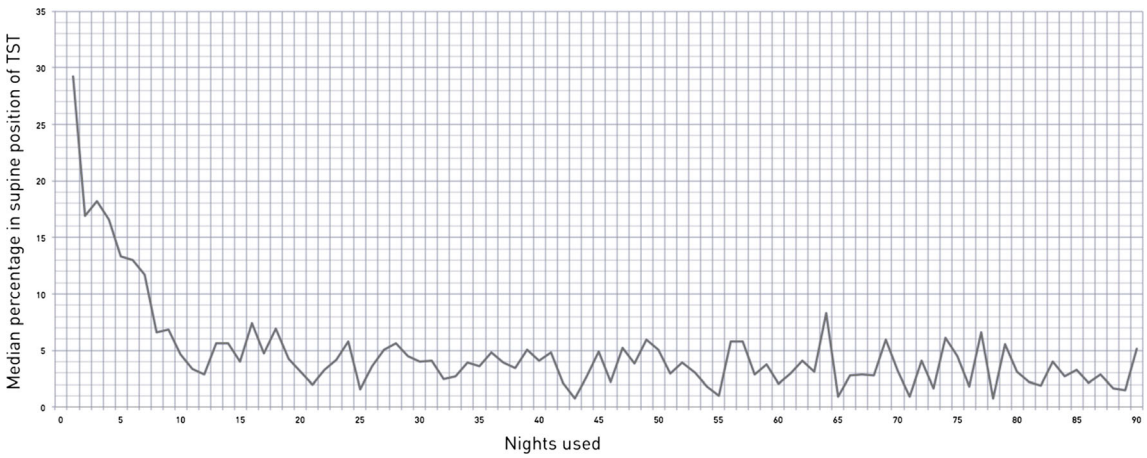

Fig. 2 Median percentage of sleep time in the supine position per night. The first 9 days of the SPT therapy are part of the training program in which the SPT gradually decreases the number of times in which patients can sleep on their backs

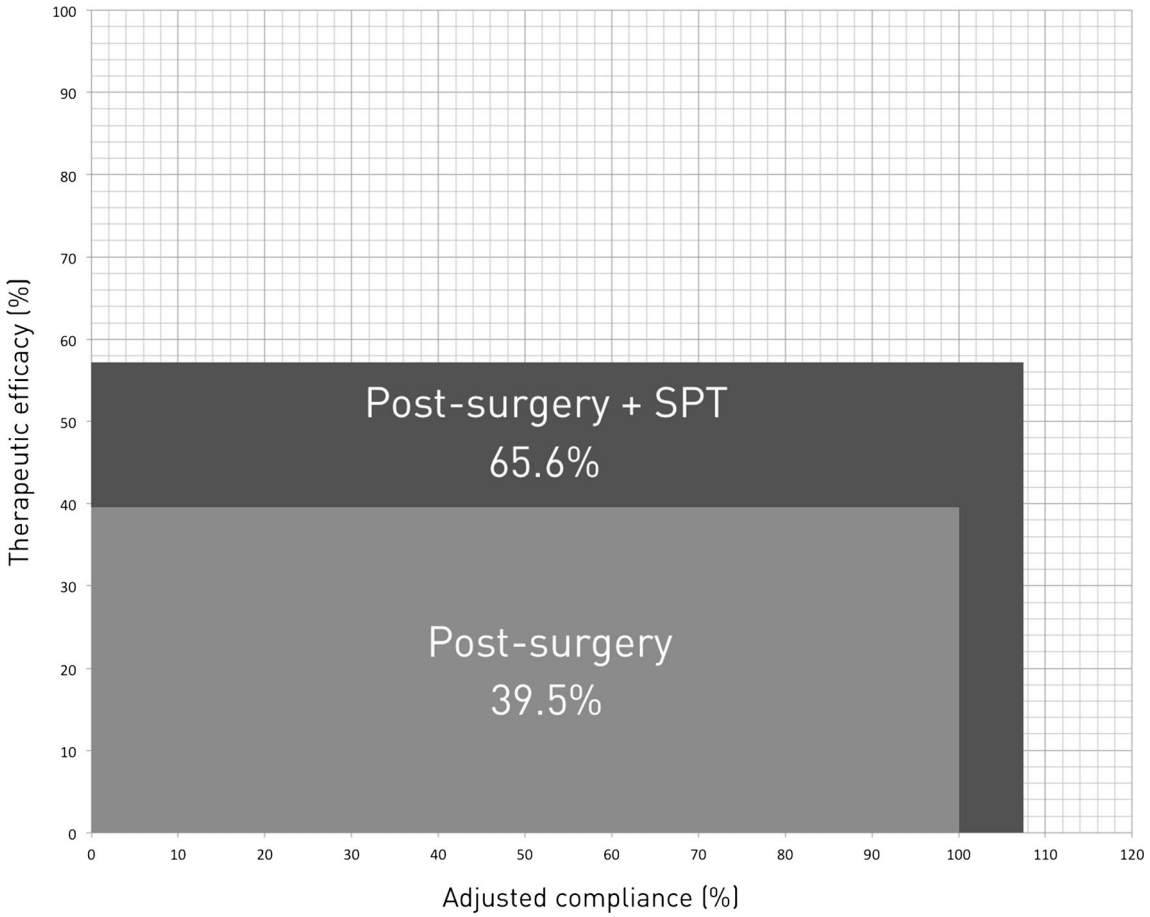

Fig. 3 The combination of surgery with PT. MDA is calculated by the adjusted compliance (objective use/TST) in % + therapeutic efficacy (AHI baseline—AHI with therapy) in %/100

effect of gravity. In some cases, surgery will only have a partial treatment effect and it appears that those patients can have residual apneic events in only the supine sleep position. In addition, some studies found that surgical success was inversely related to the AHI: the higher the AHI preoperatively, the lower the success rate [17, 28–32]. The influence of gravity (i.e., sleep position) has, therefore, impact on the surgical outcome. Within our cohort, the median AHI was reduced with surgery from 28.5 [18.0–52.8] to 18.3 [13.7–24.0], which means that moderate and severe OSA reversed into mild and moderate POSA patients before they were included in the study.

In general, there is a wide dispersion in success rates of surgery, depending not only on the applied surgical technique but also on variables such as baseline AHI and BMI; level, severity, and configuration of obstruction assessed during DISE; and on the definition of success used [16, 17, 28, 32]. Besides the aforementioned parameters, we believe that sleep position is equally important in the evaluation of success rates, and indeed, some studies have evaluated the influence of sleep position after upper airway surgery for OSA. Katsantonis et al. found a significant improvement of the AHI in lateral sleep position following UPPP and suggested that additional PT could significantly improve response to treatment with UPPP [33].

A retrospective analysis by Lee et al. also evaluated the effect of sleep position on surgical outcome and found that patients with treatment failure were more often POSA patients compared to the other groups and that fluctuation of sleep position in each polysomnography might confound the surgical outcome [34]. A second paper from the same group indicated that UPPP is a successful treatment for obstructive events occurring in the lateral sleep position, especially in patients without positional dependency [35].

Van Maanen et al. showed that in patients who previously underwent UPPP/ZPP +/− RFTB, the reduction in AHI was significantly higher in non-positional OSA patients compared to POSA patients [23]. They suggest to apply PT after surgery or even to start with PT as a monotherapy prior to surgery. Furthermore, they concluded that the effect of UPPP is most successful in decreasing the AHI in the lateral sleep position.

Additional PT postoperatively could potentially improve treatment outcome.

Li et al. analyzed a series of patients treated with relocation pharyngoplasty. They showed that the AHI significantly decreased in both positional and non-positional patients. They also noted that non-positional patients frequently became positional following the operation and suggested the latter could additionally benefit from positional therapy which is in line with the results of our study [10, 36].

Compliance and MDA Even the most efficient therapy is only effective when it is used appropriately, and therefore, objective compliance and efficacy need to be taken into account when evaluating therapeutic effectiveness [37]. Previous studies have reported on the compliance of OAT and CPAP therapy. It is well-known that CPAP therapy is highly effective but compliance is often poor, in contrast with OAT therapy which has higher adherence rates but is less effective in reducing the AHI [10]. Dieltjens et al. showed that the objective MDA for OAT after a 1-year follow-up was 54.9 % [38]. In the study of Ravesloot et al., a comparison has been made between CPAP therapy (high efficacy, low adherence) and surgical treatment (100 % compliance, sub-therapeutic). They concluded that both treatment modalities may achieve the same mean AHI due to differences in efficacy and usage per night [36]. In a prospective randomized study by Eijsvogel et al., the short-term results of SPT versus tennis ball technique (TBT) were evaluated. Both therapies effectively reduced respiratory indices and supine sleeping; however, compliance improved significantly more in the SPT group resulting in a MDA of 70.5 % versus 48.6 % for TBT. The combination of surgery with PT resulted in a MDA of 65.6 % in our study.

Limitations This study has various limitations, mainly because of its design with selected cases and a small sample size which limits the strength of our conclusions. We could not run extensive tests on predictors for responsiveness since the power of our model would not be sufficient. Given the fact that we had 32 participants, a maximum of three possible variables could be tested. Since none of these variables were significant in our cohort, we were unable to perform advanced statistical analysis. Due to the small number of patients included, our cohort mainly consisted of male patients. Disparity in treatment response between the genders could therefore not be tested. Third, in the present study, different surgical techniques were applied and compared with each other. Although we combined surgical data for the present study, no significant differences were found in treatment response between the surgical subgroups. Further research is needed to reveal not only the factors predicting therapeutic response and success of PT but also to gain objective results with the implementation of a more qualitative and comparative study design with larger cohort sizes.

Conclusions

This study demonstrates that additional PT in a complex patient population with residual POSA after partial effective upper airway surgery can increase overall therapeutic effectiveness. Previous studies have reported on combining different OSA therapies to increase therapeutic response; however, this is still an under-evaluated and under-investigated matter. More research is required to identify the predictors of non-responders of PT in residual post-operative OSA/or in patients who have OSA treatment failure.

Although the results of this study demonstrate that the number of non-responders is high, PT could still be considered a valuable treatment option in positional patients with previous therapy failure since it has proven to be very successful in the responders group, in terms of both AHI decrease and compliance. Further research, however, is required to assess the factors for predicting therapeutic responsiveness.

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Compliance with ethical standards

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Conflict of interest Drs. L.B.L. Benoist, M. Verhagen, B. Torensma and J.P. van Maanen certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership or other equity interest, and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript. Prof. dr. N. de Vries is a member of the Medical Advisory Board of NightBalance, consultant of Philips Healthcare and Olympus, researcher for Inspire Medical Systems, member of ReVent's Medical Advisory Board, and has shares in NightBalance and ReVent.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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