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EMERGING TECHNOLOGIES

Variable negative external pressure—an alternative to continuous positive airway pressure for the treatment of obstructive sleep apnea: a pilot study

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Study Objectives: To assess variable negative external pressure (vNEP) therapy using a range of pressures and varying collar sizes and shapes to identify combinations that improve the efficacy and comfort of this emerging therapy for obstructive sleep apnea (OSA).

Methods: This prospective, open-label pilot study included 28 eligible patients (71% men) having documented moderate OSA (apnea-hypopnea index [AHI] 15 events/h ≤ AHI ≤ 30 events/h) at 1 sleep clinic for an overnight, in-lab sleep trial. Each participant tested at least 2 of 6 available vNEP devices during sleep periods ≥ 2 hours. During the assessment of AHI by polysomnography, negative pressures of −20 cm H_2O to −35 cm H_2O were adjusted to improve each patient's response. Participants' therapeutic preferences were assessed by a questionnaire and interviews.

Results: Twenty (71%) of the participants responded to vNEP therapy: excellent response (AHI ≤ 5 events/h) was observed in 14 (50%); 6 (21%) achieved a partial response (AHI ≤ 50% baseline). For the 20 responders, the therapy reduced the fraction of total sleep time when peripheral oxygen saturation < 90% and improved minimum pulse oximetry oxygen saturation. Six patients experienced a minor, self-limited adverse event. Twenty-six participants (93%) stated that they would use vNEP nightly.

Conclusions: In this pilot study, vNEP therapy markedly improved AHI and oxygenation in most patients with moderate OSA. The majority of participants found vNEP comfortable and preferable to prevailing OSA therapies. Further development and studies of vNEP are warranted.

Clinical Trial Registration: Registry: ClinicalTrials.gov; Name: Study of Variable Negative External Pressure (vNEP) in Reducing Respiratory Event in Individuals With OSA; URL: https://clinicaltrials.gov/ct2/show/NCT04718142; Identifier: NCT04718142.

Keywords: negative pressure therapy, obstructive sleep apnea, medical device

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Patients with obstructive sleep apnea frequently find the most commonly prescribed treatment, continuous positive airway pressure, cumbersome in daily use; in 1 long-term study, nearly half of patients refused or eventually abandoned the therapy. An alternative approach that applies negative external pressure over the upper airway has been developed, with the aim of improving patient compliance.

Study Impact: In this pilot study of variable negative external pressure therapy, we found that adjusting the pressure throughout the night and selecting collars that maximize patient fit and comfort alleviated obstructive sleep apnea in most participants. Moreover, nearly all participants found this alternative therapy acceptable for nightly use, suggesting it could significantly improve adherence. Additional research is indicated to optimize this approach for long-term use.

INTRODUCTION

Sleep is an essential biological function. Conditions that interfere with restful and restorative sleep lead to many health problems.[1–3]

Obstructive sleep apnea (OSA) is among the most common causes of poor sleep. An international survey of published data used the American Academy of Sleep Medicine (AASM) 2012 diagnostic criteria to estimate that 936 million adults between the ages of 30 and 69 experience mild-to-severe OSA. Of those, 425 million people are thought have moderate-to-severe OSA.[4] Despite its high prevalence and health impacts, evidence suggests that this chronic condition is commonly underdiagnosed and untreated in all populations and especially in under-served communities.[4]

OSA involves repeated partial or complete obstruction of airflow during sleep despite an ongoing effort to breathe. Apnea (defined as cessation of airflow for ≥ 10 seconds) and hypopnea (a 30% reduction in airflow for ≥ 10 seconds accompanied by arousal or a ≥ 3% decrease in peripheral oxygen saturation [SpO_2]) occur when the muscles in the pharynx relax during sleep, causing soft tissue in the back of the throat to collapse and block the upper airway.[5]

Sleep clinicians diagnose OSA primarily by measuring a patient's apnea-hypopnea index (AHI), the average hourly number of apneas and hypopneas during sleep. The broadly accepted categories of sleep apnea are mild (5 events/h < AHI < 15 events/h), moderate (15 events/h ≤ AHI < 30 events/h), and severe (AHI ≥ 30 events/h).

Untreated moderate-to-severe OSA is associated with numerous comorbid conditions, including hypertension, atrial

fibrillation, and diabetes. The condition frequently impacts cognitive function and causes daytime sleepiness.[6]

Treatment of moderate OSA currently includes continuous positive airway pressure (CPAP; widely considered the gold standard), oral appliances, and surgery. Although CPAP is the most frequently prescribed therapy, studies have found patient adherence over the long term to be poor. In a study that followed up on patients 5 years after they were prescribed CPAP, Wolkove et al[7] found that 31% never started the therapy, 15% had abandoned CPAP after less than 2 years, and continued adherence was just 54%. Higher adherences have been reported more recently, with a rate of 70.3% with usual follow up and up to 87% with advanced adherence technology, yet adherence remains a problem.[8,9] Common reasons for discontinuation of CPAP use reported in the literature include discomfort or claustrophobic feelings when using the mask, nasal discomfort, frequent awakening, and complaints from a cosleeper.[10]

Oral appliances tend to be less effective than CPAP but to have better adherence, yielding an overall benefit that may match that of CPAP.[11] Surgical intervention involves higher costs and the risks of anesthesia. The morbidity and mortality associated with untreated and undertreated OSA reflect a pressing need for innovative treatments that are both effective and more acceptable to nightly users.

An emerging new class of devices to treat OSA uses negative external pressure (NEP), rather than positive airway pressure, to assist breathing. This approach, which builds on a principle first demonstrated by Drinker's iron lung in 1929, prevents the collapse of the upper airway by reducing air pressure around the anterior of the neck.[12] In a 2015 study, Kato et al[13] found NEP up to −50 cm H_2O to be effective in opening the airways of women having body mass index < 25 kg/m^2 but not in women of body mass index ≥ 25 kg/m^2. The US Food and Drug Administration approved the use of continuous NEP postsedation during selected procedures, following a pilot study that reduced respiratory impairment events following screening colonoscopy by 45%.[14] A subsequent pilot study with 15 participants showed promising results in applying continuous NEP to reduce the AHI in people diagnosed with mild-to-severe OSA.[15] A 2019 study used similar collars and applied constant pressures of either −25 or −30 cm H_2O in nightly home use over 3 weeks.[16] In that study, most participants (as well as their bed partners) preferred the external collar to CPAP or other OSA treatments.

This pilot study is the first to test the hypothesis that a wider selection of collar sizes and shapes, combined with variable pressures adjusted throughout the night, further improves both the efficacy of NEP and participants' self-reported preference of NEP therapy over other OSA-treatment devices they have used. A secondary goal was to identify aspects of the vNEP collar design and pressure adjustment approach that could be improved by further research.

METHODS

Design and endpoints

The pilot study was an observational, prospective, open-label trial conducted at the California Center for Sleep Disorders in San Leandro, CA. Sleep measurements were performed for each participant in the AASM-accredited sleep laboratory, with questionnaires and follow-up interviews conducted on following days. Endpoints for the study were registered in advance at ClinicalTrials.gov. Study endpoints were defined as a complete response if the lowest AHI was ≤ 5 events/h and a partial response if the lowest AHI reached a reduction of at least 50% compared to the baseline AHI. Participants not reaching these results were classified as not having reached the study's endpoint.

Enrollment

Participants were recruited from within the California Center for Sleep Disorders database by contacting patients who had a diagnosis of moderate OSA confirmed by a nighttime polysomnogram or a home sleep test within the prior 12 months. Of the 47 patients who enrolled and gave informed consent, 19 participants did not proceed with the study due to medical and personal reasons (see **Table 1** for details). The remaining group of 28 participants met the eligibility criteria for the study (**Table 2**) and had no medical contraindications or hesitancy to participate during a collar-fitting study. Baseline AHI measurements for participants were obtained from their patient records. Participants were not specifically predisposed against CPAP therapy. Some of the participants that were satisfied with their CPAP device indicated preference to vNEP in their interviews.

Informed consent

The study was submitted to Institutional Review Board Services, an independent ethics committee, which approved the design, protocol, and informed consent agreement before patients were enrolled. All participants reviewed and signed informed consent agreements and were compensated for their participation in this study.

Data collection and management

Patient data from qualifying sleep studies and the polysomnogram reports from the in-lab sleep study were stored on a secure server. Information required for this study was then transcribed onto paper case report forms for security. A registered technician scored polysomnograms, which were then reviewed and interpreted by a board-certified sleep specialist (J.A.K.). A representative selected by the sponsor monitored the study.

Study devices

Six vNEP collars of varying length, width, depth, and relative proportions were used in this study (**Figure 1**). Each of the devices included a port through which the negative pressure applied to the neck could be externally controlled by a technician. Prior to the overnight trial, each participant was fitted with a collar that fit comfortably beneath the mandible and around the anterior portion of the neck (**Figure 2**). During the overnight, in-lab study, participants were permitted to try other collars for improved fit as desired; all participants were required to test at least 2 collars of different sizes or shapes.

vNEP fitting and clinical measurements

Participants currently on CPAP therapy were instructed to abstain from using CPAP for 2 days prior to the overnight trial

to reduce confounding residual effects. Participants selected a suitable vNEP collar in a fitting meeting prior to their overnight trial. At the start of the sleep trial, participants donned the selected collar, and an initial negative pressure of −25 cm H_2O was applied. An external vacuum pump was used to maintain the negative pressure. The pressure was measured by a sensor connected to the pump base station and recorded during the study as a function of time. The pump was located in a different room and attached to the collar through a sealed external hose. All participants collars were attached to the same pump while the collar varied though the study. Pressure was always initiated at −25 cm H_2O and was subsequently adjusted by the technician in 5-cm H_2O increments based on participant's comfort and best AHI response.

Polysomnography was performed according to AASM criteria by a single registered sleep technologist. The technologist followed a predefined protocol during the study. During an initial sleep session of at least 2 hours, the applied pressure was initiated at −25 cm H_2O and varied within the range −25 to −35 cm H_2O in 5-cm H_2O increments as needed to improve breathing sufficiently to achieve a complete or partial response, where possible based on participant's comfort level. Once a response was achieved, the pressure setting was maintained for approximately half of the night.

The collar was switched to another of the 6 prototypes approximately halfway through the overnight trial or earlier if needed in the technician's judgment due to leaks, discomfort, or failure to achieve a response. The second collar was similarly initiated at −25 cm H_2O pressure level and was subsequently adjusted in 5-cm H_2O increments to improve the AHI response (if possible) based on participant's comfort. In line with AASM and Medicare guidelines, AHI was calculated from measurements taken during periods of at least 120 minutes of continuous sleep.[17,18]

Total sleep time was calculated for each prototype and pressure interval. For each participant, the interval with lowest AHI with a goal of a minimum of 2 hours total sleep time and greatest patient comfort was chosen to be reported in this study.

The following morning, participants completed a poststudy questionnaire, which used Likert-scale ratings to assess their comfort with the vNEP device, whether they preferred vNEP over their prior treatment (for those having experience with those devices), and their willingness to use vNEP daily. The principal investigator also conducted a poststudy interview at a later date to elicit qualitative feedback about the therapy.

Statistical methods

Descriptive and inferential statistics were used to summarize study data. For AHI, time at $SpO_2 < 90\%$ and minimum SpO_2, baseline, and in-lab polysomnogram with vNEP were compared

Table 1—Participants reasons for noncompletion.

Reasons for Noncompletion	n
Time constraints	2
Pandemic concerns	6
Failed screening PSG	5
Problems fitting collar	5
Bearded and declined shaving	1
Total	19

PSG = polysomnography.

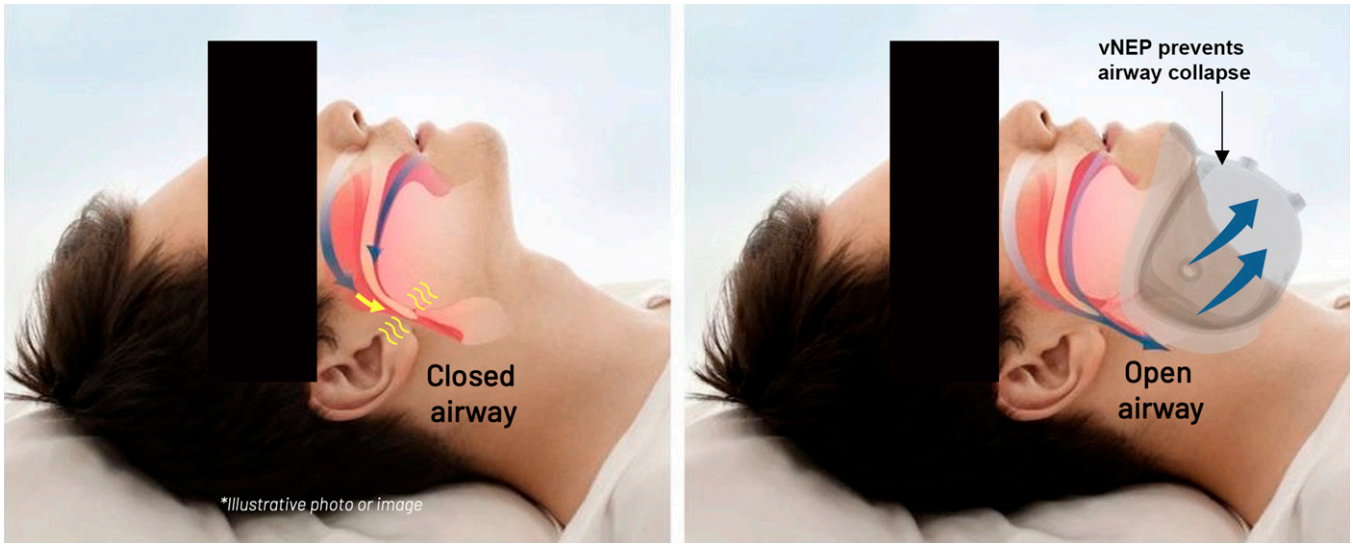
Figure 1—Illustration of variable negative external pressure collar.

Table 2—Inclusion criteria and demographic characteristics of the 28 adult participants (20 males, 8 females).

	Inclusion Criteria (Subject to PI Discretion)	Mean (± SD)	Range
Sex (20 male, 8 female)	Male and female		
Age (years)	18–65	48.5 (±13.0)	23–69
Baseline AHI (events/h)	15 ≤ AHI ≤ 30	20.9 (±4.6)	15.0–29.7
BMI (kg/m^2)		28.2 (±3.97)	23.1–40.6
Neck circumference (cm)		40.4 (±2.5)	35.6–47.0
Beard	Clean shaven or very short		

AHI = apnea-hypopnea index, BMI = body mass index, PI = Principal Investigator, SD = standard deviation.

Figure 2—Illustration of prototype of variable negative external pressure collar.



Negative pressure applied to the front of the neck by the vNEP collar reduces apnea and hypopnea events by opening the airway. vNEP = variable negative external pressure.

Table 3—Results of vNEP therapy: AHI analysis.

	n	%	Baseline, Mean (Range), Events/h	With vNEP, Mean (SD), Events/h	Paired *t*-Test Results	
					P (2-tailed)	Mean Decrease (95% CI), Events/h
Reached endpoint	20	71	20.5 (15.3–29.7)	3.6 (3.0)	< .0001	16.9 (14.7–19.1)
Complete response (target AHI: ≤ 5 events/h)	14	50	19.7 (15.3–29.7)	1.9 (1.4)	< .0001	17.8 (15.0–20.6)
Partial response (target AHI: ≤ 50% baseline AHI)	6	21	22.4 (15.5–28.9)	7.6 (1.3)	.0004	14.8 (10.1–19.4)
Did not reach endpoint	8	29	21.7 (15.0–27.1)	20.7 (6.5)	.7254	0.8 (−4.3 to 5.9)
All participants	28	100	20.9 (15.0–29.7)	8.5 (9.0)	< .0001	12.3 (8.8–15.8)

AHI = apnea-hypopnea index, CI = confidence interval, SD = standard deviation, vNEP = variable negative external pressure.

using a paired sample *t*-test, along with 95% confidence intervals. Two-sample *t*-tests, allowing for separate variances, were used to compare AHI, time at $SpO_2 < 90\%$, and minimum SpO_2 (**Table 3**, **Table 4**, and **Table 5**).

RESULTS

The study enrolled 20 male and 8 female adults having moderate OSA. Participants were predominantly middle-aged and overweight or obese (**Table 2**). To assist in determining the generalizability of vNEP treatment, participants were asked to identify their race and/or ethnicity optionally. All did so: 6 self-identified as Asian/Pacific Islander, 5 as Black, 16 as White, and 1 as Middle Eastern (**Figure 3**).

Few adverse events were reported; all were minor and self-limited. Five participants experienced mild skin irritation below the chin and on the sides of the neck (around the edges) similar to CPAP marks. These resolved without treatment within 20 minutes after participants were awake. One participant with a prominent bony chin had a small bruise that went away in the next 24 hours. There is no distinction in the occurrence of these few adverse events whether they were responders, partial responders, and nonresponders. All participants slept with the device for 1 night. The internal design testing team slept with it for up to 2 weeks and did not find any significant deformation.

Clinical response

Twenty (71%) of the participants responded to vNEP therapy by meeting 1 of the 2 pre-established endpoints, with half of all

Table 4—Results of vNEP therapy: % TST SpO_2 < 90% analysis.

	n	%	Baseline, Mean (Range), %	With vNEP, Mean (SD), %	Paired *t*-Test Results	
					P (2-tailed)	Mean Decrease (95% CI), %
Reached endpoint	20	71	7.8 (0.0–51.6)	0.4 (0.9)	.0129	7.4 (1.8–13.0)
Complete response (target AHI: ≤ 5 events/h)	14	50	8.6 (0.0–51.6)	0.1 (0.2)	.0391	8.6 (0.5–16.6)
Partial response (target AHI: ≤ 50% baseline AHI)	6	21	5.9 (0.1–14.9)	1.3 (1.3)	.0917	4.6 (−1.1 to 10.4)
Did not reach endpoint	8	29	14.3 (1.4–31.6)	11.9 (7.6)	.6034	3.3 (−7.8 to 12.5)
All participants	28	100	9.7 (0.0–51.6)	3.7 (6.6)	.0147	5.9 (1.3–10.6)

AHI = apnea-hypopnea index, CI = confidence interval, SD = standard deviation, SpO_2 = oxygen saturation, TST = total sleep time, vNEP = variable negative external pressure.

Table 5—Results of vNEP therapy: minimum SpO_2 analysis.

	n	%	Baseline, Mean (Range), %	With vNEP, Mean (SD), %	Paired *t*-Test Results	
					P (2-tailed)	Mean Increase (95% CI), %
Reached endpoint	20	71	80 (66–90)	91 (3.0)	< .0001	10 (6.9–13.3)
Complete response (target AHI: ≤ 5 events/h)	14	50	81 (66–90)	92 (1.6)	< .0001	11 (6.6–15.4)
Partial response (target AHI: ≤ 50% baseline AHI)	6	21	80 (69–84)	88 (3.5)	.0069	8 (3.4–12.7)
Did not reach endpoint	8	29	77.1 (69–85)	79 (5.4)	.4002	2 (3.7–8.2)
All participants	28	100	80 (66–90)	88 (6.5)	< .0001	8 (4.9–10.8)

AHI = apnea-hypopnea index, CI = confidence interval, SpO_2 = oxygen saturation, vNEP = variable negative external pressure.

participants achieving a complete response and an additional 6 (21%) achieving a partial response (**Table 3**, **Figure 4**). All the female participants experienced at least a partial response, and patients in each of the self-identified racial/ethnic categories experienced a complete response.

Among the 20 responders, the mean decrease in AHI from baseline was 16.9 (95% confidence interval 14.6–19.1), resulting in a mean AHI of 3.6 events/h (standard deviation 3.0 events/h) (**Table 3**). No clear ethnic, demographic, or other known baseline characteristics distinguished responders from nonresponders; this may be a consequence of the small trial size. Total treatment time for both collars was approximately 7 hours for each participant and included different collars and pressure adjustments. Average of total sleep time for the best collar was 191.4 minutes with standard deviation of 73.10 and median of 172.5

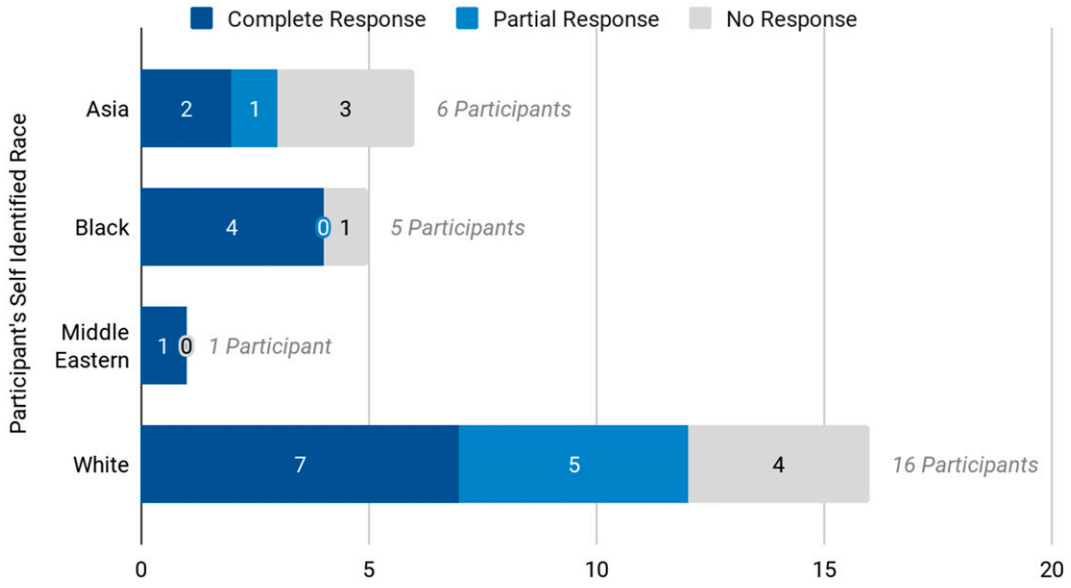
In 3 participants, AHI got worse. One of those participants unconsciously kept pulling at the prototype, in effect not receiving vNEP therapy. The other 2 participants had massive neck soft tissue that allowed for a seal but filled the collar, possibly leading to compression rather than expansion of the air space.

In the other nonresponders, while there was a trend toward improvement, there was difficulty finding a collar that provided a good seal. The technician inadvertently changed the prototype 7 minutes short of the minimum 2-h mark in 1 respondent. This participant's response is included in the analysis. One patient was excluded from analysis as he was mistakenly entered into the study, although his baseline AHI was 44.5 events/h.

Results observed by oximetry were similar. In the 20 responders, time below 90% SpO_2 decreased (**Figure 5**, top panel). The mean decrease among them was 94.4% (95% confidence interval 1.8–13.0), resulting in a mean time below 90% SpO_2 of 0.4% (standard deviation 0.9%) (**Table 4**). All but 1 patient (96%) experienced an improvement in the minimum value of SpO_2 measured during the trial compared to their baseline data (**Figure 5**, bottom panel) (**Table 5**).

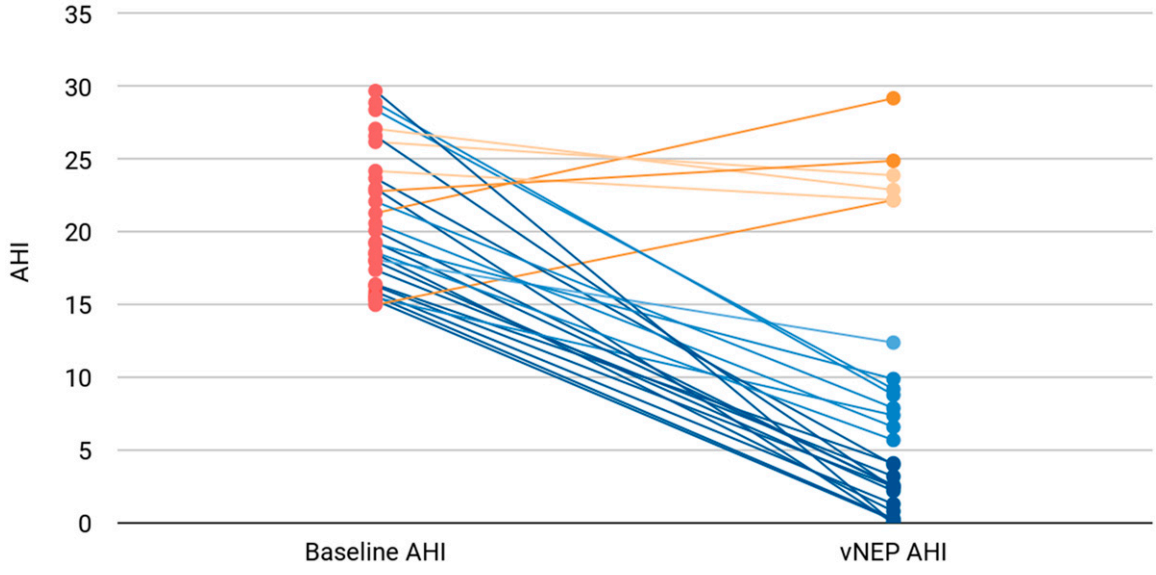
Among complete and partial responders, 3 out of 6 collars were the most comfortable. Twelve out of twenty-eight participants (43%) achieved the highest response with 1 collar type, and 8 out of 14 complete responders (57%) achieved the highest response with the same collar type. Fifteen out of twenty-eight participants (50%) found the pressure −25 cm H_2O the most comfortable; 12 out of 20 (60%) complete and partial

Figure 3—Responses to vNEP treatment by race of participants.



Participants self-identifying as Asian/Pacific Islander, Black, White, and other race/ethnicity (Middle Eastern) responded to vNEP therapy, but the small size of this study and confounding factors preclude analyses by racial/ethnic categories. vNEP = variable negative external pressure.

Figure 4—Changes in AHI during therapy.



Decreases in AHI to below 5 events/h indicated that 14 participants (50%) exhibited an excellent response to vNEP treatment (green lines). Another 6 participants experienced a partial response to the therapy (blue lines). AHI = apnea-hypopnea index, vNEP = variable negative external pressure.

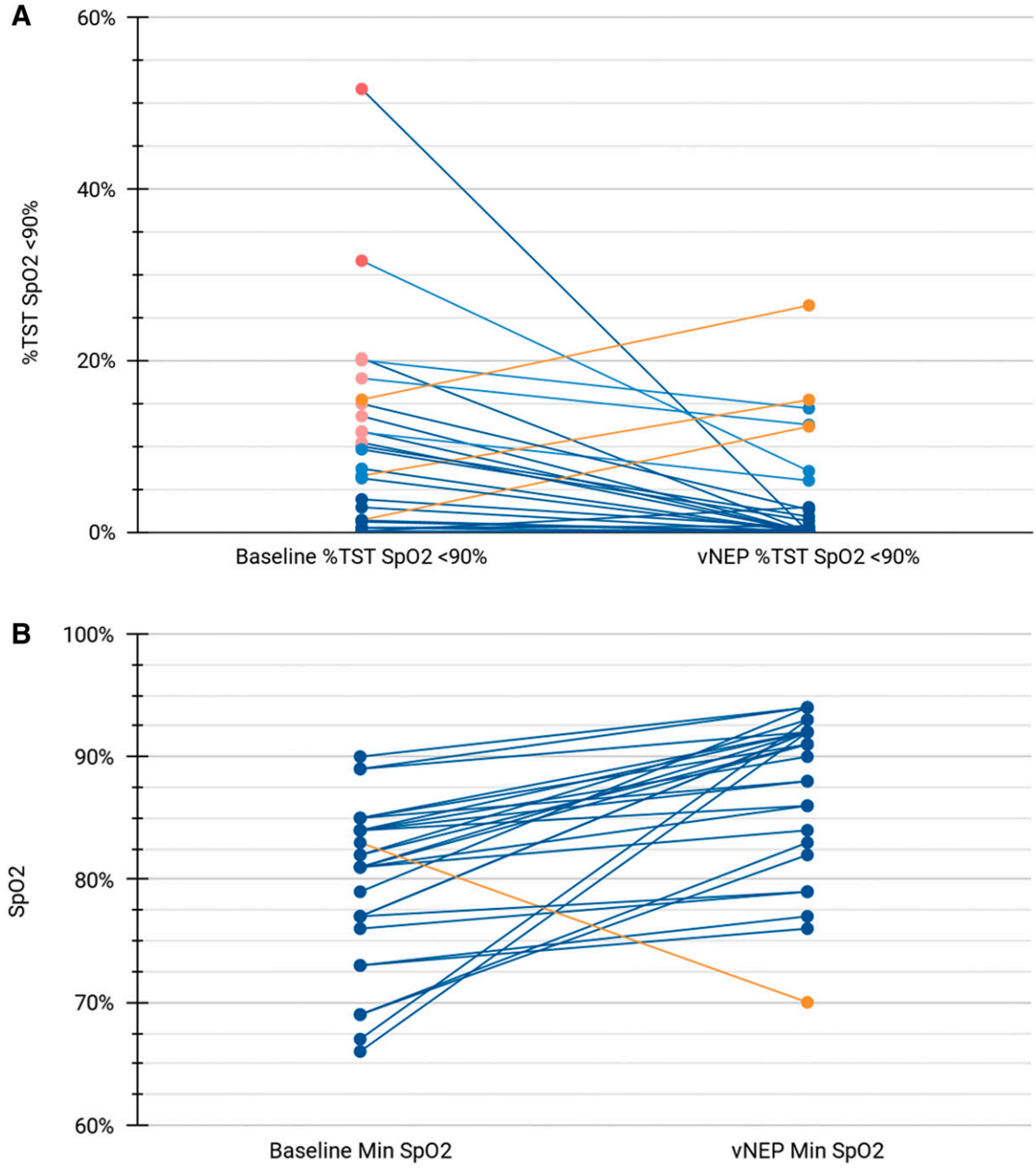
responders achieved the highest response with pressure −25 cm H_2O and found 1 collar type and pressure the most comfortable. Pressure and collars varied for all 8 nonresponders, so it is hard to draw any conclusions. Also, there is no connection of pressure and collar type with race, body mass index, age, and neck circumference.

All female participants were responders or partial responders. There were no major differences between men and women in the collar fit. In general, women found the device more comfortable than the men and did not have any adverse events. All nonresponders were men. There was a trend toward wider necks with double and boney chins in male nonresponders.

Subjective responses

Twenty-six participants (93%) rated the vNEP device as comfortable or very comfortable (**Figure 6**). All but 3 of the patients

Figure 5—Changes in SpO_2 during sleep.



(Top) During vNEP treatment, the fraction of sleep time during which SpO_2 < 90% decreased (green lines) for all but 6 participants measured. **(Bottom)** vNEP therapy also increased the minimum SpO_2 measured during sleep (green lines) for all but one participant. SpO_2 = oxygen saturation, TST = total sleep time, vNEP = variable negative external pressure.

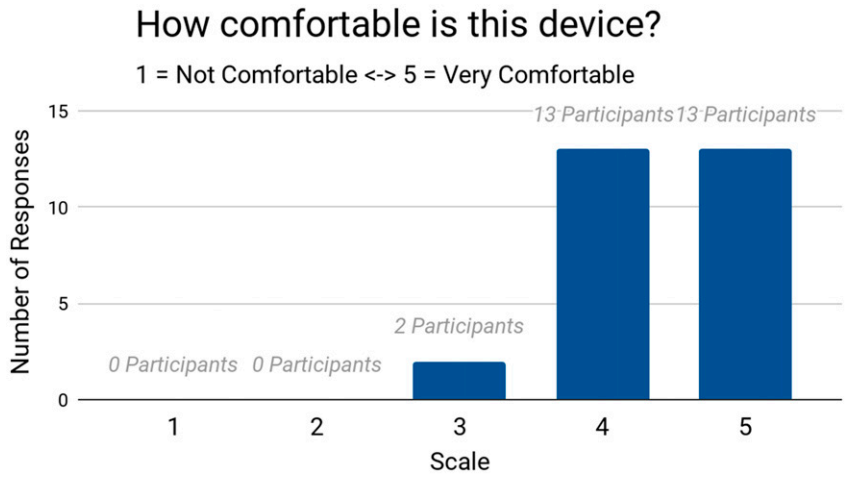
who had previously used CPAP or an oral appliance for OSA treatment stated that they found vNEP to be superior or equivalent in comfort to those prevailing therapies (Figure 7). Twenty-five participants (89%), including those from each self-identified racial/ethnic category, reported being likely or very likely to wear the vNEP device nightly if prescribed one (Figure 8).

In interviews with all but 1 of the participants conducted by the primary investigator approximately 2 weeks after their study, 27 patients expressed positive impressions of vNEP and a preference of vNEP over CPAP for treatment of their OSA.

DISCUSSION

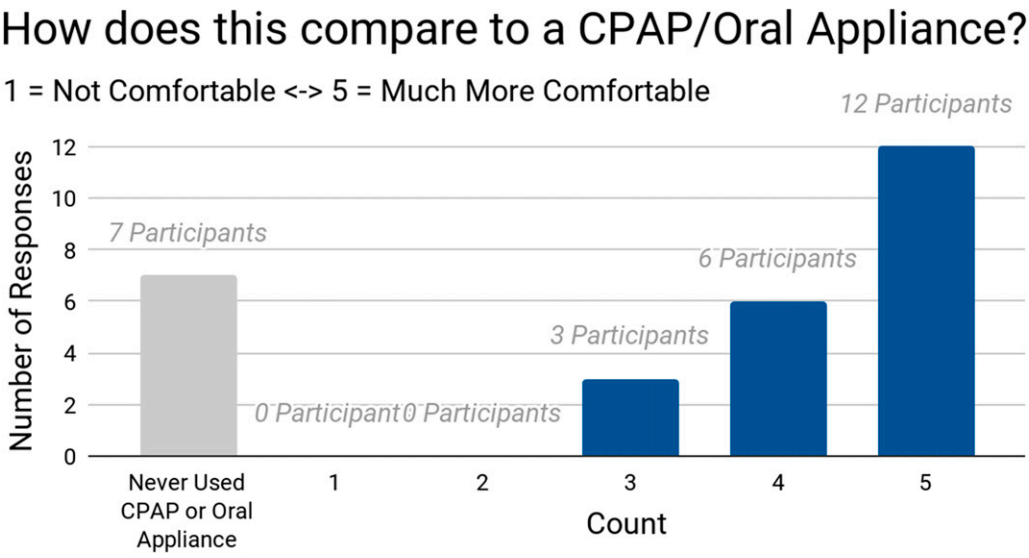
The emerging technology of negative external pressure as a treatment of OSA has shown promising results in several small

Figure 6—Comfort participants felt wearing the vNEP device.



None reported discomfort and 93% rated the collars comfortable or very comfortable. vNEP = variable negative external pressure.

Figure 7—Participant comparison to other OSA treatments.



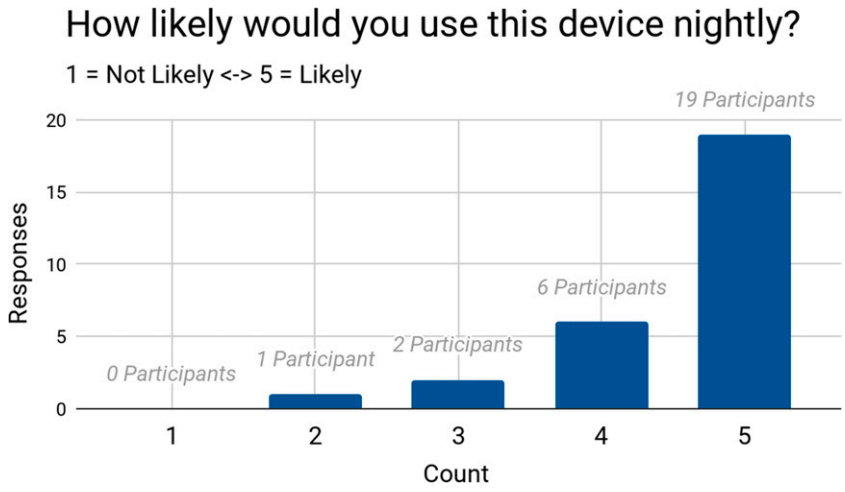
Of those who had experience using CPAP or an oral appliance, 86% rated the vNEP therapy more comfortable or much more comfortable. CPAP = continuous positive airway pressure, OSA = obstructive sleep apnea, vNEP = variable negative external pressure.

studies.[12,13] The current report differs from the 2017 report in several important ways.[15]

In 2017, a single-size collar was used with no collar change in the night's study. The current study used 6 vNEP collars of varying length, width, depth, and relative proportions. Participants selected a suitable vNEP collar in a fitting meeting prior to their overnight trial. At the start of the sleep trial, participants donned the selected collars (at least 2), and an initial negative pressure of −25 cm H_2O was applied and then adjusted based on the participant's comfort and efficacy.

In the 2017 study, continuous NEP was titrated from −20 to −45 cm H_2O to determine the pressure that resulted in the lowest AHI. In the current study, the pressure was initiated at −25 cm H_2O for each collar, and pressure variability was decided based on the participant's comfort level and improved efficacy with the best collar size and seal. Current study also includes participants' self-reported experience gathered immediately after the night study and later in the telemedicine call with the primary investigator (J.A.K.).

Figure 8—Participant willingness to use vNEP nightly.



The 89% positive or very positive response to this question suggests that adherence to vNEP therapy may be high in longer-term trials. vNEP = variable negative external pressure.

This pilot study provides further evidence that the therapy is effective, well-tolerated, and perceived as preferable to CPAP for the majority of patients who have moderate OSA.

This trial is the first to report clinical results of vNEP, in which the external pressure applied to the upper airway is varied during sleep to reduce apneas and hypopneas further and increase SpO_2 based on participants' comfort level. This study also tested a wider range of shapes and sizes of NEP collars than have been included in previous trials.

There were sex differences in that all the nonresponders were men. Although this may be due to the small sample size, as 71% of the participants were men, it could suggest this treatment may have greater benefit in women.

Although there remains room for improvement in collar design, the self-reported responses from participants show a high degree of comfort with the therapy, 17 participant that had used CPAP and 4 that had used an oral appliance expressed a strong preference and a broad willingness to wear a vNEP device nightly (**Figure 6**, **Figure 7**, and **Figure 8**). These encouraging results suggest that adherence to vNEP therapy could improve the relatively low long-term adherence to prevailing treatment. A limitation of the study is that the exposure to the collar was only 1 night, so further study will be needed to assess long-term concerns. On the single night study, only minor marks similar to those left by CPAP were seen. These resolved spontaneously within hours, with only 1 patient noting some soreness for a day or 2. Another limitation of this pilot study is that this was not a blinded study. The primary scoring of polysomnogram results was done by the lead technician in the sleep center. However, with the sponsor's support, an outside independent scoring service that had no knowledge of the purpose of the scoring rescored all studies. The results correlated well, so this was not included in our manuscript but provides support for the accuracy of the data. Additional limitation is that although the sleep stages were scored, the response during different sleep stages was not calculated and compared during this study. Therefore, this device might not be effective during rapid eye movement sleep.

Finally, the blood pressure was not monitored. This is a challenge in a sleep study without interrupting participant's sleep. A previous report of this technology, which resulted in Food and Drug Administration approval for continuous NEP in patients, was conducted in the recovery room with close monitoring after sedation and did not mention any issues related to blood pressure.[14]

Improvements to oxygen saturation and AHI in this trial confirm that vNEP can effectively open the airway during sleep for many people (**Figure 4** and **Figure 5**). Even partial responders reached a final AHI below 10 events/h. It is unclear why some participants did not respond, nor why all nonresponders were male in this study. There was 1 participant who was a responder that reported that he had a stroke but had recovered prior to the study. A home study done on him after the study showed no significant apnea. These questions bear further investigation in future trials. The primary limitations of this study are its relatively small size, and the need to conduct further studies at home to ensure long-term comfort, efficacy, and adherence.

CONCLUSIONS

Marked improvements in AHI and oxygenation data, coupled with highly positive participant responses to a comfort questionnaire, indicate that vNEP is effective and welcomed by users as an additional therapeutic option for treating moderate sleep apnea. Further studies are warranted to test the efficacy of vNEP in treating mild and severe OSA and evaluates its long-term use at home.

ABBREVIATIONS

AASM, American Academy of Sleep Medicine
AHI, apnea-hypopnea index
CPAP, continuous positive airway pressure
NEP, negative external pressure
OSA, obstructive sleep apnea
SpO_2, pulse oximetry oxygen saturation
vNEP, variable negative external pressure

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EDITOR'S NOTE

The Emerging Technologies section focuses on new tools and techniques of potential utility in the diagnosis and management of any and all sleep disorders. The technologies may not yet be marketed, and indeed may only exist in prototype form. Some preliminary evidence of efficacy must be available, which can consist of small pilot studies or even data from animal studies, but definitive evidence of efficacy will not be required, and the submissions will be reviewed according to this standard. The intent is to alert readers of *Journal of Clinical Sleep Medicine* of promising technology that is in early stages of development. With this information, the reader may wish to (1) contact the author(s) in order to offer assistance in more definitive studies of the technology; (2) use the ideas underlying the technology to develop novel approaches of their own (with due respect for any patent issues); and (3) focus on subsequent publications involving the technology in order to determine when and if it is suitable for application to their own clinical practice. The *Journal of Clinical Sleep Medicine* and the American Academy of Sleep Medicine expressly do not endorse or represent that any of the technology described in the Emerging Technologies section has proven efficacy or effectiveness in the treatment of human disease, nor that any required regulatory approval has been obtained.