Original Investigation

Diagnosis of Obstructive Sleep Apnea by Peripheral Arterial Tonometry
Meta-analysis

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IMPORTANCE Efficient diagnosis and early treatment of obstructive sleep apnea may help prevent the development of related morbidity and mortality. Compared with polysomnography (PSG), ambulatory sleep study devices offer the possibility of an accurate diagnosis with convenience and low cost.

OBJECTIVE To assess the correlation between sleep indexes measured by a portable sleep-testing device (peripheral arterial tonometry [PAT]) and those measured by PSG.

DATA SOURCES We searched PubMed, MEDLINE, the Cochrane Trial Registry (through May 2013), and relevant article bibliographies.

STUDY SELECTION Systematic review and meta-analysis of studies assessing correlation of sleep indexes between PAT devices and PSG in adults (aged >18 years). Included studies provided a bivariate correlation coefficient for sleep indexes, specifically the respiratory disturbance index (RDI), apnea-hypopnea index (AHI), and oxygen desaturation index (ODI).

DATA EXTRACTION AND SYNTHESIS Included studies were reviewed by 2 independent reviewers. Reported correlation values for the RDI, AHI, and ODI between a commercially available PAT device (WatchPAT) and PSG were systematically reviewed. A comprehensive meta-analysis software package was used for statistical analysis.

MAIN OUTCOMES AND MEASURES Assessment of the correlation between PAT and PSG as measured by AHI, RDI, and ODI.

RESULTS Fourteen studies met inclusion criteria and had data suitable for pooling (909 patients). Of these, 13 studies had blinded study designs, with PAT and PSG conducted simultaneously in the home or the laboratory setting. One study contained 2 trial phases for the same patient group (n = 29), one laboratory based and the other home based, which were analyzed separately. One study contained 2 different study groups based on age. Overall, correlation of the RDI and AHI was high (r = 0.889 [95% CI, 0.862-0.911]; P < .001). Studies comparing the RDI between PAT and PSG had a combined correlation of 0.879 (95% CI, 0.849-0.904; P < .001); those comparing the AHI, 0.893 (0.857-0.920; P < .001); and those comparing the ODI, 0.942 (0.894-0.969; P < .001). Analysis of publication bias revealed a nonsignificant Egger regression intercept.

CONCLUSIONS AND RELEVANCE Respiratory indexes calculated using PAT-based portable devices positively correlated with those calculated from the scoring of PSG. Strengthened by the blinded design of most of the included studies, this technology represents a viable alternative to PSG for confirmation of clinically suspected sleep apnea.

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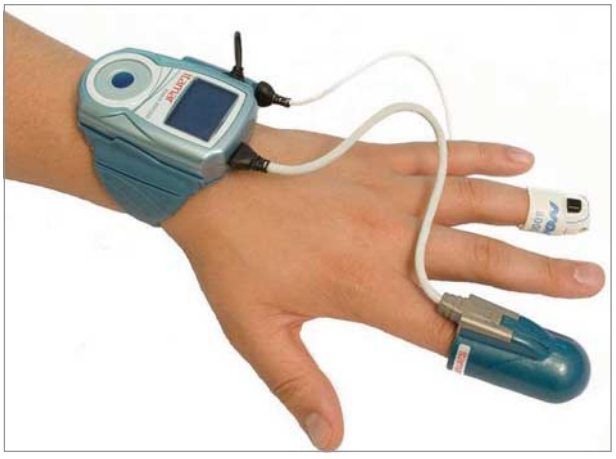
Obstructive sleep apnea (OSA) is a common disorder characterized by repetitive episodes of partial or complete upper airway collapse during sleep, potentially leading to intermittent hypoxemia, hypercapnea, and frequent arousals in an attempt to reestablish airway patency.[1] This pattern of sleep fragmentation can result in nonrestorative sleep and consequent daytime sleepiness, morning headache, impairment of cognitive and psychomotor performance, automobile and industrial accidents, and an overall decreased quality of life.[2-6] Furthermore, OSA has been associated with a number of clinical consequences that include but have not been limited to adverse cardiovascular and cerebrovascular events.[7] With an estimated prevalence of 4% in men and 2% in women,[8] efficient diagnosis and early treatment of OSA may help to prevent the development of severe cardiovascular morbidity and mortality and, thus, secondarily lead to reduced health care costs.

The criterion standard technique for the diagnosis of OSA is an attended overnight polysomnography (PSG) recording. The level 1 laboratory-based setting provides the most accurate description of sleep disorders via objective measures of airflow, chest/abdominal movements, electromyography, electrocardiography, and oxygen saturation levels.[9] However, PSG remains an unappealing and cumbersome study with costly labor requirements and long waiting lists that lead to delays. This predicament has led to the experimental development of multiple ambulatory sleep study devices that incorporate a relatively user-friendly interface with the ultimate goal of diagnosing OSA with accuracy comparable to that of formal PSG. Although most devices have not gained clinical appeal secondary to insufficient evidence, devices using peripheral arterial tonometry (PAT), such as the WatchPAT device (Itamar Medical, Ltd), have recently acquired popularity.

The WatchPAT (**Figure 1**) is a unique, wrist-worn ambulatory sleep study device that uses PAT in conjunction with pulse oximetry and actigraphy to assess respiratory disturbances. Given that obstruction-induced transient elevations of sympathetic tone have been associated with arousals from sleep,[10-16] the WatchPAT device indirectly detects apnea and hypopnea via selectively measuring peripheral arterial volume changes (mediated by α-adrenergic receptors of vascular smooth muscle) using a finger-mounted plethysmograph. The information is collated with pulse oximetry (detection of oxygen desaturation) in conjunction with heart rate and is further analyzed using a predeveloped automated algorithm. This algorithm associates arousals with measurement of oxygen desaturation levels to determine respiratory effort-related arousals. Furthermore, with the advantage of eliminating interscorer variability, this relatively novel approach has been proposed to offer an accurate, reproducible, and simple alternative to PSG. Multiple studies have demonstrated high correlation of sleep indexes measured by PAT, such as the respiratory disturbance index (RDI) or the apnea-hypopnea index (AHI), compared with the same indexes measured by formal PSG.[17-27] However, many trials included small samples, thereby limiting their statistical power to represent such correlations accurately. Therefore, the purpose of this investigation is to assess the correlation between the sleep indexes measured by PAT and PSG based on published studies. PAT technology is relatively unknown to the otolaryngology community, making this meta-analysis important because it presents a viable option for the diagnosis and subsequent treatment of OSA.

Figure 1. The Peripheral Arterial Tonometer (WatchPAT; Itamar Medical, Ltd)



The device uses peripheral arterial tonometry in conjunction with pulse oximetry and actigraphy to assess for respiratory disturbances.

Methods

Literature Search

We conducted a computerized search to identify literature on the topic of sleep indexes recorded by PAT vs PSG in adult patients with sleep apnea. We performed a comprehensive literature search using PubMed, MEDLINE, and the Cochrane Trial Registry (through May 2013). Search items included the following keywords: *peripheral arterial tonometry* AND *polysomnography*; *obstructive sleep apnea-hypopnea syndrome*, *WatchPAT*, AND *polysomnography*; *peripheral arterial tonometry* AND *respiratory disturbance index*; and *peripheral arterial tonometry* AND *apnea-hypopnea index*.

Inclusion and Exclusion Criteria

The meta-analysis was designed to review those studies reporting the RDI or AHI in adult subjects who underwent formal PSG and PAT for suspected OSA. The research inquiry for the study was to assess the correlation of sleep indexes, specifically the RDI and AHI as measured by PAT and PSG, to thereby assess the utility of PAT devices as diagnostic tools for adults with OSA. The following inclusion criteria were used:

1. All subjects reported must be older than 18 years.
2. The study must report correlation values between PSG and PAT for the RDI or AHI.
3. All subjects must have PAT and PSG recordings.
4. Studies must be written in English.

Furthermore, if studies included correlations of the ODI between PAT and PSG, we included those calculations in our

meta-analysis. We also examined reference sections of identified studies for additional relevant articles to review. Case reports, abstracts, and letters to the editor were not reviewed. At the end of this process, we identified 14 studies that presented adequate data and met inclusion criteria (**Figure 2**). Multiple studies published by the same author or group were analyzed for duplication of patient populations. This analysis was performed by reviewing the articles and contacting the primary author. Included studies were reviewed by 2 independent reviewers (S.Y. and C.H.). Institutional review board approval and informed consent were not required for this review of previously published studies.

Variations of Sleep Indexes Measured

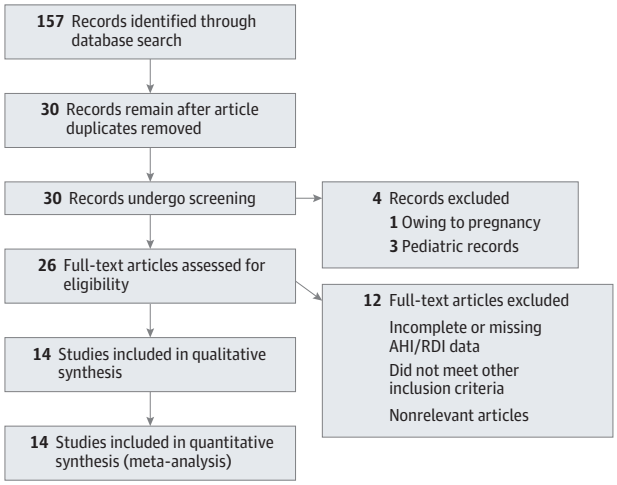
The outcome measurements AHI and RDI have varied in definition among the studies included in this meta-analysis. We have therefore attempted to standardize the data obtained based on the sleep-scoring protocol of the American Academy of Sleep Medicine.[28] For the purpose of this study, the AHI was defined as the total number of apneas and hypopneas divided by total sleep time (in hours), and the RDI was defined as the total number of apneas, hyopneas, and respiratory effort-related arousals divided by total sleep time (in hours). In all included studies, apnea was defined as at least a 90% decrease in airflow for at least 10 seconds relative to basal amplitude. In 10 studies, hypopnea was defined as at least a 50% decrease in the airflow amplitude relative to the baseline value lasting for at least 10 seconds with the presence of arousal or an oxygen desaturation level of at least 3%; in 4 studies, hypopnea was defined as an associated oxygen desaturation level of at least 4%.

Statistical Analysis

Data were retrieved and reviewed systematically. All calculations and plot syntheses were performed using a commercially available statistical software package (Comprehensive Meta-analysis, version 2; Biostat). We performed the following 4 procedures:

1. The Cochran *Q* test for determining heterogeneity was applied, where $P < .05$ was considered a significant difference of sample population between studies. The I^2 value was calculated from bivariate correlation coefficients (*r* values) for the RDI and AHI obtained between PAT and PSG. The I^2 values ranged from 0% to 100% and quantified the effect of heterogeneity, with a greater I^2 value representing a greater degree of heterogeneity.
2. The correlation analysis calculated *r* values for the RDI and AHI between PAT and PSG using the random-effects model. All studies were weighted for effect. A forest plot was synthesized.
3. The correlation analysis calculated *r* values for the ODI between PAT and PSG using the random-effects model. All studies were weighted for effect. A forest plot was synthesized.
4. Sensitivity analysis was performed to determine the influence of specific sleep variables (AHI, RDI, and ODI), the study design (blinded vs nonblinded), and the study setting (laboratory vs home) in regard to its correlation with PSG. Forest plots were synthesized.

Figure 2. Graphic Representation of the Literature Review



Inclusion and exclusion criteria were used to arrive at studies to be included for statistical analysis. AHI indicates apnea-hypopnea index; RDI, respiratory disturbance index.

5. Analysis of publication bias was performed by calculating the Egger regression intercept. Precision funnel plots with imputed values were created using the trim and fill method of Duval and Tweedie.[29]

Results

Fourteen studies consisting of data from a total of 909 participants were included for review (**Table 1**). Of the articles reporting the sex of the participants, 72.2% of the participants (range, 32.4%-84.0%) were men, and the mean (SD) age was 47.2 (SD, 7.6; range, 30.7-60.0) years. One study compared 2 age ranges, with group 1 including participants aged 20 to 35 years, and group 2, 50 to 65 years. These 2 groups were analyzed separately in our study. The mean (SD) body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared) was 30.0 (2.9) (range, 26.2-34.6).

Quality of Data

The level of evidence for all studies was graded as level 2c based on the Center for Evidence-Based Medicine ranking system (http://www.cebm.net/?o=1025). Analysis of the types of bias associated with each type of study is outlined in **Table 2**. The likelihood of selection bias exists because most of the included studies used all or most individuals who were referred to the trial secondary to confirmed or suspected OSA.

Assessment of Bias

Publication bias was assessed mathematically using the Egger regression intercept (2-tailed $P = .99$) and graphically using a precision funnel plot with the trim and fill method (**Figure 3**). A nonsignificant Egger regression intercept was found, thus decreasing the occurrence of publication bias. Furthermore,

Table 1. Characteristics of Included Studies[a]

Source	Country	No. of Patients/ Mean Age, y	Mean BMI	Sex, No. M/F	Study Design	Devices Used	Sleep Index	Setting
Pillar et al,[17] 2002	Germany	94/46.2	28.5	NR	B	PAT/PSG	AHI[b]	Laboratory
Penzel et al,[18] 2002	Germany	21/56.6	33.7	NR	B	PAT/PSG	AHI	Laboratory
Bar et al,[19] 2003	Israel	99/41.4	26.8	74/24	B	PAT/PSG	AHI[b]	Laboratory
Ayas et al,[20] 2003	United States	30/47.0	31.0	19/11	B	PAT/PSG	AHI	Laboratory
Pillar et al,[21] 2003	Israel	68/46.3	28.6	54/14	B	PAT/PSG	AHI[b]	Laboratory
Penzel et al,[22] 2004[c]	Germany	17/NR	NR	NR	B and B	PAT/PSG and PAT/PSG	AHI and RDI	Laboratory and laboratory
Pittman et al,[23] 2004[d]	United States	29/43.2	33.9	21/8	B and NB	PAT/PSG and PAT Alone	AHI[b]	Laboratory and home
Zou et al,[24] 2006[e]	Sweden	98/60.0	28.0	55/43	B	PAT/PSG	AHI and RDI	Home
Pang et al,[25] 2007	United States	32/50.1	34.6	12/25	B	PAT/PSG	AHI	Laboratory
Choi et al,[26] 2010	Korea	25/40.9	26.2	21/4	NB	PAT/PSG	AHI	Laboratory
Hedner et al,[27] 2011	Sweden	227/49.0	29.0	NR	B	PAT/PSG	AHI	Laboratory
Onder et al,[30] 2012	Turkey	56/30.72 (group 1) and 55.0 (group 2)		36/20	B	PAT/PSG	RDI	Laboratory
Yuceege et al,[31] 2013	Turkey	90/NR	NR	85/0	B	PAT/PSG	AHI and RDI	Laboratory
Weimin et al,[32] 2013	China	28/47.45	29.99	20/8	B	PAT/PSG	AHI	Laboratory

Abbreviations: AHI, apnea-hypopnea index; B, blinded; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); NB, nonblinded; NR, not reported; PAT, peripheral arterial tonometry; PSG, polysomnography; RDI, respiratory disturbance index.

[a] Level of evidence was 2c for all studies.

[b] Original study reports an RDI value; however, the value was found to be equivalent to AHI, which was defined as the total number of apneas and hypopneas divided by total sleep time (in hours).

[c] Compared AHI and RDI between PSG and PAT conducted in a nonsimultaneous fashion.

[d] Compared PAT and PSG twice within the same patient population with AHI measured from home-based PAT and laboratory-based PSG.

[e] Compared RDI and AHI measured from home-based PAT and PSG in the same study group.

the calculated I^2 value, based on a random-effects model, was found to be 11.61%. This low I^2 value indicates that little heterogeneity exists between the studies.

Meta-analysis by Sleep Index Used

Among the 14 studies that were included, 4 compared RDI between PSG and PAT individually or in conjunction with AHI.[22,24,27,31] Comparison of RDI had a high correlation (r = 0.879 [95% CI, 0.849-0.904; P < .001]). In addition, 13 studies compared AHI between PSG and PAT,[17-26,30-32] and 1 trial compared PAT and PSG twice within the same patient population.[23] Comparison of AHI demonstrated a high correlation (r = 0.893 [95% CI, 0.857-0.920; P < .001]). The combined overall correlation for RDI and AHI between PSG and PAT was high (r = 0.889 [95% CI, 0.862-0.911; P < .001]) (**Figure 4**).

In addition, 5 studies[22-24,30,31] compared ODI between PSG and PAT. This index also demonstrated a high correlation (r = 0.942 [95% CI, 0.894-0.969; P < .001]) (**Figure 5**). As such, RDI, AHI, and ODI retrieved from PAT all correlate significantly with those obtained from formal PSG.

Meta-analysis by Study Setting

Laboratory

Three of the 14 studies compared RDI between laboratory-based PSG and PAT, individually or in conjunction with AHI within the same study group.[22,27,31] This index had a significant correlation (r = 0.878 [95% CI, 0.827-0.915; P < .001]). Twelve studies[17-23,25,26,30-32] compared AHI between laboratory-based PSG and PAT. This variable also demonstrated a high correlation (r = 0.899 [95% CI, 0.862-0.927; P < .001]). Predictably, the overall correlation for RDI and AHI measured from laboratory-based PSG and PAT was high (r = 0.894 [95% CI, 0.877-0.904; P < .001]) (**Figure 6**).

In addition, 4 studies[22,23,30,31] compared ODI between laboratory-based PSG and PAT and demonstrated a high correlation (r = 0.959 [95% CI, 0.909-0.982; P < .001]). As such, RDI, AHI, and ODI retrieved from a laboratory-based PAT device correlate significantly with the same sleep indexes obtained from laboratory-based PSG.

Home

Only 1 of the 14 studies compared RDI and AHI measured from home-based PAT and PSG in the same study group (r = 0.890 [95% CI, 0.857-0.916; P < .001]).[24] One additional study compared only AHI measured from home-based PAT and laboratory-based PSG.[23] The weighted AHI correlation between these 2 studies was 0.838 (95% CI, 0.581-0.943; P < .001). The overall weighted correlation of RDI and AHI between home-based PAT and home- and laboratory-based PSG was high (r = 0.862 [95% CI, 0.779-0.915; P < .001]). The same 2 studies also compared ODI as measured from home-based PAT and PSG (r = 0.879 [95% CI, 0.714-0.952]). As such, RDI, AHI, and ODI retrieved from a home-based PAT device also correlate significantly with the same sleep indexes obtained from laboratory-based PSG.

Table 2. Study Design and Bias

Source	Design and Bias
Exploratory Cohort Studies	
Pillar et al,[17] 2002	96 Patients undergoing simultaneous laboratory-based PAT and PSG[a]; assessed correlation between PAT-based and ASDA-based arousal index derived from PSG
Penzel et al,[18] 2002	21 Patients with confirmed OSA and arterial hypertension undergoing simultaneous laboratory-based PAT, PSG, and blood pressure monitoring[a]; assessed correlation between PAT signal attenuation and cortical arousals
Bar et al,[19] 2003	102 Individuals, 69 with suspected OSA and 33 healthy volunteers, undergoing laboratory-based simultaneous PST and PAT plus 14 undergoing home-based PAT studies[a]; evaluated the efficacy, reliability, and reproducibility of PAT device
Ayas et al,[20] 2003	30 Individuals with and without suspected OSA undergoing simultaneous laboratory-based PSG and wearing PAT device[a]; evaluated the accuracy of PAT to diagnose OSA
Pillar et al,[21] 2003	68 Individuals undergoing simultaneous laboratory-based PSG with PAT signal recording using PAT device[a]; examined the accuracy of PAT device in detection of arousals from sleep
Penzel et al,[22] 2004	17 Individuals with suspected sleep apnea undergoing simultaneous laboratory-based PSG and PAT[a]; determined the reliability of PAT device to detect arousals, apneas, and hypopneas compared with formal PSG
Onder et al,[30] 2012	56 Individuals with suspected OSA, split into group 1 (age range, 20-35 y) and group 2 (age range, 50-65 y)[a]; investigated consequences of aging on PAT-based sleep analysis in patients with OSA
Validation Cohort Studies	
Pittman et al,[23] 2004	29 Individuals undergoing 2 overnight studies with PAT device: 1 night laboratory based with concurrent PSG and 1 night home based with only PAT[a]; assessed the accuracy of PAT device to diagnose OSA in a home setting
Zou et al,[24] 2006	98 Individuals undergoing simultaneous unattended in-home PSG and PAT[a]; assessed the validity of PAT to diagnose OSA in the unattended home setting
Pang et al,[25] 2007	37 Individuals with suspected OSA undergoing simultaneous laboratory-based PSG while wearing PAT device[a]; validated the reliability and predictive capability of PAT device to diagnose OSA
Choi et al,[26] 2010	25 Individuals with suspected OSA undergoing hospital-based PAT at 1 mo after full PSG evaluation[a]; assessed the accuracy and efficacy of PAT device to diagnose OSA; bias: night-to-night variability unaccounted for secondary to nonblinded design
Hedner et al,[27] 2011	228 Individuals undergoing simultaneous laboratory-based PSG and PAT[a]; analyzed signals from PAT recorder to validate the detection of sleep stages
Yuceege et al,[31] 2013	90 Highway bus drivers undergoing simultaneous laboratory-based PSG and PAT; predicted the validity of the PAT device for sleep-related breathing disorder among highway bus drivers
Weimin et al,[32] 2013	28 Individuals with suspected OSA undergoing simultaneous laboratory-based PSG and PAT[a]; assessed the accuracy of PAT device to diagnose OSA

Abbreviations: ASDA, American Sleep Disorders Association; OSA, obstructive sleep apnea; PAT, peripheral arterial tonometry; PSG, polysomnography.

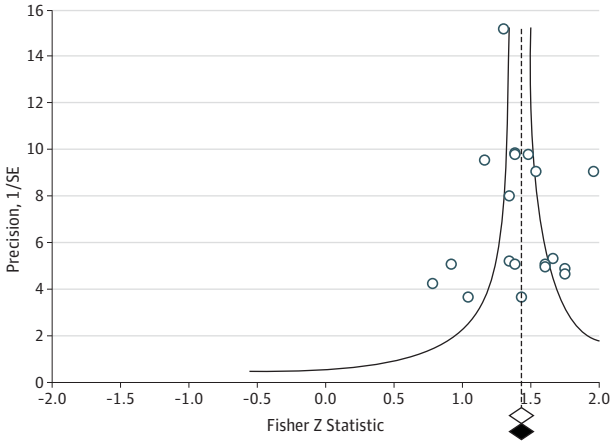
[a] Indicates selection bias. The study included all or most individuals who were referred to trial secondary to confirmed or suspected OSA. Results cannot be generalized to the overall population because participants are not equally balanced and objectively represented.

Meta-analysis by Study Design

Blinded

Four of the 14 studies compared RDI between simultaneously conducted PSG and PAT.[22,24,27,31] This variable had a high correlation (r = 0.879 [95% CI, 0.849-0.904; P < .001]). In addition, 13 studies compared AHI between simultaneously conducted PSG and PAT.[17-25,27,30-32] This variable also had a high correlation (r = 0.896 [95% CI, 0.861-0.923; P < .001]). Predictably, the overall weighted correlation for RDI and AHI as measured between simultaneously conducted PSG and PAT was high (r = 0.891 [95% CI, 0.865-0.913; P < .001]). Also, 5 studies[22-24,30,31] compared ODI between simultaneously conducted PSG and PAT. This variable also had a high correlation (r = 0.953 [95% CI, 0.913-0.975; P < .001]). Therefore, RDI, AHI, and ODI retrieved simultaneously from PAT correlate significantly with the same sleep indexes obtained from PSG.

Figure 3. Precision Fisher Z Funnel Plot to Access Publication Bias



Circle dots represent published studies used in the meta-analysis; dotted center line, corrected effect size; solid lines, overall effect size.

Nonblinded

No study compared RDI between independently conducted PSG and PAT. However, 2 studies compared AHI between PSG and PAT conducted in a nonsimultaneous fashion.[22,26] This comparison demonstrated a correlation of 0.866 (95% CI, 0.466-0.972; P = .001). One study[23] also compared ODI between nonsimultaneously conducted PSG and PAT with a correlation value of 0.800 (95% CI, 0.613-0.902). As such, among the 2 studies that were conducted with a nonblinded design, AHI and ODI retrieved via PAT also correlate significantly with those obtained from PSG.

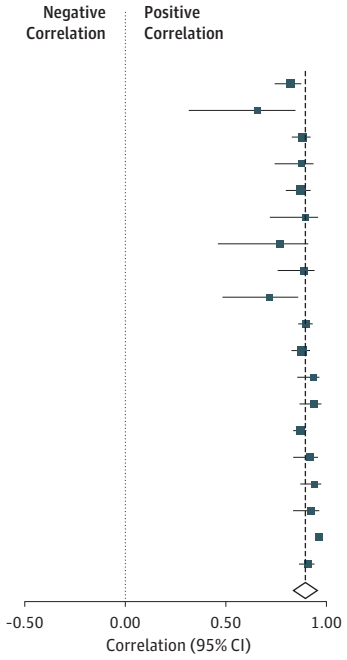
Discussion

In this study, we assessed the utility of PAT as a diagnostic modality for OSA based on a meta-analysis of the published studies. Our initial literature search returned 157 articles. After imposing our exclusion criteria, 14 studies remained for analysis, including a total of 909 patients. Because the studies included in this analysis had varied protocols, we used the random-effects model. The model assumes that the studies are drawn from populations that differ from each other in variables that may have a direct effect on outcomes; in addition, any observed differences will be the result of a random error or a true variation in effect. When applied to this study, the random-effects model suggests that despite the variance among protocols and patient population, our results may represent the true association of sleep indexes obtained by PAT and PSG.

With all studies included, our data suggest that overall respiratory indexes calculated from PAT correlate well with those

Figure 4. Overall Correlation of the Respiratory Disturbance Index (RDI) and Apnea-Hypopnea Index (AHI) Between Polysomonography (PSG) and Peripheral Arterial Tonometry (PAT)

Source (Study Setting), (Design)	Subgroup Within Study	Correlation, *r* Value	Statistics: Lower Limit (95% CI)	Statistics: Upper Limit (95% CI)	*Z* Value	*P* Value
Pillar et al,[17] 2000 (L), (B)	AHI[a]	0.820	0.740	0.877	11.035	<.001
Penzel et al,[18] 2002 (L), (B)	AHI	0.656	0.313	0.848	3.334	.001
Bar et al,[19] 2003 (L), (B)	AHI[a]	0.880	0.826	0.918	13.480	<.001
Ayas et al,[20] 2003 (L), (B)	AHI	0.870	0.742	0.937	6.927	<.001
Pillar et al,[21] 2003 (L), (B)	AHI[a]	0.870	0.797	0.918	10.748	<.001
Penzel et al,[22] 2004 (L), (B)	AHI	0.890	0.715	0.960	5.320	<.001
Penzel et al,[22] 2004 (L), (B)	RDI	0.770	0.459	0.913	3.818	<.001
Pittman et al,[23] 2004 (L), (B)	AHI[a]	0.880	0.758	0.943	7.015	<.001
Pittman et al,[23] 2004 (L), (B)	AHI[a]	0.720	0.480	0.860	4.628	<.001
Zou et al,[24] 2006 (H), (B)	AHI	0.900	0.854	0.932	14.349	<.001
Zou et al,[24] 2006 (H), (B)	RDI	0.880	0.826	0.918	13.409	<.001
Pang et al,[25] 2007 (L), (B)	AHI	0.929	0.858	0.965	8.883	<.001
Choi et al,[26] 2010 (L), (NB)	AHI	0.940	0.867	0.974	8.152	<.001
Hedner et al,[27] 2011 (L), (B)	RDI	0.870	0.834	0.898	19.962	<.001
Onder et al,[30] 2012 (L), (B group 1)	AHI	0.920	0.835	0.962	8.102	<.001
Onder et al,[30] 2012 (L), (B group 2)	AHI	0.940	0.871	0.973	8.515	<.001
Weimin et al,[32] 2013 (L), (B)	AHI	0.920	0.833	0.963	7.945	<.001
Yuceege et al,[31] 2013 (L), (B)	AHI	0.960	0.939	0.974	17.621	<.001
Yuceege et al,[31] 2013 (L), (B)	RDI	0.909	0.863	0.940	13.780	<.001
Overall		0.889	0.862	0.911	24.096	<.001

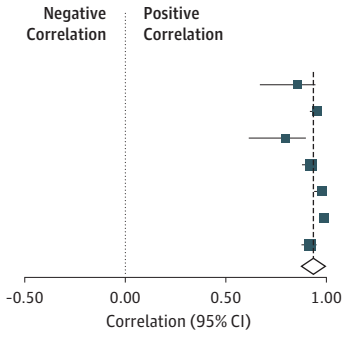


We calculated overall correlation using the random-effects model. Size of the data marker corresponds to the relative weight assigned in the pooled analysis. B indicates blinded; H, home setting; L, laboratory setting; and NB, nonblinded.

[a]Study reported the value as RDI; however, recent American Academy of Sleep Medicine criteria defined the value as AHI.

Figure 5. Correlation Analysis of the Oxygen Desaturation Index (ODI) Between Polysomonography (PSG) and Peripheral Arterial Tonometry (PAT)

Source (Study Setting), (Design)	Subgroup Within Study	Correlation, *r* Value	Statistics: Lower Limit (95% CI)	Statistics: Upper Limit (95% CI)	*Z* Value	*P* Value
Penzel et al,[22] 2004 (L), (B)	ODI	0.870	0.669	0.952	4.988	<.001
Pittman et al,[23] 2004 (L), (B)	ODI	0.960	0.916	0.981	9.922	<.001
Pittman et al,[23] 2004 (H), (B)	ODI	0.800	0.613	0.902	5.602	<.001
Zou et al,[24] 2006 (H), (B)	ODI	0.920	0.883	0.946	15.488	<.001
Onder et al,[30] 2012 (L), (B group 1)	ODI	0.970	0.936	0.986	10.669	<.001
Onder et al,[30] 2012 (L), (B group 2)	ODI	0.990	0.978	0.995	12.966	<.001
Yuceege et al,[31] 2013 (L), (B)	ODI	0.923	0.884	0.949	14.569	<.001
Overall		0.942	0.894	0.969	10.877	<.001

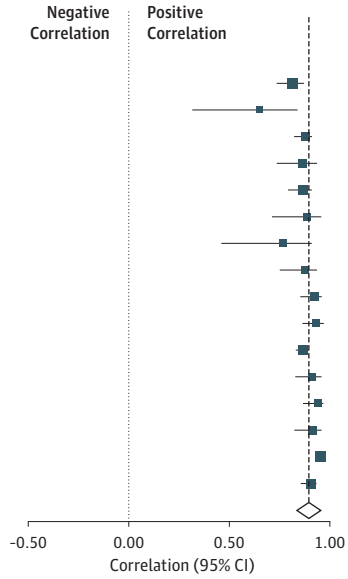


Correlation analysis of studies reporting ODI between PSG and PAT using the random-effects model. Size of the data marker corresponds to the relative weight assigned in the pooled analysis. B indicates blinded; H, home setting; L, laboratory setting; and NB, nonblinded.

calculated from PSG. The strength of this correlation was further supported by the fact that most of the included studies had a blinded design, which helped to eliminate night-to-night variations in data recording. The clinical significance of this correlation rests on the notion that PAT technology represents a viable alternative to PSG. Given the rising prevalence of OSA, this tool can provide clinicians a relatively rapid and accurate means for diagnosis. However, specific selection criteria must first be determined to evaluate its appropriate diagnostic use for patients with suspected OSA. Recent guidelines have generalized home-based diagnostic devices to be prescribed only to individuals with a high pretest probability of OSA. Given that PAT devices are not as sensitive as PSG, patients with a negative result would be then encouraged to undergo formal laboratory-

Figure 6. Correlation Analysis of All Laboratory-Based Studies Reporting Respiratory Disturbance Index (RDI) and Apnea-Hypopnea Index (AHI)

Source (Study Setting), (Design)	Subgroup Within Study	Correlation, *r* Value	Statistics: Lower Limit (95% CI)	Statistics: Upper Limit (95% CI)	*Z* Value	*P* Value
Pillar et al,[17] 2002 (L), (B)	AHI[a]	0.820	(0.740-0.877)		11.035	<.001
Penzel et al,[18] 2002 (L), (B)	AHI	0.656	(0.313-0.848)		3.334	.001
Bar et al,[19] 2003 (L), (B)	AHI[a]	0.880	(0.826-0.918)		13.480	<.001
Ayas et al,[20] 2003 (L), (B)	AHI	0.870	(0.742-0.937)		6.927	<.001
Pillar et al,[21] 2003 (L), (B)	AHI[a]	0.870	(0.797-0.918)		10.748	<.001
Penzel et al,[22] 2004 (L), (B)	AHI	0.890	(0.715-0.960)		5.320	<.001
Penzel et al,[22] 2004 (L), (B)	RDI	0.770	(0.459-0.913)		3.818	<.001
Pittman et al,[23] 2004 (L), (B)	AHI[a]	0.880	(0.758-0.943)		7.015	<.001
Pang et al,[25] 2007 (L), (B)	AHI	0.929	(0.858-0.965)		8.883	<.001
Choi et al,[26] 2010 (L), (NB)	AHI	0.940	(0.867-0.974)		8.152	<.001
Hedner et al,[27] 2011 (L), (B)	RDI	0.870	(0.834-0.898)		19.962	<.001
Onder et al,[30] 2012 (L), (B group 1)	AHI	0.920	(0.835-0.962)		8.102	<.001
Onder et al,[30] 2012 (L), (B group 2)	AHI	0.940	(0.871-0.973)		8.515	<.001
Weimin et al,[32] 2013 (L), (B)	AHI	0.920	(0.833-0.963)		7.945	<.001
Yuceege et al,[31] 2013 (L), (B)	AHI	0.960	(0.939-0.974)		17.621	<.001
Yuceege et al,[31] 2013 (L), (B)	RDI	0.909	(0.863-0.940)		13.780	<.001
Overall		0.894	(0.864-0.918)		21.241	<.001



Correlation analysis of all laboratory-based studies reporting RDI and AHI using the random-effects model. Size of the data marker corresponds to the relative weight assigned in the pooled analysis. B indicates blinded; H, home setting; L, laboratory setting; and NB, nonblinded.
[a]Study reports this value as RDI; however, recent American Academy of Sleep Medicine criteria defined the value as AHI.

based PSG. PAT technology is not appropriate for all patients; it is contraindicated in patients with central sleep apnea, periodic limb movement disorder, moderate to severe pulmonary disease, neuromuscular disease, and congestive heart failure. Clinicians must continue to use their clinical judgment when determining which patient population will benefit from a portable sleep-monitoring test or a formal PSG.

Disadvantages of this technology include the inability to differentiate between different types of sleep apnea (central, mixed, or obstructive). Use of PAT may also be limited by certain medications and disease. Most articles reviewed in this study used stringent criteria to exclude patients with diabetes mellitus, peripheral neuropathy, vasculopathy, bilateral sympathectomy, and cardiac disease and those taking α-adrenergic receptor–blocking agents. However, all 14 studies included patients with hypertension. Hypertension may be a confounding variable to the results measured by PAT and thus might limit universal use of the device. In addition, aging causes vascular morphological alterations, such as reduced compliance and loss of vascular homeostasis, and has been reported to be associated with impairment in vascular tone. The study by Onder et al[30] compared individuals ranging in age from 20 to 35 years with those ranging in age from 50 to 65 years. They concluded that aging did not negatively affect PAT-recorded data in terms of RDI, AHI, and ODI, but they found a significant difference between the 2 groups in terms of PAT- and PSG-recorded sleep stage 3. This finding may be attributed to aging and impaired vascular tone. However, because sleep indexes recorded by the PAT device were in good agreement with sleep indexes recorded by PSG, PAT may still be a viable alternative option for the diagnosis of OSA in elderly patients. Furthermore, most of the participants undergoing testing in the 14 studies were precategorized as patients with suspected OSA. As such, its utility may be extrapolated only to patients with a high pretest probability of OSA without the presence of any listed confounding diseases.

The limitations of meta-analysis, especially pertaining to diagnostic studies, include selection bias and confounding factors. Although the primary reviewers attempted to lessen the potential of patient selection bias through the use of the inclusion/exclusion criteria as outlined, the criteria may represent a source of selection bias. Although unavoidable, exclusion of certain articles may weigh results of one outcome over another. The consequence of limiting selection bias is the inclusion of many possible confounding factors. Publication bias was assessed using the Egger regression intercept, which failed to show significant bias and was further illustrated in the precision funnel plot.

Conclusions

Obstructive sleep apnea is a chronic, debilitating condition that, if left untreated, is associated with several adverse clinical events. With a rising obesity epidemic, OSA is anticipated to become increasingly prevalent. As such, the associated medical and financial implications have sparked the development of effective, relatively low-cost diagnostic instruments. Based on our

meta-analysis of the published studies, devices using PAT technology consistently demonstrate a relatively high degree of correlation in sleep variables when compared with the criterion standard of PSG. This finding suggests that PAT-based ambulatory devices may provide useful data for effective identification of patients with suspected OSA. However, practitioners must continue to use their clinical judgment when determining which patients will benefit from the use of PAT technology.

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Study concept and design: Hamilton, Samuelson, Friedman.
Acquisition of data: All authors.
Analysis and interpretation of data: All authors.
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