

Cost–Utility of Three Approaches to the Diagnosis of Sleep Apnea: Polysomnography, Home Testing, and Empirical Therapy

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Background: Obstructive sleep apnea syndrome (OSAS) is usually diagnosed with overnight polysomnography in a sleep laboratory. Home sleep studies can be performed at lower cost, but results are somewhat less reliable. Bedside diagnosis of OSAS without any testing has also been discussed.

Objective: To model the costs and utility of laboratory polysomnography, home study, and no testing during the 5 years after initial evaluation for OSAS.

Design: Cost–utility analysis.

Data Sources: Published data.

Target Population: Hypothetical cohort of persons suspected of having OSAS.

Time Horizon: The 5 years after initial evaluation for OSAS.

Perspective: Societal.

Intervention: Nasal continuous positive airway pressure when OSAS was diagnosed.

Measurements: Quality of life, survival and charges (as proxies for costs) for each diagnostic method.

Results of Base-Case Analysis: Under almost all modeled conditions, polysomnography provided maximal quality-adjusted life-years in the 5 years after the initial diagnostic evaluation. The incremental charges for polysomnography over home study or no testing were about \$13 400 and \$9200, respectively, per quality-adjusted life-year gained during this period.

Results of Sensitivity Analysis: Results were sensitive to the utility of treatment in the absence of OSAS.

Conclusions: The cost–utility of polysomnography instead of home study or no testing in the diagnosis of OSAS compares favorably with that of other procedures for which society judges the added utility per dollar spent to be worthwhile. More precise determination of certain key variables in this model should be a goal of future research.

Obstructive sleep apnea syndrome (OSAS) results from repeated obstruction of breathing during sleep and is associated with excessive daytime sleepiness, significant cardiovascular morbidity, and increased mortality (1–4). Recent data suggest that 2% to 4% of adults have this disorder (5). Nasal continuous positive airway pressure (CPAP) administered at home prevents collapse of the airway, is the most commonly used treatment, and has a favorable cost–utility ratio (6, 7). However, OSAS remains undiagnosed in at least 82% of men and 93% of women with the condition (8).

The gold standard for diagnosis of OSAS is nocturnal polysomnography, a recording of brain waves, eye movements, muscle activity, chest movements, air movements, and blood oxygen saturation that must be performed by trained technologists using expensive equipment. The cost of polysomnography—about \$1000 to \$1400—has generated considerable interest in many different portable devices that can record nocturnal breathing and oxygenation at home, at a much lower cost and somewhat lower efficacy (9). In addition, some researchers have argued that the pretest suspicion of OSAS, based on symptoms and physical findings alone, is sometimes sufficient to make any test superfluous (10, 11). Whether decreased costs of home studies or bedside diagnosis adequately compensate for loss of diagnostic accuracy has not yet been evaluated.

To model diagnosis of OSAS by polysomnography, home study, and no sleep testing, we applied decision analytical techniques to published data and to a range of reasonable estimates for unknown quantities. We then calculated cost–utility ratios that reflect the incremental costs of the preferred approach per quality-adjusted life-year (QALY) gained.

Methods

Model

We constructed a decision tree (Figure 1) in which a hypothetical adult patient in whom OSAS is suspected enters at left and proceeds on a path to

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the right through a square node that represents the decision among three alternative approaches to diagnosis, circular nodes that represent the chances of a positive or negative test result (and treatment or no treatment with CPAP, respectively), circular nodes that represent the probability that OSAS is actually present, and terminal triangular nodes that reflect the utility of the resulting health state. The values for utilities and probabilities shown in **Figure 1** and discussed below are calculated for a baseline case. Few assumptions were made about baseline patient age, comorbid conditions, or severity of sleep apnea. The published data used in the tree (for example, utility and survival data) were derived from consecutive, sleep-center-referred, adult case series in which inclusion criteria beyond a diagnosis of OSAS were avoided and stratified results for subcategories of patients were not given. The only exception is that health state utilities were derived from a series that did not include mild OSAS that might be treated at some other sleep centers (7). On average, the patients that we modeled were in the sixth decade of life, most were male, and many had cardiovascular comorbid conditions (3, 7).

Outcome Measures

Outcome utility can be calculated in QALYs (utility \times expected life span) when the utility of a health state is assumed to remain constant over time. To avoid such an assumption for patients with OSAS, we calculated QALYs for the first 5 years after evaluation for OSAS (QALY_{5s}) rather than for total life expectancy. The QALY_{5s} represent the product of 1) the utility of the health state and 2) the average number of years, within the 5-year period that follows diagnostic evaluation, that a patient in that health state can be expected to survive. We used QALY_{5s} because currently available data on compliance, quality of life, survival with and without CPAP, and costs for patients with OSAS are limited to approximately 5 years rather than remaining life spans. Data are limited in part because widespread diagnosis and treatment of OSAS represent relatively recent accomplishments.

We used decision analysis software (TreePlan version 1.57, Decision Support Services, San Francisco, California) to help determine the magnitude of the advantage afforded by the best diagnostic approach—polysomnography, home study, or no testing—measured in QALY_{5s}. We then calculated the 5-year cost in U.S. dollars of obtaining that advantage. In cost–utility ratios that compared polysomnography with either home study or no testing, the numerator was the 5-year difference in total costs and the denominator was the difference in QALY_{5s} for the same period. All cost–utility ratios discussed in this report are therefore incremental

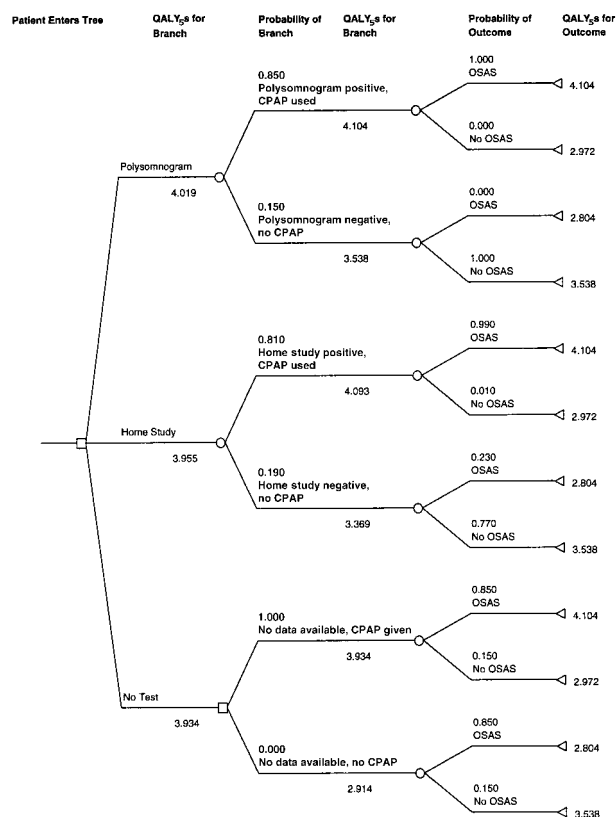


Figure 1. Decision tree with quality-adjusted life-years, calculated for the 5 years after initial evaluation (QALY_{5s}), as the outcome measure. Assumptions are those listed as baseline estimates in **Table 4**. Squares represent decision nodes, circles represent chance nodes, and triangles represent outcomes. Calculation of the total QALY_{5s} for the home study branch, for example, was as follows: (0.99)(4.104) + (0.01)(2.972) = 4.093 (QALY_{5s} for continuous positive airway pressure [CPAP] branch) and (0.23)(2.804) + (0.77)(3.538) = 3.369 (QALY_{5s} for no CPAP branch), then (0.81)(4.093) + (0.19)(3.369) = 3.955 (QALY_{5s} for home study branch). OSAS = obstructive sleep apnea syndrome.

(they compare two diagnostic options) rather than absolute (referring to one option).

The QALY_{5s} in this report cannot be compared directly with QALYs in other research, which are usually calculated with life expectancies rather than average survival during 5-year study periods. However, the final results—incremental cost–utility ratios, measured in dollars per single QALY₅ gained—are comparable to other incremental cost–utility ratios calculated in dollars per QALY gained; the subscript “5” is retained only as a reminder that current data are not derived from longer follow-up periods. Comparisons of cost–utility ratios among studies are important in assessment of the value of different tests or procedures in disparate medical fields.

After we derived results for a base-case, we performed univariate sensitivity analyses to test the effects on the model of different but plausible utilities, survival rates, pretest probabilities of OSAS, test characteristics, and costs. We performed a two-variable sensitivity analysis to model the perfor-

Table 1. Baseline Utilities of Four Possible Health States (Outcomes), Mean Survival during 5-Year Periods after Diagnostic Evaluation, and Resulting Quality-Adjusted Life-Years*

Health State		Utility	Mean Survival during 5-Year Periods, y	Quality-Adjusted Life-Yearst	How Values Were Estimated (Reference)
OSAS	CPAP				
Yes	Yes	0.87	5.0	4.104	Utility determined by standard gamble technique with OSAS patients (7).
No	Yes	0.63	5.0	2.972	Utility not published but estimated at 0.63, equivalent to untreated OSAS, by reasoning that few patients would have substantial improvement and that inconvenience of CPAP for no gain in some patients might be counterbalanced by improvement in snoring or upper airway resistance in others (13). Utility subjected to wide sensitivity analysis.
Yes	No	0.63	4.7	2.804	Utility determined by standard gamble technique with OSAS patients (7). Reduced 5-year survival in untreated OSAS, mainly due to cardiovascular mortality, was derived from the study by Partinen and colleagues (3) and was suggested by other studies (2, 4) but remains unproved (14); thus, sensitivity analyses were performed.
No	No	0.75	5.0	3.538	Utility estimated to lie midway between utilities for untreated and treated OSAS on the basis of the following observations. 1) Among patients tested for OSAS, those without and those with OSAS often have equivalent morbidity (15) and, presumably, health state utility (about 0.63). Some patients without OSAS receive alternative diagnoses and treatments, which are often less efficacious than CPAP. 2) With the utility set at 0.75, the decrease in utility due to the inconvenience of CPAP among patients without OSAS ($0.75 - 0.63 = 0.12$) approximates the decrease among patients with OSAS ($1.00 - 0.87 = 0.13$). The utility estimate was subjected to a wide sensitivity analysis.

* CPAP = continuous positive airway pressure; OSAS = obstructive sleep apnea syndrome.

† Derived from utilities, summed over average years of survival, and discounted at 3% per year after the first year.

mance of a particularly inexpensive home study as a screening tool. To further explore the overall level of uncertainty in our model, we performed a 1000-iteration Monte Carlo simulation (DATA version 3.0, TreeAge Software, Inc., Williamstown, Massachusetts) in which all model variables were allowed to vary simultaneously, between trials, within plausible logit-normal distributions (12). Logit-normal distributions were used to normalize the distributions of variables with delimited ranges (for example, from 0 to 1 for probabilities). From these data,

we calculated 2000 cost-utility ratios—1000 for polysomnography compared with home study and 1000 for polysomnography compared with no test—and estimated the frequency with which given levels of marginal cost-utility would be obtained.

Utilities, Survival, Test Characteristics, Predictive Values, and Other Probabilities

Baseline utility and survival values and their derivations are shown in **Table 1**. One-night laboratory polysomnography with standard equipment and scoring procedures is a gold standard considered sufficient to make or rule out the diagnosis of OSAS in most persons (16). A baseline assumption in our model (**Figure 1**) was that polysomnograms are positive in all patients with OSAS and negative in all patients without OSAS. However, results can vary night to night, and a small percentage of polysomnograms may meet criteria for OSAS on a second study after failing to do so on an initial night (17). Our model therefore included outcomes to represent false-positive and false-negative diagnoses based on polysomnography, and we performed narrow sensitivity analyses to determine whether results of our model would change on the basis of sensitivities and specificities between 0.95 and 1.0. Because biological night-to-night variability would affect the home studies in equal measure, their test characteristics were simultaneously reduced by equivalent amounts in these sensitivity analyses.

The pretest probability of OSAS is high when most tested patients are referred by a sleep special-

Table 2. Baseline Estimates of 5-Year Diagnostic and Treatment Charges for a Patient with Obstructive Sleep Apnea Syndrome*

Component Charges	Diagnostic Approach		
	Polysomnogram	Home Study	No Test
	←—————\$—————→		
Polysomnography	1190		
Titration of CPAP	1190	1190	1190
Home study		440	
Equipment for CPAP†	1290	1290	1290
Initial office visit	210	210	210
Five annual follow-up office visits‡	330	330	330
Total	4210	3460	3020

* Charges for a patient found to have no obstructive sleep apnea syndrome were similar except that no CPAP equipment and one rather than five follow-up office visits were included. Each figure, except where indicated, represents the approximate charge at University of Michigan Sleep Center, Ann Arbor, Michigan. CPAP = continuous positive airway pressure.

† To estimate this charge, we surveyed the three home care vendors that most commonly supply our own patients and found that the average charge for the CPAP unit, nasal mask, headgear, and filters was \$1290 (range, \$1100 to \$1420). However, in each instance, specially negotiated discounts—a \$550 reduction in one example—were available for patients who belonged to particular health maintenance organizations.

‡ Calculated at \$70 per visit and discounted at 3% per year after the first year.

ist: About 85% of polysomnograms obtained for suspected sleep apnea in the University of Michigan Sleep Laboratory confirm the diagnosis. However, this estimate is not easily generalized because of variation in sources of referrals and interpretation of test results. Some sleep specialists report that as few as 54% of their patients tested for OSAS have a positive polysomnogram (18). We therefore subjected our model to a wide range of pretest probabilities of OSAS.

Like portable devices made by other companies, the EdenTrace Model 2700 (EdenTec, Eden Prairie, Minnesota) provides an unattended recording of several cardiorespiratory variables during sleep. The sensitivity of the EdenTrace Model 2700 for polysomnographically confirmed OSAS is 0.95 and the specificity is 0.96 (19). With a pretest probability of OSAS of 0.85, the positive predictive value of the EdenTrace Model 2700 is 0.99 and the negative predictive value is 0.77 (Figure 1). The proportion of all home studies expected to yield positive results is $(0.95 \times 0.85) + (0.04 \times 0.15) = 0.81$. Home study devices other than the EdenTrace Model 2700 have sensitivities as low as 0.80 and specificities as low as 0.70 (9); thus, these ranges were also tested in our model.

In the no-test branch of the model, all patients suspected of having OSAS receive treatment. The decision of whether to treat all or none of these patients with CPAP yields the highest QALY₅s when all patients are treated (as long as the pretest probability of OSAS is at least 0.31).

Costs

Because of a dearth of published data on costs, we used charges as a proxy for costs. Baseline values, shown in Table 2, were subjected to broad sensitivity analyses. We assumed that each patient who received a diagnosis of OSAS (by polysomnography, home study, or no testing) subsequently had polysomnography (at a charge of \$1190) to titrate CPAP to an appropriate pressure for home use. A separate laboratory titration study is currently standard practice because for most patients; attempts to

combine diagnostic and treatment goals into one night are believed to considerably compromise the usefulness of the studies (20). Titration with a home study is not recommended (21) and is not common in practice. To calculate the average total charge for a patient in any given branch of the decision tree, we used the 5-year total charges for any tests, office visits, and CPAP setups along with the probability that each charge would be incurred. Charges after the first year were discounted at 3% per year; future utilities were also discounted at the same rate, as is generally recommended (22).

A cost-utility analysis from a societal perspective should include indirect costs of the illness (23). For patients with OSAS, chief among these costs are those of long-term health services required when OSAS remains untreated. Kryger and colleagues (24) recently found that the annual total health care costs for 97 patients with untreated OSAS exceeded costs for 97 matched controls by \$375 to \$750 per patient. The report did not identify what portion of the increased costs was due to OSAS rather than obesity nor the amount that would have been saved by treatment with CPAP. Because of the lack of more definitive published data, we calculated our baseline analyses conservatively, without inclusion of long-term health costs. However, to examine cost-utility ratios that are probably more realistic from a societal perspective, we also computed results for a range of additional costs for untreated OSAS, up to \$750 per year.

Results

Baseline Decision, Charges, and Cost-Utility Ratios

In the baseline decision analysis (Figure 1), polysomnography generated higher QALY₅s (4.019) than did home study (3.955) or no testing (3.934). The 5-year diagnostic and treatment charges for a patient with OSAS were \$4210 for the polysomnography branch, \$3460 for the home study branch, and \$3020 for the no testing branch (Table 2); those charges for the baseline patient (who may or may

Table 3. Calculation of Baseline Cost-Utility Ratios*

Component of Formula	Formula	Polysomnography Compared with Home Study	Polysomnography Compared with No Testing
Numerator (expressed as charge in U.S. dollars)	$[(P^+)(\text{Charge}^+) + (P^-)(\text{Charge}^-)]_{\text{Dx Approach A}} - [(P^+)(\text{Charge}^+) + (P^-)(\text{Charge}^-)]_{\text{Dx Approach B}}$	$[(0.85)(4210) + (0.15)(1470)] - [(0.81)(3460) + (0.19)(720)]$	$[(0.85)(4210) + (0.15)(1470)] - [(1.0)(3020) + (0.0)(280)]$
Denominator (expressed as benefit in QALY ₅ s)	$\text{QALY}_{5\text{Dx Approach A}} - \text{QALY}_{5\text{Dx Approach B}}$	4.019 - 3.955	4.019 - 3.934
Cost-utility ratio (expressed as U.S. dollars/QALY ₅ s)	Charge/QALY ₅ gained	13 431	9165

* Charge⁺ = total 5-year charges for a patient whose result on a test for the obstructive sleep apnea syndrome is positive; Charge⁻ = total 5-year charges for a patient whose test result is negative; Dx = diagnostic; P⁺ = probability of a positive test result; P⁻ = probability of a negative test result; QALY₅s = quality-adjusted life-years, calculated from data that pertain to a 5-year period after diagnostic evaluation.

Table 4. Results of Sensitivity Analyses*

Variable	Baseline Estimate	Range Tested	Approach with the Most QALY ₅ s	Range of Cost–Utility Ratios	
				Polysomnography Compared with Home Study	Polysomnography Compared with No Testing
				<i>\$/QALY₅ gained</i>	
Utility of CPAP if patient has OSAS	0.63	0.50 to 0.82	Polysomnography if utility < 0.75; no testing if utility ≥ 0.75	12 458 to 15 081	4401 to –15 580
Utility of no CPAP if patient has OSAS	0.75	0.68 to 0.95	Polysomnography	13 644 to 12 641	21 639 to 3432
5-year survival in untreated OSAS	4.7 years	4.5 to 5.0 years	Polysomnography	12 458 to 15 350	9165
Pretest probability of OSAS	0.85	0.35 to 0.95	Polysomnography	19 530 to 13 646	–1606 to 36 310
Polysomnography					
Sensitivity†	1.00	0.95 to 1.00	Polysomnography	13 957 to 13 431	22 131 to 9165
Specificity‡	1.00	0.95 to 1.00	Polysomnography	14 679 to 13 431	9888 to 9165
Home study					
Sensitivity	0.95	0.80 to 0.95	Polysomnography	5354 to 13 431	9165
Specificity	0.96	0.70 to 0.96	Polysomnography	9272 to 13 431	9165
Cost of polysomnography or CPAP titration	\$1190	\$400 to \$1400	Polysomnography	594 to 16 844	1265 to 11 265
Cost of home study	\$440	\$50 to \$1200	Polysomnography	19 525 to 1556	9165
Cost of CPAP set-up	\$1290	\$800 to \$2000	Polysomnography	13 125 to 13 875	10 029 to 7912
Cost of office visits over 5 years§	\$540	\$400 to \$900	Polysomnography	13 389 to 13 539	9283 to 8859
Cost of health care added by 5 years of untreated OSAS	\$0	\$0 to \$3540	Polysomnography	13 431 to 11 014	9165

* CPAP = continuous positive airway pressure; OSAS = obstructive sleep apnea syndrome; QALY₅ = quality-adjusted life-year, calculated from data that pertain to a 5-year period after diagnostic evaluation.

† The difference between the sensitivities of polysomnography and home study was maintained at 5%.

‡ The difference between the specificities of polysomnography and home study was maintained at 4%.

§ Baseline cost of two office visits (\$280), for patients without OSAS, varied proportionately.

not have OSAS) were \$3799, \$2939, and \$3020, respectively. The incremental cost–utility ratio for polysomnography compared with home study was \$13 431 per QALY gained (Table 3). The cost–utility ratio for polysomnography compared with no testing was \$9165.

Sensitivity to Utilities

The decision to use polysomnography was sensitive to tested increases in the utility of CPAP for patients without OSAS (Table 4); as this utility reached 0.75 and began to approach the utility of treated OSAS (0.87), no testing became the diagnostic approach of choice. In contrast, the decision to use polysomnography did not change when we varied the utility of no CPAP in patients without OSAS through a wide range of plausible values (0.68 to 0.95). The cost–utility ratios for polysomnography compared with home study were largely unaffected by changes in utilities for patients without OSAS. The cost–utility ratios for polysomnography compared with no testing were more sensitive, and when the utility of CPAP in patients without OSAS was at least 0.75, the no-testing option “dominated” polysomnography (that is, no test was both preferred and less expensive). As this utility increased toward 0.75, the cost–utility ratio for polysomnography compared with no testing in-

creased sharply; for example, it became \$37 100 when the utility was set at 0.72.

Sensitivity to Survival Rate

The baseline assumption that 5-year survival for untreated OSAS patients is lower (4.7) than survival in the other patients (5.0) affected neither the no-testing branch, in which all patients received CPAP, nor the polysomnography branch, in which all OSAS patients received treatment. The home study branch was affected, but not extensively (Table 4): When the differential survival rate was eliminated from the model, polysomnography was still preferable to home study and no testing, home study was preferable to no testing, and the cost per additional QALY₅ provided by polysomnography over home study (\$15 350) was not substantially increased.

Sensitivity to Pretest Probability of Obstructive Sleep Apnea Syndrome

When we varied the pretest probability of OSAS between 35% and 95%, the polysomnography approach always resulted in the highest QALY₅s (Figure 2, top). Lower prevalence led to decreased total treatment charges in the polysomnography and home study branches but not in the no-testing branch, for which utility was maximized by treating

all patients (**Figure 2, middle**). Cost–utility ratios for polysomnography compared with home study did not show much variation with the pretest probability of OSAS (**Figure 2, bottom**, and **Table 4**). In contrast, with a very high pretest probability (95%), polysomnography cost an additional \$36 310 per QALY₅ gained over no testing. However, this cost–utility ratio quickly decreased with lower pretest probabilities and polysomnography became less expensive than no testing when the pretest probability decreased to 55%.

Sensitivity to Test Characteristics

As shown in **Table 4**, plausible reductions in sensitivity or specificity of polysomnography or home study were individually tested and did not affect the decisions based on QALY₅s. Reductions in the sensitivity or specificity of polysomnography to values as low as 0.95 had no substantial effect on cost–utility ratios, with one exception: As sensitivity of polysomnography decreased to 0.95, the cost–utility ratio of polysomnography comparison with no testing increased to \$22 131. Outside the ranges listed in **Table 4**, the sensitivity level below which polysomnography would have ceased to be the preferred approach (and be superseded by no test) was 0.93; no level of reduced specificity of polysomnography led to a change in the preferred approach. The cost–utility ratios of polysomnography compared with home study diminished with reductions in the specificity of home study and diminished substantially with reductions in the sensitivity of home study.

Sensitivity to Costs

Plausible variation in charges for testing (polysomnography or home study), compared with plausible variation in other charges (CPAP or office visits), generally had a larger effect on cost–utility ratios, especially for polysomnography compared with home study (**Table 4**). However, for all charges tested, comparisons of polysomnography with home study or no testing showed relatively low cost–utility ratios. Medical costs of untreated OSAS affected patients in the home study branch but not the polysomnography branch (no diagnoses missed) or no-testing branch (all cases treated). The cost–utility ratio for polysomnography compared with home study decreased to \$11 014 with the addition of \$750 per year (discounted by 3% per year after the first year) for extra health care costs among patients with untreated OSAS.

Multivariable Sensitivity Analyses

We recalculated cost–utility ratios under new assumptions both that the frequency of OSAS was only 0.35 and that the charge for home study was

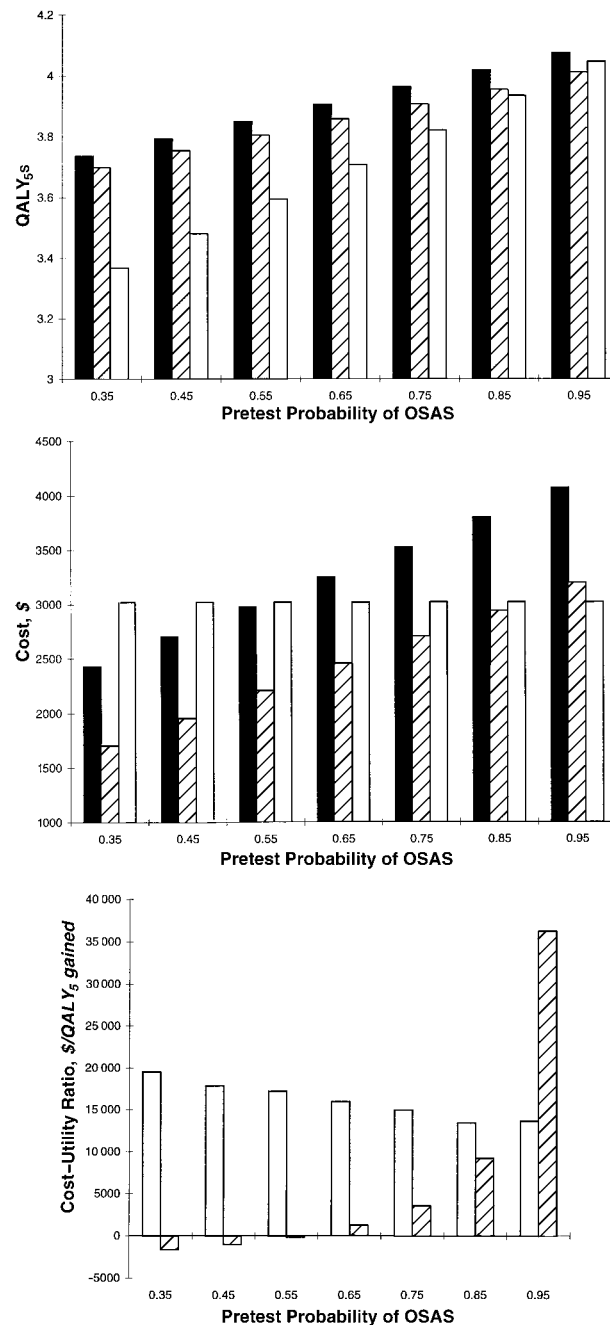


Figure 2. Sensitivity of 1) quality-adjusted life-years, calculated for the 5 years after initial evaluation (QALY₅) (top); 2) 5-year costs (middle); and 3) cost–utility ratios (bottom) to the pretest probability of obstructive sleep apnea syndrome (OSAS). The pretest probability of OSAS was varied while other variables were held at the baseline estimates listed in **Table 4**. In the top and middle sections, black bars represent polysomnography, striped bars represent home study, and white bars represent no testing. In the bottom section, white bars represent polysomnography compared with home study and striped bars represent polysomnography compared with no testing.

only \$50 (each change alone had previously resulted in ratios less favorable to the polysomnography approach, as shown in **Table 4**). Under these simultaneous assumptions, the cost–utility ratio for polysomnography compared with home study increased only to \$30 070 per additional QALY₅ gained by polysomnography (**Table 5**). In practice, however, a

Table 5. Results of Multivariable Sensitivity Analysis To Model Use of an Inexpensive Home Study as a Screening Tool*

Variable	Baseline Value	Value Tested	Approach with Most QALY ₅ s	Cost–Utility Ratio for Polysomnography Compared with Home Study, \$/QALY ₅ gained
Pretest probability of OSAS	0.85	0.35	Polysomnography > home study > no testing	30 070
Cost of home study	\$440	\$50		
Pretest probability of OSAS	0.85	0.35	Polysomnography > home study > no testing	3968
Home study				
Cost	\$440	\$50		
Sensitivity	0.95	0.80		
Specificity	0.96	0.70		

* OSAS = obstructive sleep apnea syndrome; QALY₅ = quality-adjusted life-year, calculated from data that pertain to a 5-year period after diagnostic evaluation.

\$50 home study might not achieve 95% sensitivity and 96% specificity (baseline values). If the sensitivity and specificity are at lower ends of plausible ranges (80% and 70%, respectively), the cost–utility ratio of polysomnography compared with home study would decrease to about \$4000.

For the Monte Carlo simulation, estimated variable means with 95% CIs and possible variable ranges are shown in **Table 6**. Three of the four utilities were calculated to correlate with the remaining one—the utility of CPAP in the presence of OSAS—as is recommended when utilities are interdependent (12). The Monte Carlo simulation showed that the proportion of 1000 iterations in which polysomnography dominated home studies (that is, led to lower cost and higher QALY₅s) was 0.05, and the proportion in which the incremental cost–utility ratio was positive but less than \$40 000 was 0.88. Similarly, the proportion of 1000 iterations in which polysomnography dominated no testing was 0.08, and the proportion in which the incremental cost–utility ratio was positive but less than \$40 000 was 0.58. The QALY₅s produced by the polysomnography approach were less than those produced by the no-testing approach in 16% of the trials.

Discussion

Our decision analysis suggests that polysomnography usually provides improved QALY₅s over both home study and no testing and that the cost of this advantage is not high. Sensitivity analyses showed our conclusions to be largely insensitive to variation in assumptions made about the individual model variables except for one: the utility of CPAP in patients who do not have OSAS. Although several additional variables required in our model have not been well studied, a Monte Carlo simulation—in which all assumed values were allowed to vary simultaneously within plausible ranges—showed that use of polysomnography rather than home studies or no tests cost less than \$40 000 per QALY₅

gained in most cases. Compared with other medical procedures, the advantage gained by polysomnography over either home study or no testing seems to be well worth the added expense. Coronary artery bypass surgery for left main artery occlusion was calculated to cost about \$6200 per QALY gained (in 1996 dollars) (25), renal dialysis cost \$47 200 (in 1996 dollars) (26), and screening asymptomatic patients for carotid stenosis cost about \$120 000 (reported in 1997) (27).

To our knowledge, our study is the first to apply decision-analytical techniques to diagnostic options in OSAS. The finding that polysomnography provides an advantage over no testing is not surprising, but the sensitivity of the decision to the utility of CPAP in the absence of OSAS shows that determination of this utility should be an important goal for future research. If this utility is as high as 0.73 or 0.75, sleep studies for patients in whom OSAS is suspected on clinical grounds would fail to be cost-effective or preferable, respectively (**Table 4**). In the Monte Carlo simulation, the sometimes high utility of CPAP in the absence of OSAS decreased the proportion of trials in which polysomnography was dominant or cost-effective compared with no testing. A high utility for CPAP in the absence of OSAS is possible, but we suspect that in practice, the detriment to quality of life caused by administration of CPAP when it is not needed is likely to balance the benefit experienced by some patients without OSAS (13). We therefore predict that the utility of CPAP in patients who are not shown to have OSAS as the cause of their symptoms is unlikely to be much higher than 0.63.

In contrast to the sensitivity of the model to a key utility, inclusion or exclusion of excess mortality associated with OSAS (2–4, 14) had little effect on the decision and cost–utility analyses. The improvement in quality of life that CPAP provides was more influential than reduced mortality, even if CPAP was assumed to completely negate suspected levels of excess mortality. Similarly, in untreated OSAS, the reduced quality of life affected cost–utility ratios much more than did costs of medical

complications. Pretest probability of OSAS also had little influence on comparative desirability of diagnostic approaches based on cost–utility; unless the pretest probability of OSAS was increased above 95%, the incremental cost per additional QALY₅ gained from polysomnography compared with either of the other approaches was less than \$40 000.

The finding that polysomnography was preferable to home study under all tested circumstances was not surprising because polysomnography has a higher sensitivity and specificity. In contrast, we did not anticipate the extent to which polysomnography would also prove more cost-effective. Like many other clinicians, we have been impressed with reports that some relatively inexpensive home studies have high sensitivity and specificity, such as 95% and 96%, respectively, for the EdenTrace Model 2700 (19). Use of home study devices has increased: At least one highly regarded sleep center now performs home studies as often as laboratory studies to diagnose OSAS, and at least one large health maintenance organization has required that home studies be performed in place of full polysomnography (28).

Our study highlights at least two factors that should be considered before the type of test is chosen.

First, sensitivity and specificity do not take into account the frequency of OSAS among the patients to be tested. At our center, the positive predictive value of the home study is high (0.99), but the negative predictive value is not (0.77); this means that 23% of patients with negative results could be left with untreated OSAS. At centers with lower pretest probability of OSAS, the negative predictive value of the home study is higher but the positive predictive value is lower, and a notable preference for polysomnography over home study would be maintained (**Figure 2**). Second, the costs of treatment or no treatment are high compared with the costs of diagnosis. Although polysomnography is the more costly option, the losses in dollars and quality of life due to diagnostic errors seem to warrant investment in this more precise diagnostic technique.

Our analyses were conservative in several respects. The test variables for the home study device that we modeled were generated in the largest of

Table 6. Variable Means, 95% CIs for Means, and Possible Ranges Used for Logit-Normal Distributions in Monte Carlo Simulation*

Variable	Mean Value (95%CI), Possible Range	Rationale
Utilities		
1: CPAP in patient with OSAS	0.87 (0.79–0.95), 0.4–1.0	Published data (7) are consistent with this mean, 95% CI, and range. Data not available, but utility 2 was estimated to approximate utility 3 (see Table 1). Published data (7) are consistent with this mean, 95% CI, and range. Data not available, but the mean for utility 4 was estimated to lie between that of utility 1 and that of utility 3 (see Table 1); distribution follows those for utility 1 and utility 3.
2: CPAP in patient without OSAS	Utility 1 × 0.73 (0.59–0.87), 0–1.0	
3: No CPAP in patient with OSAS	Utility 1 × 0.73 (0.59–0.87), 0–1.0	
4: No CPAP in patient without OSAS	(Utility 1 + Utility 3)/2	
Probabilities		
Pretest probability of OSAS	0.85 (0.5)‡, 0.35–0.95	Estimated as described in the text. Mean based on published data (3); 95% CI and range were estimated.
Untreated 5-year survival in OSAS, y	4.7 (4.5–4.9), 4.4–5.0	
Test characteristics		
Polysomnography		
Sensitivity	0.99 (0.95)‡, 0.9–1.0	The gold standard—polysomnography—defines OSAS, but the effect of night-to-night biological variability (as yet insufficiently characterized) was estimated; the mean was set at 0.99 rather than 1.00 to accommodate logit-normal distribution. See above.
Specificity	0.99 (0.95)‡, 0.9–1.0	
Home study		
Sensitivity	Polysomnography sensitivity minus 0.05 (0.10)§, 0.03–0.2	The mean reflects data published for modeled device (19); the 95% CI and range were estimated from published data (9). See above.
Specificity	Polysomnography specificity minus 0.04 (0.2)§, 0.02–0.3	
Charges, \$		
Polysomnography or CPAP titration	1190 (590–1790), 300–2000	The mean reflects model baseline value; the 95% CI and range were estimated. See above.
Home study	440 (140–740), 50–1200	
Set-up of CPAP	1290 (590–1990), 550–2000	See above
Five office visits	540 (300–780), 250–900	See above
Two office visits	280 (160–400), 100–450	See above
Untreated OSAS	100 (2000)§, 0–3540	The mean reflects baseline assumptions (see text), the range reflects published data (24), and the 95% CI was estimated; the mean was set at 100 rather than 0 to accommodate logit-normal distribution.

* The validity of values and distributions selected was supported by the proximity of baseline and mean simulated values for QALY₅s and costs in the polysomnography, home study, and no-testing branches of the model. Simulated means were, respectively, 3.995, 3.937, and 3.928 QALY₅s and \$4002, \$3043, and \$3243; minor deviations from baseline values were all in the same direction, and the baseline relative order was preserved. OSAS = obstructive sleep apnea syndrome; QALY₅ = quality-adjusted life-year, calculated from data that pertain to a 5-year period after diagnostic evaluation.

‡ Lower limit of CI.
§ Upper limit of CI.

seven recently reviewed studies (9). This device also performed better than average. Some centers use portable pulse oximetry alone to test for OSAS. Data from eight studies of pulse oximetry indicated that the predictive value is usually considerably less than that of instruments that also monitor such variables as airflow, chest expansion, and heart rate (9). Although some more rarely used portable monitoring devices now record almost all of the same variables that are monitored in the laboratory, no data are available on the costs (which may be substantial) or efficacy of these unattended studies (9).

Our analyses were also conservative because we modeled results for the first 5 years after evaluation for OSAS. This time frame was necessary because data from patients with OSAS on quality of life, survival, and costs for longer periods are not yet published. A longer perspective, which will eventually be possible, will most likely increase both the value of accurate initial diagnosis and the cost-effectiveness of polysomnography. One reason is that costs for each year of continued CPAP use are lower than costs in the first year, when initial testing and equipment costs are incurred. Therefore, the cost per QALY over longer periods is likely to be lower and the importance of accurate initial diagnosis will be somewhat higher. A second reason is that mortality for patients with untreated OSAS is likely to increase with time because the main cause of increased mortality is cardiovascular disease, which takes many years to develop. Higher mortality makes accurate initial diagnosis more cost-effective (**Table 4**).

Although we examined three options in the diagnosis of OSAS, several others also exist. The type of test needed can be determined by a clinician after he or she estimates the pretest probability of disease. For example, some sleep experts believe that portable monitoring may be appropriate for patients judged on clinical grounds to have only a mildly elevated or else a very elevated risk for OSAS (29). Such an approach was not supported by our model, which was largely insensitive to variation in pretest probability of OSAS between 35% and 95%.

Some sleep specialists have begun to use "split-night" polysomnography, in which diagnosis and CPAP titration are performed successively on the same night. Comparison of split-night studies with polysomnography, home study, and no testing will become possible as additional data are generated that define the sensitivity and specificity of these studies for OSAS and the utility of CPAP when a pressure setting is determined by this method. We also did not consider the possibility that in practice, patients may have more than one opportunity for OSAS to be diagnosed. For example, patients with

negative results on home studies but no other explanations for persistent symptoms may undergo second home studies or polysomnography. The utility of delayed diagnoses in such situations is not currently known but could affect the initial choice of a diagnostic approach. Finally, not only diagnostic methods but also treatment options for OSAS are expanding. In the future, alternative ways to establish CPAP therapy (such as home CPAP titration [30]) or to control sleep apnea (such as oral appliances [31]) may reduce treatment costs associated with OSAS and thereby alter cost-utility calculations.

Our conclusion that polysomnography is preferable and cost-effective in comparison to home study or no testing is predicated on the widely prevalent assumption that polysomnography and not home study should be the gold standard. Single-night polysomnography is not perfect, and false-negative results have been reported (32). Plausible reductions in the sensitivity or specificity of polysomnography did not change our model conclusions, but reductions in both variables might have had more important effects. Reduction in the sensitivity of polysomnography below 0.93, although perhaps unrealistic, made no testing the preferred approach and highlighted the importance of high sensitivity in any test for OSAS. Future refinements in home study equipment or further research may show that health-outcome-related advantages of diagnostic testing in the home environment rival or exceed the advantages of laboratory-based polysomnography. In this situation, home studies could become both preferable and cost-effective.

Decision analysis models to predict optimal outcomes, combined with cost-utility calculations to assess relative costs, will become increasingly important as the current trend toward managed care accelerates faster than the ability to perform the required large-scale clinical trials. Without these models or definitive data, health care managers might be tempted, on the basis of the high sensitivity and specificity of portable monitoring, to encourage this inexpensive method to diagnose OSAS at a perceived lower cost. In the future, prospective clinical trials may better define how OSAS should be diagnosed. Until such data are available, however, the results of our model suggest that the more precise and more expensive test (polysomnography) not only provides better outcomes from the patient's perspective but also represents, from a societal perspective, a cost-effective option relative to home studies and no testing. Finally, compared with other medical procedures to which society could allocate limited funds, polysomnography in patients suspected of having OSAS seems to be a worthwhile investment.

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