

# Cost-effectiveness of a 3-Year Tele-Messaging Intervention for Positive Airway Pressure Use

Jaejin An, BPharm, PhD; Dennis Hwang, MD; Amy M. Sawyer, PhD, RN; Jessica Arguelles, BS; Charles J. Bae, MD; Aiyu Chen, MPH; Brendan T. Keenan, MS; Samuel T. Kuna, MD; Greg Maislin, MS, MA; Diego R. Mazzotti, PhD; Allan I. Pack, MBChB, PhD; Jiaxiao M. Shi, PhD; Alexa J. Watach, PhD, RN; and Henry A. Glick, PhD

**M**oderate to severe obstructive sleep apnea (OSA) is a chronic condition affecting 24 million individuals in the United States<sup>1</sup> and has important consequences for health.<sup>2,3</sup> It has been shown to be associated with cardiovascular, cerebrovascular, and metabolic diseases, as well as motor vehicle and occupational accidents.<sup>4-7</sup> Through these mechanisms, it has also been shown to be associated with increased health care costs<sup>4-6,8</sup> and reduced quality of life.<sup>7</sup>

Positive airway pressure (PAP) therapy is the treatment of choice for OSA.<sup>5-7,9,10</sup> If effectively used, it may reduce the health burden and cost of OSA and improve quality of life.<sup>5,11-13</sup> However, PAP benefits may be limited by a lack of long-term adherence.<sup>5,6,11,13</sup> Strategies aimed at improving long-term PAP adherence are often labor intensive or utilize behavioral interventions without widespread expertise in the community, limiting feasibility of application in real-world settings.<sup>14</sup>

The Tele-OSA randomized clinical trial (NCT02279901) evaluated the impact of a web-based OSA education and automated tele-messaging intervention on improving PAP adherence.<sup>15,16</sup> The automated tele-messaging intervention was based on device data from a cloud-based application (U-Sleep; ResMed Corp). Based on predefined PAP usage thresholds, a message was automatically sent to the patient providing encouragement to improve PAP use or positively reinforcing successful PAP adherence. Patients received tele-messages via phone call, text messaging, or email depending on their preference. The trial demonstrated that participants who received the tele-messaging intervention had a higher PAP mean daily use at 3 months (4.4 hours in the tele-messaging intervention group vs 3.8 hours in the usual care group). The findings suggest that automated messaging to patients for PAP use may be a useful and possibly cost-effective approach to enhance long-term adherence. After the 3-month clinical trial, a group of patients continued their tele-messaging as part of clinical care, whereas others stopped receiving the messaging.

Practice guidelines suggest telemonitoring-guided interventions for initial PAP treatment monitoring period but acknowledge that the costs of this approach are not known.<sup>17</sup> The goal of our study was

## ABSTRACT

**OBJECTIVES:** To evaluate the cost-effectiveness of a 3-year tele-messaging intervention for positive airway pressure (PAP) use in obstructive sleep apnea (OSA).

**STUDY DESIGN:** A post hoc cost-effectiveness analysis (from US payers' perspective) of data from a 3-month tele-OSA trial, augmented with 33 months of epidemiologic follow-up.

**METHODS:** Cost-effectiveness was compared among 3 groups of participants with an apnea-hypopnea index of at least 15 events/hour: (1) no messaging (n = 172), (2) messaging for 3 months (n = 124), and (3) messaging for 3 years (n = 46). We report the incremental cost (2020 US\$) per incremental hour of PAP use and the fraction probability of acceptability based on a willingness-to-pay threshold of \$1825 per year (\$5/day).

**RESULTS:** The use of 3 years of messaging had similar mean annual costs (\$5825) compared with no messaging (\$5889;  $P = .89$ ) but lower mean cost compared with 3 months of messaging (\$7376;  $P = .02$ ). Those who received messaging for 3 years had the highest mean PAP use (4.11 hours/night), followed by no messaging (3.03 hours/night) and 3 months of messaging (2.84 hours/night) (all  $P < .05$ ). The incremental cost-effectiveness ratios indicated that 3 years of messaging showed lower costs and greater hours of PAP use compared with both no messaging and 3 months of messaging. Based on a willingness-to-pay threshold of \$1825, there is a greater than 97.5% chance (ie, 95% confidence) that 3 years of messaging is acceptable compared with the other 2 interventions.

**CONCLUSIONS:** Long-term tele-messaging is highly likely to be cost-effective compared with both no and short-term messaging, with an acceptable willingness-to-pay threshold. Future long-term cost-effectiveness studies in a randomized controlled trial setting are warranted.

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to use data from participants in the Tele-OSA study to evaluate the 3-year cost-effectiveness of 3 strategies for improving PAP adherence for patients with moderate to severe OSA: no messaging, 3 months of tele-messaging, and 3 years of tele-messaging.

## METHODS

### Trial

The Tele-OSA study was a 4-arm, randomized clinical trial conducted at Kaiser Permanente Southern California (KPSC) that enrolled participants from 2015 to 2016.<sup>15,16</sup> The primary outcome was PAP usage. The 4 treatment arms were (1) usual care alone, (2) usual care plus telemedicine web-based education (Tele-ed), (3) usual care plus PAP telemonitoring with automated feedback messaging based on usage data (Tele-messaging), and (4) usual care plus both Tele-ed and Tele-messaging (Tele-both). Usual care included a 1-hour, small-group education class about home sleep apnea testing setup and PAP therapy, a PAP trial for 1 week, and a 3-month follow-up appointment after PAP prescription. Formal follow-up in the trial was for 3 months, and only a subset of participants from the Tele-messaging and Tele-both arms received their messaging continuously, whereas the remainder had their messaging discontinued at 3 months. Epidemiologic follow-up (based on electronic health records) was continued for all groups for an additional 33 months.

### Ethics

The Tele-OSA study and all subsequent analyses based on the study cohort were approved by the KPSC Institutional Review Board (#10284). Participant written informed consent was waived for both the within-trial and epidemiologic follow-up analyses due to the minimal risk of the study interventions and data collection procedures.

### Study Sample

The current study includes Tele-OSA trial participants. We subdivided the trial sample into 3 groups: (1) participants in the usual care only and Tele-ed arms who never received tele-messaging (group 1: no messaging); (2) participants in the Tele-messaging and Tele-both arms who received tele-messaging for the first 3 months of the trial only (group 2: 3 months of messaging), and (3) participants in the Tele-messaging and Tele-both arms who indefinitely received tele-messaging (group 3: 3 years of messaging). In addition, we excluded those participants who at randomization did not have moderate to severe OSA (apnea-hypopnea index [AHI] < 15 events/hour).

### Outcomes

Our primary outcomes were incremental cost-effectiveness ratios. They were calculated as the ratio of the difference in incremental health care costs (2020 US\$) and the difference in incremental hours of PAP use among the 3 pairs of treatment groups from US

## TAKEAWAY POINTS

- ▶ Although tele-management systems have been shown to improve positive airway pressure (PAP) adherence, cost-effectiveness studies of these interventions have been limited.
- ▶ We found that 3 years of tele-messaging is more effective than no messaging where costs are similar; 3 years of tele-messaging is a cost-effective strategy compared with no messaging for adults with moderate to severe obstructive sleep apnea (OSA).
- ▶ Use of 3 years of tele-messaging is more effective and cost-saving compared with 3 months of tele-messaging for PAP use.
- ▶ Payers and health care policy makers should consider a long-term rather than short-term telehealth intervention for patients with OSA.

payers' perspectives. Both costs and effects were discounted at a rate of 3% per year.

Costs were derived by multiplying health service use recorded in KPSC electronic health records by costs reported in federal fee schedules. The recorded services included hospitalizations, other hospital services, pharmacy, sleep-related and other office visits, telephone calls, radiology, laboratory, sleep-related and other durable medical equipment, and emergency department visits. The fee schedules included the National Inpatient Sample,<sup>18</sup> the Medicaid National Average Drug Acquisition Cost Schedule,<sup>19</sup> the Physician Fee Schedule,<sup>20</sup> the Clinical Laboratory Fee Schedule,<sup>21</sup> and the Durable Medical Equipment Fee Schedule.<sup>22</sup>

Hours of PAP use were derived from an autotitrating device (AirSense 10; ResMed Corp) that wirelessly transmitted daily PAP data via a cellular signal into a cloud database.

### Analysis

We compared participant sociodemographic and clinical characteristics among the 3 groups using analysis of variance for continuous variables and  $\chi^2$  tests for categorical variables.

Cost differences (total and by subtype) between 3 months vs no messaging, 3 years vs no messaging, and 3 years vs 3 months of messaging were derived from the per-group predicted annual costs by use of a repeated measures generalized linear model (GLM). Explanatory variables included demographic characteristics (age, sex, race/ethnicity), clinical and economic characteristics that may be associated with cost and PAP use (AHI, Charlson Comorbidity Index, diabetes without complications, preoperative referral to sleep clinic prior to randomization, prior-to-enrollment 6-month cost, zip code-derived median household income) and indicator variables representing 6-month intervals.

Between-group differences in hours of PAP use (total and by year) were also derived from a repeated measures GLM. Except for prior cost, we used the same explanatory variables as were included in the cost models.

For the analysis of both costs and hours of PAP use, we summarized costs and hours of PAP use in 6-month intervals (1-6, 7-12, 13-18, 19-24, 25-30, and 31-36 months) to capture enough expected health care utilization during each time interval (for example, PAP-related durable medical equipment is usually replaced every 3-6 months).

We addressed within-participant correlations between the repeated measures by use of Stata's cluster option (which yields the sandwich estimator of variance). GLM links and the families were derived based on the results of the Pregibon link test, the Pearson correlation test, and the modified Hosmer-Lemeshow test (for the link) and the modified Parks test (for the family).<sup>23</sup> Participants may have lost KPSC membership during follow-up; therefore, cost or PAP data were not available for those participants who lost membership. To address these missing data, we used inverse probability censoring weights estimated by use of repeated measure logistic regression predicting observed vs missing data<sup>24,25</sup> as a function of time period, age, sex, race/ethnicity, Charlson Comorbidity Index, log of prior 6-month cost, Medicaid indicator, and percentage of no-show for medical appointments.

The incremental cost-effectiveness ratios were calculated by use of the differences in annual costs and differences in mean daily hours of PAP use derived earlier. After eliminating any strongly or weakly dominated therapies, we recommend the therapy that had the largest estimate of incremental effectiveness, yet an incremental cost-effectiveness ratio that was less than the willingness-to-pay threshold.<sup>23</sup> There is no consensus value of willingness to pay for an incremental hour of PAP use. In our primary analysis, we compared the ratios with a willingness-to-pay threshold of \$1825 per year (equals 365 days multiplied by \$5, or the willingness-to-pay threshold that would result if we were willing to pay \$5/day for a hypothetical once-daily pharmacological agent [eg, oral tablet] that on average increased daily PAP use by 1 hour for an entire year). In additional analyses, we assessed acceptability for a range of values of willingness to pay, between \$0 (if we were willing to pay \$0 for a once-daily pharmaceutical agent) and \$4000 per year (if we were willing to pay approximately \$11/day for such an agent).

To describe sampling uncertainty, SEs, correlations, *P* values, and CIs for the differences in costs and effects, as well as the empirical joint distribution of the differences in costs and effects, were estimated by use of a nonparametric bootstrap within the multivariable analysis framework. We described sampling uncertainty for our cost-effectiveness analyses by reporting cost-effectiveness planes for the 3 pairwise comparisons, 95% CIs for the cost-effectiveness ratios, and cost-effectiveness acceptability curves.<sup>23</sup> We estimated CIs for cost-effectiveness ratios and acceptability curves parametrically by use of the SEs and correlations derived from the bootstrap.

The cost-effectiveness plane plots bootstrapped cost/effect pairs on a graph where the x-axis represents the difference in effect between 2 therapies and the y-axis represents the difference in cost. Pairs in the lower right quadrant of the plane represent ones where the therapy dominates (is more effective and less costly than) the alternative. Pairs in the upper right quadrant of the plane represent ones where the therapy is more effective and more costly. If the ratio of the difference in cost to difference in effect is below the willingness-to-pay threshold, the pair represents good value; if it is above the willingness-to-pay threshold, it represents poor value. The cost-effectiveness acceptability curve reports the

likelihood that the therapy is good value for different thresholds for defining good value.

In sensitivity analyses, we tested the sensitivity of our cost-effectiveness results to the link and family specifications we used for our GLM analysis to estimate incremental costs by substituting the commonly used log link and gamma family. We also evaluated an incremental cost-effectiveness ratio for the 3-year group vs a group made up of the combination of those who received no messaging and 3 months of messaging. Finally, we added a weekly \$1.23 cost for tele-messaging interventions and evaluated an incremental cost-effectiveness ratio.<sup>26</sup>

## RESULTS

### Participant Characteristics

Of the 1455 participants enrolled, 556 were prescribed PAP treatment (**eAppendix Figure 1** [eAppendix available at [ajmc.com](http://ajmc.com)]). **Table 1** shows the baseline characteristics for the 3 treatment groups. We included a total of 342 participants with moderate to severe OSA. There were 172 (50.3%) in the group that received no messaging, 124 (36.3%) in the group that received 3 months of messaging, and 46 (13.4%) in the group that received 3 years of messaging. Characteristics were generally similar among the groups.

### Costs and Hours of PAP Use

**Table 2** shows costs and hours of PAP use for the 3 groups after adjusting for covariates. Missing values for both costs and hours of PAP use during follow-up are shown in **eAppendix Table 1**. Crude mean (SD) cost and hours of PAP use per 6-month time interval are shown in **eAppendix Tables 2 and 3**, respectively. Those who received 3 years of messaging had the lowest mean annual costs (\$5825), followed by no messaging (\$5889) and 3 months of messaging (\$7376). These differences were significant for no messaging vs 3 months of messaging ( $P = .02$ ) and 3 years vs 3 months of messaging ( $P = .02$ ), but not for 3 years of messaging vs no messaging ( $P = .89$ ).

Those who received messaging for 3 years had the highest mean number of hours of nightly PAP use (4.11), followed by no messaging (3.03) and 3 months of messaging (2.84). These differences were significant for 3 years of messaging vs no messaging ( $P = .01$ ) and 3 years vs 3 months of messaging ( $P = .002$ ), but not for no messaging vs 3 months of messaging ( $P = .50$ ). **eAppendix Tables 4 and 5** show the results of the GLM predicting total costs and hours of PAP use.

### Cost-effectiveness

**Table 3** shows the results of the cost-effectiveness analysis. The point estimates for costs and PAP hours indicate that 3 years of messaging dominated (ie, lower costs and greater hours of PAP use) both no messaging and 3 months of messaging. Thus, there are no point estimates for the incremental cost-effectiveness ratios to report. The fact that the solid black circle point estimates on the cost-effectiveness planes (**Figure 1** [A and B]) both fall in the lower right quadrant reinforces this finding (**eAppendix Figure 2** [A] shows

the cost-effectiveness plane for no messaging vs 3 months of messaging). For the comparisons of both 3 years of messaging vs no messaging and 3 years vs 3 months of messaging, the lower limits of the cost-effectiveness ratios indicate that 3 years of messaging may have dominated the other 2 therapies. The upper limits, on the other hand, indicate that we can be 95% confident that 3 years of messaging may have had an incremental ratio as high as \$1198/year for a mean 1 hour/night increase in PAP use vs no messaging and as high as \$33/year for a mean 1 hour/night increase vs 3 months of messaging.

**Figure 2** [A and B] reports the acceptability curves. Based on a willingness-to-pay threshold of \$1825 per year, there is a greater than 97.5% chance (ie, 95% confidence) that 3 years of messaging was good value compared with the 2 other groups. If we consider points on the acceptability curve that fall above 0.5 as representing good value, then for both contrasts we can be confident of the value of 3 years of messaging for all values of willingness to pay. Finally, we can be 95% confident of value for 3 years of messaging vs no messaging for all values of willingness to pay greater than or equal to \$1198 (\$3.28/day) and for 3 years vs 3 months of messaging for all values of willingness to pay greater than or equal to \$33 (\$0.09/day). eAppendix Figure 2 [B] shows the acceptability curve for no messaging vs 3 months of messaging.

**Sensitivity Analysis**

Use of a log link and gamma family (rather than the power -0.1 link and Poisson family) would have had a minimal impact on our recommendations. The use of 3 years of messaging continued to dominate both no messaging and 3 months of messaging (eAppendix Table 6). Pooling the groups that received no messaging and 3 months of messaging and comparing them with 3 years of messaging indicated that 3 years of messaging might have dominated the combined group or it might have had an incremental ratio as high as \$384/hour. Adding intervention costs to the 3 months and 3 years of messaging groups increased the annual costs to \$7382 (compared with \$7376) and \$5880 (compared with \$5825), respectively. The use of 3 years of messaging continued to dominate both no messaging and 3 months of messaging.

**TABLE 1.** Patient Demographic and Clinical Characteristics by Intervention Group<sup>a</sup>

Variable	Total (N = 342)	Group 1: no messaging (n = 172)	Group 2: 3 months of messaging (n = 124)	Group 3: 3 years of messaging (n = 46)	P <sup>b</sup>
<b>Continuous variables, mean (SD)</b>					
Age in years	50.4 (12.1)	51.7 (12.5)	47.7 (11.6)	52.6 (10.8)	.008
Body mass index, kg/m <sup>2</sup>	36.0 (7.8)	36.1 (8.0)	35.8 (7.6)	36.4 (7.7)	.89
Neighborhood median household income, US\$	77,004 (27,805)	76,670 (27,930)	74,687 (25,313)	84,666 (32,798)	.12
Neighborhood % of high school or less	42.5 (15.7)	42.4 (15.7)	43 (15.9)	42.4 (15.4)	>.99
Epworth Sleepiness Scale score	9.3 (5.3)	9.2 (5.0)	9.3 (5.6)	9.3 (5.5)	.99
Functional Outcomes of Sleep Questionnaire <sup>c</sup>	13.9 (4.6)	14.4 (4.5)	13.4 (4.8)	13.5 (4.6)	.20
AHI, events/hour	41.9 (24.7)	41.1 (24.6)	44 (27)	38 (17)	.29
Charlson Comorbidity Index score (weighted)	0.9 (1.4)	1.1 (1.5)	0.8 (1.3)	0.8 (1.2)	.08
Health care costs 6 months prior to the index, US\$	2879 (1382)	2691 (3273)	3475 (6913)	1969 (1872)	.20
<b>Categorical variables, n (%)</b>					
Male	219 (64)	110 (64)	80 (65)	29 (63)	.98
Race/ethnicity					.98
Non-Hispanic Asian/Pacific Islander	27 (8)	12 (7)	10 (8)	5 (11)	
Non-Hispanic Black	25 (7)	12 (7)	9 (7)	4 (9)	
Hispanic	135 (39)	68 (40)	50 (40)	17 (37)	
Non-Hispanic White	149 (44)	76 (44)	54 (44)	19 (41)	
Other	6 (2)	4 (2)	1 (1)	1 (2)	
Obesity class					.81
Normal	9 (3)	4 (2)	3 (2)	2 (4)	
Overweight	69 (20)	31 (18)	30 (24)	8 (17)	
Moderately obese	174 (51)	94 (55)	59 (48)	21 (46)	
Severely obese	85 (25)	40 (23)	31 (25)	14 (30)	
Missing	5 (1)	3 (2)	1 (1)	1 (2)	
Medicaid indicator	28 (8)	11 (6)	12 (10)	5 (11)	.46
Smoking					.75
Never/passive	200 (58)	103 (60)	73 (59)	24 (52)	
Quit	107 (31)	53 (31)	37 (30)	17 (37)	
Active	26 (8)	10 (6)	12 (10)	4 (9)	
Missing	9 (3)	6 (3)	2 (2)	1 (2)	
Neighborhood median household income, US\$					.07
< 80,000	193 (56)	100 (58)	72 (58)	21 (46)	
Marital status					.61
Married/partner	226 (66)	113 (66)	81 (65)	32 (70)	
Single/divorced/widowed	91 (27)	44 (26)	37 (30)	10 (22)	
Unknown	25 (7)	15 (9)	6 (5)	4 (9)	

(continued)



**TABLE 1.** (Continued) Patient Demographic and Clinical Characteristics by Intervention Group\*

Variable	Total (N = 342)	Group 1: no messaging (n = 172)	Group 2: 3 months of messaging (n = 124)	Group 3: 3 years of messaging (n = 46)	P <sup>b</sup>
<b>Continuous variables, mean (SD)</b>					
Epworth Sleepiness Scale score					.56
< 11	207 (61)	100 (58)	78 (63)	29 (63)	
11-14.9	68 (20)	41 (24)	20 (16)	7 (15)	
≥ 15	61 (18)	28 (16)	23 (19)	10 (22)	
Missing	6 (2)	3 (2)	3 (2)	0 (0)	
AHI, events/hour					.79
15-29.9	141 (41)	74 (43)	49 (40)	18 (39)	
≥ 30	201 (59)	98 (57)	75 (60)	28 (61)	
Hypertension	140 (41)	79 (46)	43 (35)	18 (39)	.15
<b>Charlson comorbidities<sup>d</sup></b>					
Diabetes without complications	59 (17)	38 (22)	11 (9)	10 (22)	<b>.046</b>
Diabetes with complications	29 (8)	18 (10)	6 (5)	5 (11)	.19
Chronic pulmonary disease	68 (20)	36 (21)	26 (21)	6 (13)	.46
Peripheral vascular disease	21 (6)	13 (8)	7 (6)	1 (2)	.39
Renal disease	22 (6)	16 (9)	4 (3)	2 (4)	.09
Mild liver disease	16 (5)	10 (6)	4 (3)	2 (4)	.58
Cancer	14 (4)	7 (4)	4 (3)	3 (7)	.63
Congestive heart failure	6 (2)	5 (3)	1 (1)	0 (0)	.25
Cerebrovascular disease	6 (2)	4 (2)	2 (2)	0 (0)	.56
Myocardial infarction	8 (2)	5 (3)	2 (2)	1 (2)	.77
Rheumatic disease	4 (1)	3 (2)	1 (1)	0 (0)	.55
Paraplegia/hemiplegia	3 (1)	2 (1)	1 (1)	0 (0)	.75
Metastatic carcinoma	2 (1)	0 (0)	2 (2)	0 (0)	.17
Sleep clinic referral due to preoperative assessment	26 (8)	9 (5)	13 (10)	4 (9)	.23

AHI, apnea-hypopnea index; OSA, obstructive sleep apnea.

\*Statistically significant results (*P* < .05) are bolded.

<sup>b</sup>*P* values from analysis of variance for continuous variables and  $\chi^2$  tests for categorical variables.

<sup>c</sup>Missing: n = 26.

<sup>d</sup>No participants had dementia, peptic ulcer disease, moderate or severe liver disease, or AIDS/HIV as part of Charlson comorbidities; therefore, these comorbidities were not shown in the table.

## DISCUSSION

We found that 3 years of tele-messaging is a cost-effective strategy compared with both no messaging and 3 months of messaging for adults with moderate to severe OSA. The use of 3 years of messaging significantly improved hours of PAP use compared with both 3 months of messaging and no messaging. Moreover, 3 years of messaging showed cost savings compared with 3 months of messaging or no impact on costs compared with no messaging. To our knowledge, this is the first evidence to show the cost-effectiveness of automated long-term tele-messaging to improve PAP use in the United States.

This is a post hoc analysis of the Tele-OSA trial, which mainly evaluated the impact of an automated tele-messaging intervention

on improving PAP adherence. The main clinical trial results demonstrated that participants who received the tele-messaging intervention had a mean of 4.4 hours of daily PAP use at 3 months,<sup>15,16</sup> and this post hoc analysis showed that participants who received 3 years of messaging had a mean of 4.11 hours of daily PAP use during 3 years of follow-up. The mean daily PAP use values for 3 years for participants who did not receive messaging or who received 3 months of messaging were much lower, at 3.04 and 2.84 hours, respectively. CMS defines only short-term (first 90 days) PAP adherence as at least 4 hours/night on 70% of nights, and a growing body of literature also suggests that adherence to PAP therapy (≥ 4 hours/night of use) was associated with lower inpatient visits, cardiovascular events, and costs compared with nonadherence.<sup>27-29</sup> The current analysis suggests that long-term tele-messaging may help improve PAP adherence while not increasing health care costs. Although long-term PAP use may be associated with a higher equipment cost (eg, replacement masks, head gear, other PAP replacement supplies) and intervention cost, this increase in costs may be offset by a decrease in other health care costs related to the health burden of OSA.

Although tele-management systems have been shown to improve PAP adherence, cost-effectiveness studies of these interventions have been limited. Two published randomized controlled trials that tested telemonitoring or virtual PAP adherence interventions showed the cost-effectiveness of telemonitoring; however, both evaluated only short-term outcomes (ie, 3 months).<sup>4,11</sup> Another trial tested a telephone follow-up intervention to monitor PAP use compared with usual care with a primary end point at 2 years and estimated total cost savings of \$48,962 (mean, \$31.60 per person), but this was limited to cardiovascular-related hospitalizations.<sup>30</sup>

In this study, we captured comprehensive health care utilization from electronic health records to evaluate direct health care costs including sleep-related visits, education sessions or counseling related to PAP use, and sleep-related durable medical equipment (eg, mask replacement), as well as all other health care costs to be able to capture the reduced burden of health care associated with PAP use. We observed cost savings from 3 years of messaging compared with 3 months of messaging, mainly driven by reduction in hospitalization costs. With the comprehensive health care cost evaluation, our study provides further evidence

**TABLE 2.** Mean Adjusted Annual Costs (in \$) and PAP Use (in hours/night)<sup>a</sup>

Cost and PAP use	Group 1: no messaging (n = 172)	Group 2: 3 months of messaging (n = 124)	Group 3: 3 years of messaging (n = 46)	Groups 2 vs 1: 3 months vs no messaging, P	Groups 3 vs 1: 3 years vs no messaging, P	Groups 3 vs 2: 3 years vs 3 months of messaging, P	3-group comparison, P
Mean (SE) costs							
Sleep-related office visit	138 (7)	138 (7)	136 (6)	>.99	.63	.57	.85
Non-sleep-related office visit	1607 (25)	1871 (29)	1887 (30)	.07	<b>.04</b>	.93	.06
Sleep-related DME	213 (4)	206 (4)	212 (4)	.05	.76	.29	.13
Non-sleep-related DME	65 (11)	72 (1)	19 (1)	.95	.22	.25	.45
Phone visit	101 (2)	105 (2)	93 (1)	.73	.48	.34	.63
Radiology	192 (11)	259 (16)	257 (16)	.11	.21	.98	.21
Emergency department visit	107 (1)	79 (1)	54 (1)	.26	.05	.31	.13
Other hospital service	333 (19)	243 (12)	365 (22)	.38	.93	.38	.61
Hospitalization	907 (42)	1807 (100)	599 (25)	.07	.28	<b>.003</b>	<b>.01</b>
Laboratory	368 (6)	397 (6)	342 (5)	.55	.63	.30	.57
Pharmacy	2828 (221)	2742 (208)	3513 (335)	.96	.80	.76	.95
Total	5889 (113)	7376 (146)	5825 (111)	<b>.02</b>	.89	<b>.02</b>	<b>.03</b>
Mean (SE) PAP use, hours per night							
Year 1	3.48 (0.07)	3.69 (0.07)	4.44 (0.10)	.49	<b>.001</b>	.05	<b>.004</b>
Year 2	2.86 (0.08)	2.67 (0.08)	3.94 (0.09)	.57	<b>.02</b>	<b>.01</b>	<b>.02</b>
Year 3	2.71 (0.08)	2.51 (0.07)	3.27 (0.13)	.54	.10	.09	.14
Total	3.03 (0.05)	2.84 (0.05)	4.11 (0.05)	.50	<b>.01</b>	<b>.002</b>	<b>.01</b>

DME, durable medical equipment; PAP, positive airway pressure.

<sup>a</sup>Costs and P values estimated from generalized linear model adjusting for age, sex, race/ethnicity, apnea-hypopnea index, Charlson Comorbidity Index score [excluding diabetes without complications], diabetes without complications, preoperative assessment, prior 6-month cost, zip code-derived median household income, and indicator variables representing the 6-month intervals. Statistically significant results (P < .05) are bolded.

**TABLE 3.** Cost-effectiveness Analysis

Group	Annual cost in \$	ΔCost in \$ (SE)	Hours of PAP use	ΔPAP hours (SE)	ICER	95% CI
Group 2: 3 months of messaging	7376	—	2.84	—	—	—
Group 1: no messaging	5889	-1488 <sup>a</sup> (724)	3.03	0.19 (0.32)	No messaging dominates 3 months of messaging	No vs 3 months of messaging: exclusion interval <sup>b</sup>
Group 3: 3 years of messaging	5825	-64 (551)	4.11	1.07 <sup>a</sup> (0.41)	3 years dominates both 3 months and no messaging	3 years vs 3 months of messaging: dominates to \$33 3 years vs no messaging: dominates to \$1198

ICER, incremental cost-effectiveness ratio; PAP, positive airway pressure.

<sup>a</sup>Difference due to rounding.

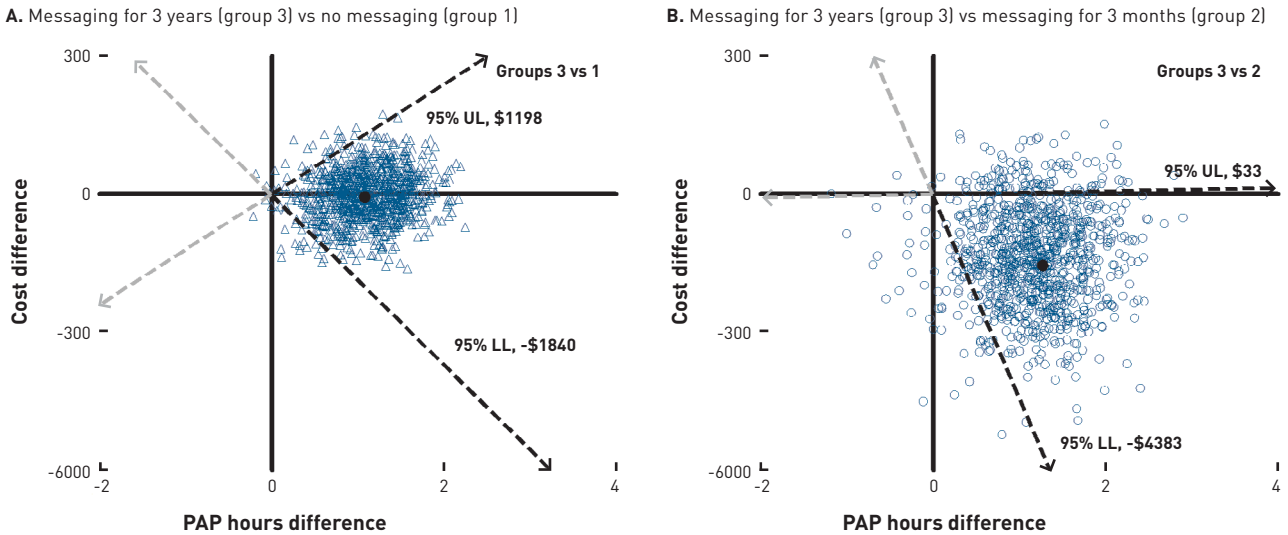
<sup>b</sup>Compared with 3 months of messaging, we can be 95% confident that no messaging is good value for values of willingness to pay between \$0 and \$1921; we cannot be 95% confident of value for any value of willingness to pay greater than \$1921.

of cost-effectiveness of long-term tele-messaging interventions for PAP use. These findings suggest that if we are willing to pay for short-term messaging, we should be even more willing to pay for long-term messaging.

It is important to note that in addition to the 3 months of within-trial follow-up, our study utilized 33 months of epidemiologic follow-up to evaluate the cost-effectiveness of interventions. The original Tele-OSA study end points were measured at 3 months after

PAP dispensation. Although the planned process for each participant was to turn off the messaging after study completion at 3 months, a subset of patients had messaging left on indefinitely. Messaging being left on was simply the result of a protocol violation in which study personnel failed to turn messaging off. Thus, whether a participant had messaging turned off or left on was an arbitrary process. This procedural variation, serendipitously, allowed us to perform post hoc analyses to assess the impact of long-term messaging.

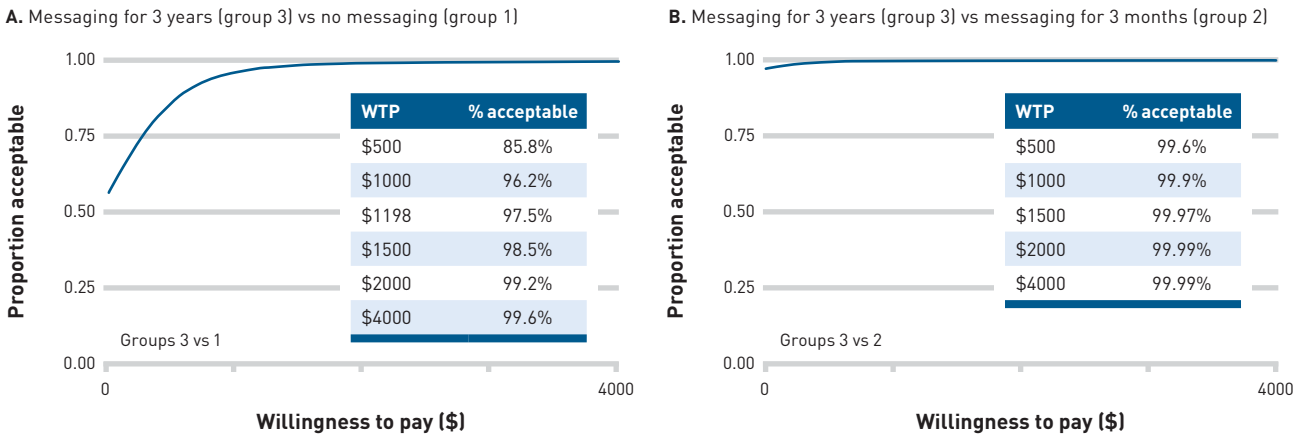
**FIGURE 1.** Average Change in Medicare Spending Under Each Policy by Quintile of Initial Medicare Spending



LL, lower limit; PAP, positive airway pressure; UL, upper limit.

\*Messaging for 3 years dominates (ie, lower costs and greater hours of PAP use; the point estimates are in the lower right quadrant of cost-effectiveness plane) both no messaging and messaging for 3 months.

**FIGURE 2.** Acceptability Curve



WTP, willingness to pay.

Our analysis reports the incremental costs per incremental hours in PAP use. Although hours of PAP use represent a reasonable and important outcome, there have been no previous studies regarding the willingness to pay for an additional hour of PAP use. Therefore, as a first step, we compared the ratios to a willingness-to-pay threshold of \$1825 per year, which assumes that we were willing to pay \$5/day to increase daily PAP use by 1 hour. We also conducted sensitivity analyses using a wide range of values of willingness to pay, with results showing that 3 years of messaging was highly acceptable even if willingness to pay is lower than we assumed.

**Limitations**

This study has several limitations. Although we captured comprehensive health care utilization that was potentially associated with the intervention, we did not directly measure intervention delivery costs (eg, infrastructure costs from payers) for this analysis. The text messaging features were available for PAP users through the Somnoware platform at no additional cost to KPSC, and we were not able to separate the intervention delivery costs. However, sensitivity analyses assuming reasonable intervention costs from a previous publication<sup>26</sup> yielded consistent results. Future studies

should investigate the program implementation cost more in depth. In addition, as described earlier, assignment to the groups receiving 3 years and 3 months of messaging interventions was not randomized; therefore, our findings may be susceptible to unmeasured confounding. Although most of the baseline characteristics across groups were similar, the mechanism of higher costs among participants who received 3 months of messaging compared with no messaging was not clear. We did observe some increased variability in costs and a higher percentage of high-cost utilizers (more than \$30,000 in 6 months) among the group that received 3 months of messaging, which could in part explain these findings. Future randomized clinical trials evaluating the impact of these interventions over the longer term are warranted.

## CONCLUSIONS

Long-term tele-messaging was more effective than no messaging, and costs are similar. Moreover, long-term tele-messaging was more effective and was associated with lower health care costs than short-term messaging. Considering both cost and effectiveness, long-term tele-messaging was also highly likely to be cost-effective compared with both no messaging and short-term messaging. Our results suggest that greater PAP use may yield both clinical and additional economic benefits. ■

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**Author Affiliations:** Department of Research and Evaluation, Kaiser Permanente Southern California (JAN, AC, JMS), Pasadena, CA; Department of Health Systems Science, Kaiser Permanente Bernard J. Tyson School of Medicine (JAN), Pasadena, CA; Sleep Medicine, Southern California Medical Group (DH, JAR), Fontana, CA; Department of Biobehavioral Health Sciences, School of Nursing (AMS, AJW) and Department of Medicine, Perelman School of Medicine (CJB, BTK, STK, GM, AIP, HAG), University of Pennsylvania, Philadelphia, PA; Corporal Michael J. Crescenz Veterans Affairs Medical Center (AMS, STK), Philadelphia, PA; Division of Medical Informatics and Division of Pulmonary Critical Care and Sleep Medicine, Department of Internal Medicine, University of Kansas Medical Center (DRM), Kansas City, KS.

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**Authorship Information:** Concept and design (JAN, DH, AMS, CJB, BTK, STK, GM, DRM, AIP, AJW, HAG); acquisition of data (JAN, DH, JAR, AC, JMS); analysis and interpretation of data (JAN, DH, AMS, JAR, CJB, AC, BTK, STK, GM, DRM, AIP, JMS, AJW, HAG); drafting of the manuscript (JAN, DH, AMS, HAG); critical revision of the manuscript for important intellectual content (JAN, JAR, CJB, AC, BTK, STK, GM, DRM, AIP, JMS, AJW, HAG); and supervision (JAN, STK).

**Address Correspondence to:** Jaejin An, BPharm, PhD, Department of Research and Evaluation, Kaiser Permanente Southern California, 100 S Los Robles, 2nd Floor, Pasadena, CA 91101. Email: jaejin.x.an@kp.org.

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**eAppendix Table 1. Missing Observations, n (%) During Follow-up**

Follow-up Time	Total (N=342)	Group 1: No Messaging (N=172)	Group 2: 3-Months of Messaging (N=124)	Group 3: 3-Years of Messaging (N=46)	<i>P</i> -value*
1 to 6 months	11 (3)	6 (3)	5 (4)	0 (0)	0.40
7 to 12 months	17 (5)	10 (6)	6 (5)	1 (2)	0.60
13 to 18 months	22 (6)	14 (8)	7 (6)	1 (2)	0.31
19 to 24 months	32 (9)	20 (12)	10 (8)	2 (4)	0.27
25 to 30 months	31 (9)	19 (11)	10 (8)	2 (4)	0.33
31 to 36 months	38 (11)	21 (12)	13 (10)	4 (9)	0.77

\**P*-values are from Chi-square test

**eAppendix Table 2. Crude Mean (SD) Cost per 6-Month Time Interval**

	Group 1: No Messaging (N=172)	Group 2: 3-Months of Messaging (N=124)	Group 3: 3-Years of Messaging (N=46)	Group 2 vs 1: 3-Months vs No Messaging, <i>P</i> -value	Group 3 vs 1: 3-Years vs No Messaging, <i>P</i> -value	Group 3 vs 2: 3-Years vs 3-Months of Messaging, <i>P</i> -value	3 group comparison, <i>P</i> value
-6 to -1 months	2691 (3273)	3475 (6913)	1969 (1872)	0.28	0.08	<b>0.04</b>	0.20
1 to 6 months	4240 (4729)	6458 (10289)	3924 (3515)	<b>0.03</b>	0.62	<b>0.02</b>	<b>0.02</b>
7 to 12 months	2723 (3356)	3194 (5660)	2887 (4292)	0.42	0.81	0.71	0.68
13 to 18 months	2906 (3637)	3545 (6206)	2770 (3343)	0.32	0.82	0.31	0.47
19 to 24 months	2393 (2397)	3963 (9430)	2709 (2499)	0.09	0.45	0.19	0.11
25 to 30 months	2992 (6405)	3242 (6266)	3317 (3873)	0.75	0.68	0.93	0.92
31 to 36 months	2917 (6294)	3269 (7490)	2345 (2005)	0.69	0.34	0.24	0.72

\**p*-values are from t-test, †ANOVA test. Percentages of participants with more than \$30,000 in 6 months were 0.4%, 2.2%, and 0% for groups 1, 2, and 3, respectively.

**eAppendix Table 3. Crude Mean (SD) Positive Airway Pressure (PAP) Use (in Hours / Night) per 6-Month Time Interval**

	Group 1: No Messaging (N=172)	Group 2: 3-Months of Messaging (N=124)	Group 3: 3-Years of Messaging (N=46)	Group 2 vs 1: 3-Months vs No Messaging, <i>P</i> -value*	Group 3 vs 1: 3-Years vs No Messaging, <i>P</i> -value*	Group 3 vs 2: 3-Years vs 3-Months of Messaging, <i>P</i> -value*	3 group comparison, <i>P</i> value†
1 to 6 months	3.72 (2.36)	4.01 (2.44)	4.80 (2.19)	0.32	<b>0.01</b>	0.06	<b>0.02</b>
7 to 12 months	3.41 (2.85)	3.05 (2.89)	4.27 (2.80)	0.29	0.08	<b>0.02</b>	0.05
13 to 18 months	3.11 (2.93)	2.89 (3.00)	4.16 (2.96)	0.55	<b>0.04</b>	<b>0.02</b>	0.05
19 to 24 months	2.94 (3.02)	2.67 (2.99)	3.87 (3.18)	0.47	0.08	<b>0.03</b>	0.08
25 to 30 months	2.92 (3.05)	2.61 (3.07)	4.01 (3.12)	0.40	<b>0.04</b>	<b>0.01</b>	<b>0.04</b>
31 to 36 months	2.84 (3.07)	2.50 (3.02)	3.97 (3.15)	0.37	<b>0.04</b>	<b>0.01</b>	<b>0.03</b>

\**p*-values are from t-test, †ANOVA test

**eAppendix Table 4. Results of Generalized Linear Model Predicting Total Cost**

Explanatory variables	Coef.	Robust SE	P-value	95% CI
Messaging for 3 Months (vs No Messaging)	-0.010	0.004	0.015	-0.018 to -0.002
Messaging for 3 Years (vs No Messaging)	0.0005	0.004	0.893	-0.006 to 0.007
Follow-up time (vs 1-6 months)				
7-12 months	0.036	0.005	<0.001	0.027 to 0.046
13-18 months	0.021	0.004	<0.001	0.013 to 0.029
10-24 months	0.023	0.005	<0.001	0.013 to 0.033
25-30 months	0.021	0.005	<0.001	0.011 to 0.031
31-36 months	0.022	0.006	<0.001	0.012 to 0.033
Age at baseline (years)	-0.0002	0.0002	0.272	-0.0005 to 0.0001
Male (vs female)	0.002	0.004	0.580	-0.005 to 0.009
Race/Ethnicity (vs Hispanic)				
Non-Hispanic White	-0.003	0.004	0.536	-0.011 to 0.006
Asian/Pacific Islander	0.016	0.005	0.001	0.007 to 0.026
Non-Hispanic Black	-0.003	0.007	0.652	-0.017 to 0.011
Other race	0.021	0.011	0.070	-0.002 to 0.043
Neighborhood income (vs $\geq$ 80,000 USD)				
<80,000 USD	-0.003	0.003	0.437	-0.009 to 0.004
Missing	0.014	0.005	0.004	0.004 to 0.023
Charlson comorbidity score excluding diabetes without complications	-0.002	0.001	0.016	-0.004 to -0.0004
Charlson comorbidity - diabetes without complications (Yes vs No)	-0.005	0.003	0.113	-0.011 to 0.001
6-month cost prior to randomization (log scale)	-0.022	0.002	0.000	-0.026 to -0.017
Apnea-Hypopnea index (log scale)	0.000	0.004	0.944	-0.008 to 0.007
Pre-operative assessment indicator (Yes vs No)	-0.015	0.005	0.005	-0.025 to -0.004
Constant	0.615	0.018	<0.001	0.580 to 0.650

Abbreviations: Coef = coefficient; SE = standard error; CI = confidence interval; USD = united states dollars

**eAppendix Table 5. Results of Generalized Linear Model Predicting Hours of Positive Airway Pressure Use**

Explanatory variables	Coef.	Robust SE	P-value	95% CI
Messaging for 3 Months (vs No Messaging)	-0.202	0.301	0.502	-0.792 to 0.388
Messaging for 3 Years (vs No Messaging)	1.105	0.416	0.008	0.290 to 1.920
Follow-up time (vs 1-6 months)				
7-12 months	-0.572	0.087	<0.001	-0.742 to -0.402
13-18 months	-0.811	0.114	<0.001	-1.034 to -0.588
10-24 months	-1.027	0.130	<0.001	-1.283 to -0.772
25-30 months	-1.069	0.143	<0.001	-1.350 to -0.788
31-36 months	-1.093	0.146	<0.001	-1.379 to -0.806
Age at baseline (years)	0.026	0.013	0.052	0.000 to 0.053
Male (vs female)	0.154	0.286	0.589	-0.407 to 0.716
Race/Ethnicity (vs Hispanic)	1.102	0.326	0.001	0.463 to 1.741
Non-Hispanic White	-0.299	0.563	0.595	-1.402 to 0.803
Asian/Pacific Islander	-0.591	0.385	0.125	-1.345 to 0.163
Non-Hispanic Black	-1.234	0.506	0.015	-2.227 to -0.242
Neighborhood income (vs $\geq$ 80,000 USD)				
<80,000 USD	-0.604	0.291	0.038	-1.174 to -0.034
Missing	-2.860	0.500	<0.001	-3.841 to -1.880
Charlson comorbidity score excluding diabetes without complications	-0.042	0.115	0.716	-0.267 to 0.183
Charlson comorbidity - diabetes without complications (Yes vs No)	-0.570	0.359	0.112	-1.275 to 0.134
Apnea-Hypopnea index (log scale)	1.067	0.258	<0.001	0.562 to 1.572
Pre-operative assessment indicator (Yes vs No)	-1.696	0.484	<0.001	-2.646 to -0.747
Constant	-1.119	1.330	0.400	-3.725 to 1.488

Abbreviations: Coef = coefficient; SE = standard error; CI = confidence interval; USD = united states dollars



**eAppendix Table 6. Sensitivity Analyses**

Group	Annual Cost [\$]	ΔCost [\$] (SE)	Hours of PAP USE	ΔPAP Hours (SE)	ICER	95% CI
Log link, Gamma Family						
3-Months of Messaging	6884	--	2.84	--	--	--
No Messaging	5759	-1125 (709)	3.03	0.19 (0.32)	No messaging dominates 3-months of messaging	Undefined*
3-Years of Messaging	5645	-114 (625)	4.11	1.07† (0.41)	3-years dominates both 3-months and no messaging	3-years vs 3-months of messaging: Dominates to 322  3-years vs no messaging: Dominates to 1305
Pooled Analysis						
No Messaging & 3-Months of Messaging	6538	--	2.95	--	--	--
3-Years of Messaging	5841	-697 (572)	4.11	1.17 (0.44)	3-years dominates combination of no messaging and 3-months of messaging	Dominates to 384
Adding Intervention Cost						
Group 2: 3-Months of Messaging	7382	--	2.84	--	--	--

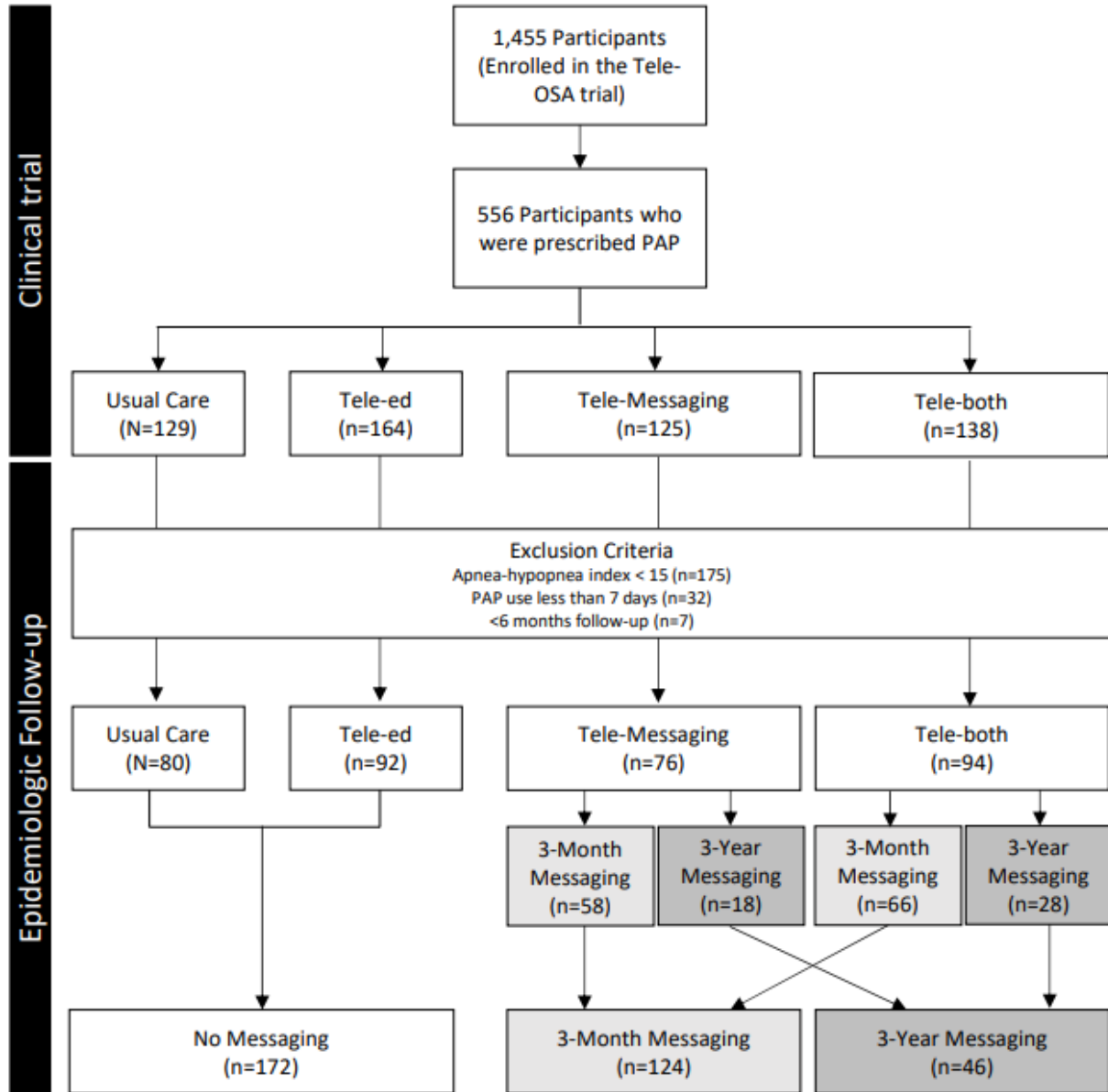
Group 1: No Messaging	5889	-1494† (724)	3.03	0.19 (0.32)	No messaging dominates 3-months of messaging	No vs 3-months of messaging: Exclusion interval‡
Group 3: 3-Years of Messaging	5880	-8 (551)	4.11	1.07† (0.41)	3-years dominates both 3-months and no messaging	3-years vs 3-months of messaging: Dominates to 70  3-years vs no messaging: Dominates to 1323

\* Widest definable confidence interval, 91.4%; widest definable confidence limit \$906. †

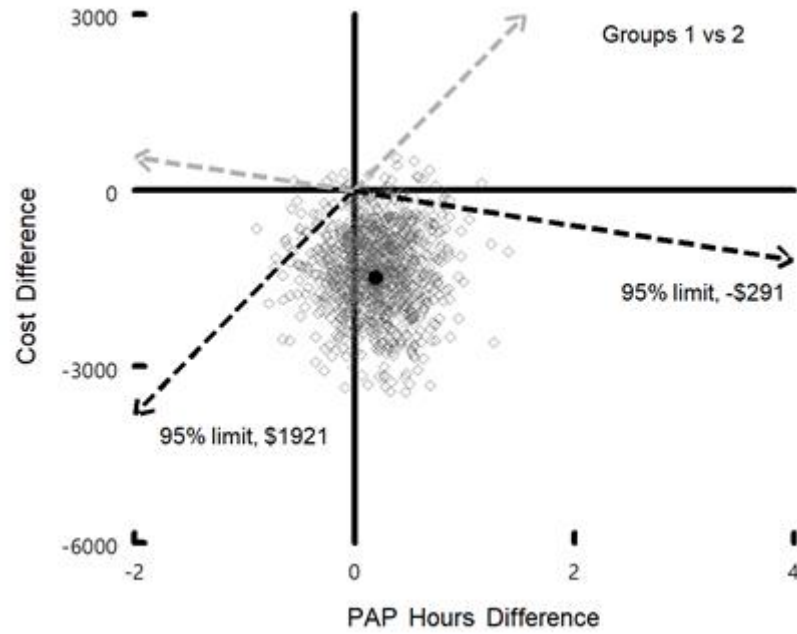
Difference due to rounding. ‡ Compared to 3-months of messaging, can be 95% confident that No messaging is good value for values of willingness to pay between \$0 and \$2010; cannot be 95% confident of value for any value of willingness to pay greater than \$2010.

Abbreviations: SE = standard error; PAP = positive airway pressure. ICER = incremental cost-effectiveness ratio; CI = confidence interval.

eAppendix Figure 1. The Study Cohort Diagram

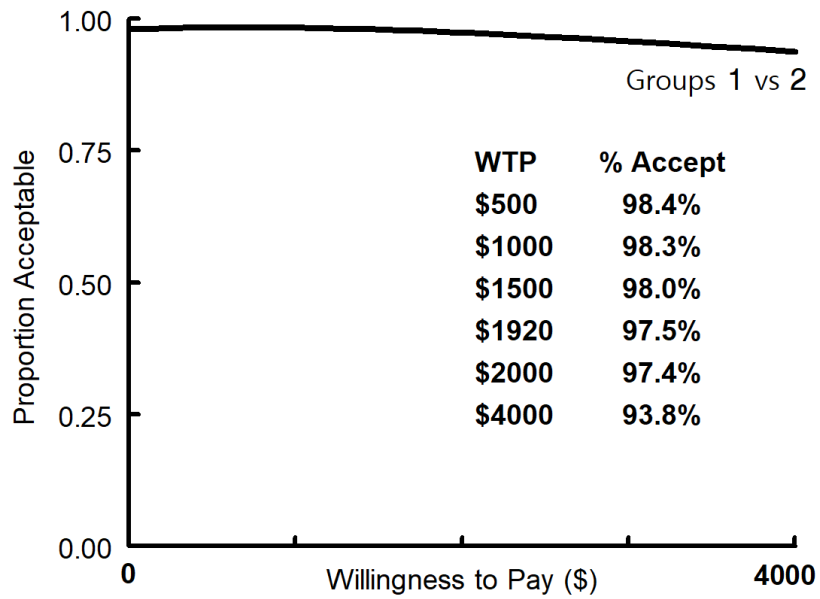


eAppendix Figure 2a. Cost-Effectiveness Plane, No messaging (Group 1) vs Messaging for 3-Months (Group 2)



Abbreviations: PAP = continuous positive airway pressure therapy

**eAppendix Figure 2b. Acceptability Curve, No messaging (Group 1) vs Messaging for 3-Months (Group 2)**



Abbreviations: WTP = willing to pay.