Comparing Treatment Effectiveness and Patient-Reported Outcome Measures of Four Treatment Options for Obstructive Sleep Apnea

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Background: Continuous positive airway pressure (CPAP), mandibular advancement device (MAD), upper airway stimulation (UAS), and maxillomandibular advancement (MMA) are techniques to reduce apnea hypopnea index (AHI) in obstructive sleep apnea (OSA) patients. Current literature does not include a direct comparison of the 4 methods.

Purpose: The purpose of this study is to measure and compare the efficacy of 4 common OSA treatments: CPAP, MAD, UAS, MMA.

Study Design, Setting, Sample: This retrospective cohort study examines data from 119 patients treated at Thomas Jefferson University Hospital in Philadelphia receiving CPAP, MAD, UAS, or MMA between January 2018 and December 2020. Patients were excluded for significant medical comorbidities, body mass index ≥45, cognitive limitations, central/mixed apnea history, or pregnancy.

Predictor Variables: The primary predictor variable was type of OSA intervention: CPAP, MAD, UAS, MMA. Treatments were assigned by treating physicians per their presenting OSA severity.

Main Outcome Variables: The primary outcome variable was efficacy defined as the therapeutic response to treatment measured using mean disease alleviation, a calculated variable (percentage) which employs post-treatment AHI adjusted by compliance (a measure of a patient's device use). Secondary therapeutic measures included remaining AHI and patient-reported outcome measures: Epworth Sleepiness Scale, Sleep Apnea Quality of Life Index, Patient-reported Apnea Questionnaire.

Covariates: Demographic covariates included age, sex, height, weight, socioeconomic status, level of education, neck size, race, and body mass index. Clinical covariates included pretreatment AHI, AHI change, O2 nadir, adjusted compliance, and compliance.

Analyses: Multivariate statistics were computed with alpha level of 0.05, including a regression with the primary outcome variables, treatment variables, and potential covariates.

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Results: The sample included 119 subjects (mean age = 56.12, standard deviation [SD] = 5.81) with males at n = 72 (60%). MMA demonstrated greatest mean disease alleviation (M = 36.08, SD = 28.56), compared to UAS (M = 22.88, SD = 3.16), MAD (M = 6.80, SD = 8.13), and CPAP (M = 5.00, SD = 14.80), analysis of variance: $P < .001$.

Conclusion and Relevance: Both surgical treatments displayed significantly greater effectiveness than CPAP and MAD, suggesting that offering surgical alternatives sooner, particularly to those with severe OSA, may be logical in formulating more effective treatment guidelines.

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Obstructive sleep apnea (OSA) is a sleep-related breathing disorder affecting about 17% of adults in the United States. An estimated 27% of women and 43% of men aged 50 to 70 years, and 9% of women and 26% of men aged 30 to 49 have been affected by OSA.[1,2] OSA is a complex, heterogeneous chronic disorder that is characterized by repetitive episodes of nocturnal breathing cessation caused by upper airway collapse during sleep.[3] Risk factors include obesity, smoking, alcohol consumption, and chronic nasal congestion.[4] OSA can lead to significant health outcomes including excessive daytime sleepiness, cardiovascular disease, hypertension, stroke, risk of motor vehicle accidents, and overall diminished quality of life.[5,6]

Treatment options for OSA, include devices that assist breathing during sleep, intraoral devices that alter the positioning of the airway during sleep, and surgical alternatives. One of the main goals of treatment for OSA is increasing the posterior airway space, which has been shown to decrease the apnea hypopnea index (AHI), which is used to indicate the severity of OSA. The AHI represents the number of apnea and hypopnea events per hour of sleep, with 30 or higher considered severe OSA.[7] Additional goals of OSA treatment include improving sleep, reducing daytime sleepiness, and reduction of cardiovascular risks that can be caused by hypertension which can be associated with untreated OSA.

OSA treatment can be divided into nonsurgical and surgical treatments. Nonsurgical treatments include continuous positive airway pressure (CPAP) and mandibular advancement devices (MADs). The surgical options are upper airway stimulation (UAS) and maxillomandibular advancement (MMA) and tend to involve modifying soft tissues and sometimes including bone adjustment. These 4 treatment options (CPAP, MAD, UAS, and MMA) are the most commonly employed for patients with OSA.[8] Please refer to Table 1.

If used correctly, all of the 4 treatments have been shown to effectively reduce AHI, as well as improve quality of life for persons with OSA.[5,8,10,11,13] However, the literature does not address which treatment is comparatively the most effective, and several researchers have asserted the need for this comparison.[6,14-16] Most importantly, a study needs to be conducted that compares all 4 procedures on the same clinical metrics.

The purpose of this research is to compare the 4 most common treatments for moderate to severe OSA—CPAP, MAD, UAS, and MMA—with respect to efficacy.[8] The investigators hypothesized that there would be statistically significant differences in mean disease alleviation (MDA - a calculated variable to estimate treatment effectiveness using AHI and device compliance) among all 4 types of treatment, specifically, that the surgical methods would lead to greater improvements in MDA, as well as greater patient satisfaction, but this might be mediated by patient compliance issues. The researchers also hypothesized that there would be statistically significant differences in patient adherence among all 4 types of treatment, and there would be statistically significant differences in patients' subjective ratings of the success of therapy among all 4 types of treatment. The specific aims of the study involved comparing a cohort of patients treated with CPAP, MAD, UAS, or MMA surgery to examine whether there are statistically significant differences in MDA, patient adherence, and patients' subjective ratings of success of therapy and measures of daytime sleepiness, assessed using patient-reported outcome measures (PROMs).

Materials and Methods

STUDY DESIGN/SAMPLE

To address the research purpose, the investigators designed and implemented a retrospective cohort study using data collected from the electronic medical records of patients at the Jefferson Health System in Philadelphia, Pennsylvania. Prior to conducting this research, approval to proceed with the study was provided by the Thomas Jefferson University Institutional Review Board.

Table 1. OSA INTERVENTIONS

Treatment	Abbreviation	Description	Advantages	Disadvantages
Continuous positive airway pressure	CPAP	Device worn while sleeping that delivers pressurized air into the upper airway to relieve obstruction during sleep.	Noninvasive treatment; the gold standard therapy; highly effective when worn consistently	Adherence to the therapy is highly variable.[5]
Upper airway stimulation	UAS	Implanted device that opens the airway space by stimulating the hypoglossal nerve and in turn protruding the tongue. Alternative nonanatomic surgical treatment for individuals with moderate to severe OSA who have failed nasal CPAP.	Improves symptoms of OSA, showing significant improvements in sleepiness, quality of life, and respiratory outcomes after at least 48 months of treatment.[9,10]	Invasive procedure; more research is needed on long-term effects.
Mandibular advancement device	MAD	Device, worn intraorally, that repositions the mandible forward opening the airway space.	Noninvasive treatment; demonstrates sound and stable treatment effects in the treatment of OSA. Effective for the long-term management of OSA.[11,12]	More research is needed on possible side effects and patient adherence.
Maxilla-mandibular advancement surgery	MMA surgery	Consists of surgically repositioning the mandible and maxilla forward to increase the airway space. Alternative to the treatment of individuals with moderate to severe OSA who have failed nasal CPAP.	Increases OSA patients' quality of life.[13]	Invasive procedure; more research is needed on possible side effects.

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The study population was composed of all patients who had presented for evaluation and management of OSA between January of 2018 and December of 2020. To be included in the study sample, patients had to be between 22 and 85 years of age, have a confirmed diagnosis of moderate to severe OSA with an AHI between 15 and 100 inclusive evidenced by polysomnography (PSG), as referenced by the American Academy of Sleep Medicine, and had to have undergone pre-PSG and post-PSG to evaluate their pretreatment and post-treatment AHI. For the current study, it should be noted that some of the patients' post intervention PSG studies had to be completed at home due to the COVID pandemic, as opposed to being conducted in a laboratory setting. Patients were excluded as study subjects if they had significant medical comorbidities (specifically those with a Charlson Comorbidity Index greater than or equal to 5, which represents severe comorbidities),[17] a body mass index (BMI) greater than or equal to 45, cognitive limitations, a history of central or mixed apnea, and be pregnant (self-reported).

VARIABLES

The predictor variable in the current study was intervention type: CPAP, MAD, UAS, and MMA. As such, 119 patients' data who had undergone the 4 treatments were obtained, 25 in the CPAP group, 27 in the MAD group, 37 in the UAS group and 30 in the MMA group (119 total patients selected). Treatments were assigned by treating physicians per their presenting OSA severity.

Covariates were assessed, including age, sex, height, weight, socioeconomic status (SES) (represented in this study as household income), level of higher education, neck size, race and BMI, pretreatment AHI, and AHI change which were obtained from the patients' electronic medical records. SES and education level were assessed because financial access and education might play a role in availability to alternative treatments for OSA, and this was also done to determine if these variables might lead to bias in which alternatives to CPAP might be presented to patients. Patient AHI was obtained both

prior to and 4 months after initiation of treatment. Following treatment, compliance and remaining AHI were assessed, leading to determination of adjusted compliance, treatment efficacy, and MDA. Additional variables such as number of days assessed and O2 nadir were also obtained. These variables were evaluated because of the potential need to control for these factors during multivariate statistical analyses.

The primary outcome variable was efficacy defined as the therapeutic response to treatment measured by the MDA calculation, given as a percentage. MDA is a method to measure the overall therapeutic effect of a clinical intervention. MDA was selected for this study because all of the relevant components were available using the retrospective data. Other potential measures, such as the effectiveness of treatment-AHI (ET-AHI – a weighted value of apnea and hypopnea incidents during both adherence and nonadherence to therapy), require assumptions of the relationship between adherence to therapy and effectiveness that are not clear for all of the 4 treatment modalities used in this study.[18] MDA is the product of objective compliance and therapeutic efficacy, where objective compliance is calculated as the objective use in time (hours used per day) divided by the total sleep time (estimated as 7) all multiplied by 100, and therapeutic efficacy is the AHI at baseline minus the AHI after intervention.[19] Compliance was assessed for both CPAP and UAS using electronic methods employed using the device. Compliance was a measure of the patient's use of the device. MAD compliance was assessed using microsensor data. Because MMA is a definitive surgical procedure, compliance was defined as 100% for all patients.

$$\begin{aligned} &\textit{Effectiveness of Treatment AHI} = \textit{Treatment AHI} \\ &\quad * \%\,\textit{Adherence to Therapy}) + (\textit{Non} \\ &\quad - \textit{Treatment AHI} * \%\,\textit{Non} \\ &\quad - \textit{Adherence to Therapy}) \end{aligned}$$

$$\begin{aligned} &\textit{Mean Disease Alleviation} = \textit{Objective Compliance} \\ &\quad * \textit{Therapeutic Efficiency} \end{aligned}$$

$$\textit{Objective Compliance} = \frac{\textit{Objective Use of Device (hours per day)}}{\textit{TotalSleepTime (estimated 7 hours)}} * 100$$

$$\begin{aligned} &\textit{Therapeutic Efficiency} = \textit{AHI (baseline)} \\ &\quad - \textit{AHI (after intervention)} \end{aligned}$$

The secondary outcomes assessed the subjective impact of treatment as measured by PROMs for all 4 types of treatment. Secondary outcome variables included remaining AHI, scores on the Epworth Sleepiness Scale (ESS), Sleep Apnea Quality of Life Index (SAQLI), and Patient-reported Apnea Questionnaire (PRAQ) which were all assessed both before initiation of treatment and post-treatment, which was 12 weeks after treatment initiation. Remaining AHI was assessed using PSG. ESS is a reliable and self-administered questionnaire, which provides a subjective measurement of the patient's general level of daytime sleepiness. Among individuals with OSA syndrome, ESS scores are significantly correlated with the respiratory disturbance index and the minimum oxygen saturation (SaO2) recorded overnight.[20] SAQLI is a survey tool that has been used in identifying impaired quality of life (QOL) in persons with OSA.[21] SAQLI is a 35-item, interview-administered scale, which assesses the 4 domains of quality of life associated with sleep apnea: daily functioning, social interactions, emotional functioning, and symptoms. Studies have shown that the SAQLI is highly effective for monitoring the efficacy of different apnea treatments.[21,22] It is also useful in identifying impaired QOL in persons with OSA. PRAQ is a validated measurement device survey tool that is sorted into ten domains, including symptoms at night, sleepiness, tiredness, daily activities, unsafe situations, memory and concentration, quality of sleep, emotions, social interactions, and health concerns. All items are scored on a 7-point Likert scale (higher scores indicate worse problems), and the average item scores in a domain form its overall domain score.[23]

DATA COLLECTION METHODS

Electronic health records for patients in this study were reviewed for demographic and clinical variables from a secure HIPAA-compliant electronic medical records database. The subject information was then de-identified.

DATA ANALYSES

Analyses were also conducted to examine whether demographic variables and pretreatment sleep study variables may have indicated a relationship with MDA values. AHI were calculated for the sample as a whole and statistically compared across the treatment groups. When statistically significant group differences were identified, these confounding variables were used as controls in subsequent statistical modeling.

Distributions of the continuously distributed outcomes were screened for normality, and one-way

analysis of variance (ANOVA) was used to compare the groups on post-treatment scores. Post hoc analyses using the Tukey's method were conducted. In this study, $P < .05$ defines statistical significance.

Results

SAMPLE DEMOGRAPHICS

During the study interval dates January of 2018 – December of 2020, a study population of 175 patients were evaluated and treated for their OSA. After applying the inclusion/exclusion criteria, the final sample was composed of 119 subjects. The sample was predominately White n = 90 (60.81%) and male n = 72 (60.50%). Age, SES, BMI, and race were significantly different across the groups (see Table 2). The study population consisted of those who had presented for evaluation and management of OSA between January of 2018 and December of 2020. However, the PROMs were only assessed from 2019, and in addition to exclusion criteria, this limited the number of potential participants for the current study to 119 participants to include the secondary outcome variables. To be included in the study sample, patients had to be between 22 and 85 years of age, have a confirmed diagnosis of moderate to severe OSA with an AHI between 15 and 100 inclusive evidenced by PSG, as referenced by the American Academy of Sleep Medicine, and had to have undergone pre-PSG and post-PSG to evaluate their pretreatment and post-treatment AHI. For the current study, it should be noted that some of the patients' post intervention PSG studies had to be completed at home due to the COVID pandemic, as opposed to being conducted in a laboratory setting. Patients in the current study were also excluded if they had significant medical

Table 2. BIVARIATE ANALYSES OF COVARIATES VERSUS TREATMENT GROUPS

Covariates	Total Sample	CPAP (n = 25)	UAS (n = 37)	MAD (n = 27)	MMA (n = 30)	*P* Value
Sex						.9
Male	72	15 (60%)	24 (65%)	16 (59%)	17 (57%)	
Female	47	10 (40%)	13 (35%)	11 (41%)	13 (43%)	
Age (years)						<.001
Mean (SD)		55.00 (12.49)	63.27 (10.45)	56.59 (10.15)	47.83 (9.18)	
SES*						<.001
$0-50,000	18	3 (12%)	5 (14%)	1 (4%)	9 (30%)	
$50,000-100,000	27	9 (36%)	11 (30%)	3 (11%)	4 (13%)	
$100,000-150,000	45	6 (24%)	5 (13%)	17 (63%)	17 (57%)	
$150,000 and above	29	7 (28%)	16 (43%)	6 (22%)	0	
BMI (kg/m^2)						<.001
Mean (SD)		32.85 (6.70)	27.94 (3.43)	29.82 (3.61)	30.79 (4.03)	
Race						<.001
White	90	16 (64%)	37 (100%)	15 (56%)	22 (73%)	
Black	17	8 (32%)	0	5 (19%)	4 (13%)	
Hispanic	7	0	0	7 (26%)	0	
Asian	5	1 (4%)	0	0	4 (13%)	
Other: non-White (vs White)	29	9 (36%)	0	12 (44%)	8 (27%)	<.001
Higher education						<.001
High school and less	34	7 (28%)	7 (19%)	2 (8%)	18 (60%)	
College	40	13 (52%)	7 (19%)	16 (59%)	4 (13%)	
Masters	36	4 (16%)	18 (49%)	6 (22%)	8 (27%)	
Doctorate	9	1 (4%)	5 (14%)	3 (11%)	0	
Pretreatment variables						
AHI – mean (SD)		32.63 (19.60)	37.06 (15.70)	18.53 (13.70)	49.89 (31.14)	<.001
O2 nadir – mean (SD)		80.45 (6.70)	81.88 (6.29)	82.17 (7.30)	76.26 (7.26)	.002
ESS – mean (SD)		8.60 (5.09)	10.86 (5.10)	10.89 (5.58)	10.9 (4.51)	.3
SAQLI – mean (SD)		3.89 (1.75)	4.16 (1.54)	3.62 (1.45)	3.58 (1.01)	.3
PRAQ – mean (SD)		3.32 (1.48)	2.68 (1.29)	2.63 (1.25)	2.73 (0.72)	.1

Note: Data represent mean and standard deviation or count and percent for the categorical data.
Abbreviation: SD, standard deviation.
* Household annual income was used as a proxy for SES.

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comorbidities (specifically those with a Charlson Comorbidity Index greater than or equal to 5, which represents severe comorbidities),[17] a BMI greater than or equal to 45, cognitive limitations, a history of central or mixed apnea, and be pregnant (self-reported).

Results showed that younger patients were more likely to have the MMA procedure. Patients within the $100,000-150,000 range were more likely to have the MAD or MMA procedures, while those of the higher SES classes of $150,000 or more were more likely to have the UAS procedure. BMI also showed distinctive patterns across the 4 groups, with patients presenting with higher BMI being more likely to be recommended for CPAP, as opposed to other interventions. Level of education was also significantly different across the 4 treatment groups, with patients with higher levels of education more likely to be in the surgical treatment groups. This may also be a factor of SES, or that persons who are more educated may be more likely. Finally, race was different among the 4 treatment groups, as shown in the table. Because cell sizes were small for the other racial groups, we collapsed the race variable from 5 groups (White, Black, Hispanic, Asian, and other) to 2 groups (Whites and non-Whites) and found a statistically significant difference in racial representation across the 4 treatment groups.

One pattern that did emerge was that non-White patients tended to have the nonsurgical treatments (CPAP and MAD), whereas the surgical alternatives (UAS and MMA) were more commonly completed for White patients (56.6 vs 27.5% for surgical treatments). An additional analysis to compare Whites to those who identified as non-White was conducted with a $\chi^2 = 19.75$, $P < .001$. This analysis is included in Table 2.

The next series of analyses involved comparisons of pretreatment sleep study data (Table 2). ANOVA analysis showed a statistically significant difference across treatment groups for pretreatment AHI (F (3,115) = 10.71, $P < .001$). Post hoc tests revealed statistically significant differences between the MMA and all 3 other groups, as well as between both CPAP and UAS and MAD. Patients selected for MMA had significantly higher pretreatment AHI than all other groups, which is consistent with the magnitude of the surgery and associated recovery with this surgical procedure. MMA may be reserved for the most severe patients with OSA. Patients with the lowest pretreatment AHI appeared to be more likely to be placed in the MAD group when compared with all 3 other groups. Moreover, pretreatment O2 nadir was also significantly different across the 4 treatment groups, with statistically significant differences between MMA and all of the other 3 groups (Table 2).

PRIMARY OUTCOME VARIABLES

Descriptive statistics were calculated for the major treatment outcome measures following the intervention for each patient, including treatment efficacy (defined as pretreatment AHI – post-treatment AHI), adjusted compliance, MDA, and remaining AHI. Clear patterns were visible across groups for each of the treatment conditions, and further statistical analyses were conducted to examine these relationships (Table 2) and the role of covariates (Tables 3 and 4).

PRIMARY ANALYSES FOR EFFECT OF TREATMENT ON MEAN DISEASE ALLEVIATION (MDA)

Mean MDA was found to be significantly different across treatment types, F (3,115) = 18.95, $P < .001$. Post hoc analyses identified statistically significant differences between CPAP and both surgical interventions, MAD and both surgical interventions, and between MDA scores for both surgical intervention methods. In other words, there was no difference between the 2 nonsurgical group MDA scores (Table 5). Table 3 displays MDA scores for each treatment type with a 95% confidence interval. These results showed a clear clinical benefit of MMA for patients, over and above improvements seen for the other 3 treatment methods. Similarly, UAS was also better than both nonsurgical methods, although it did not demonstrate as much improvement as MMA.

Post hoc analyses (Tukey's HSD) identified significant differences between CPAP and both surgical interventions (CPAP:MMA – $P < .001$ l CPAP: Inspire – $P = .004$), MAD and both surgical interventions (MAD:MMA -p < .001, MAD:Inspire – $P = .010$), and between MDA scores for both surgical intervention methods (MDA:Inspire – $P = .028$). In other words, there was no difference between the 2 nonsurgical group MDA scores. These results showed a clear clinical benefit of MMA for patients, over and above improvements seen for the other 3 treatment methods. Similarly, UAS was also better than both nonsurgical methods, although it did not show as much improvement as MMA.

In simpler terms, the MMA procedure was 7.2-times more effective than CPAP and 5.3-times more effective than MAD, and MAD was 1.63-times more effective than CPAP. While all 4 methods led to statistically significant improvement of OSA symptoms as measured by the MDA variable, the surgical procedures were much more effective, with MMA as the most effective.

FURTHER ANALYSES OF OUTCOME MEASURES

An additional ANOVA was conducted to compare the mean pretreatment AHI scores across the groups (Table 2). The ANOVA was statistically significant (F

Table 3. BIVARIATE ANALYSES OF COVARIATES VERSUS MDA

Covariates	r	*P*
Correlations with MDA		
Age	−0.084	.396
BMI	0.073	.464
Pretreatment variables: correlations with MDA		
O2 nadir	−0.379	<.001
Hours of sleep	0.193	.049
Pre-Tx AHI	0.760	<.001
Pre-ESS	0.085	.388
Pre-SAQLI	0.089	.366
Pre-PRAQ	−0.068	.489

Means analysis	Mean	SD	F/t	*P*
Sex			t (115) = −3.07	.003
Males	23.94	25.54		
Females	11.80	10.94		
SES			F (6,112) = 0.682	.665
$0-50,000	15.55	11.32		
$100,000-150,000	22.82	28.37		
$150,000-200,000	5.46	6.75		
$200,000 and above	16.37	18.82		
Race			F (3,101) = 14.52	<.001
Asian	68.02	38.03		
Black	14.12	15.31		
Hispanic	1.29	1.60		
White	16.78	18.20		
Higher education			F (5,113) = 1.52	.189
High school and less	25.39	18.17		
College	11.91	17.28		
Masters	19.90	28.10		
Doctorate	20.90	15.90		

Abbreviation: SD, standard deviation.

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(3,115) = 10.71, $P < .001$). Post hoc analysis showed a statistically significant difference between CPAP and MMA, a statistically significant difference between MAD and both UAS and MMA, and no difference between the 2 surgical procedures (UAS and MMA). On average, patients selected for MMA consistently had higher pretreatment AHI. These results are again consistent with the magnitude of the surgical intervention required for the MMA procedure. Table 2 shows the mean treatment AHI for each treatment group including 95% confidence interval.

Table 6 displays statistically significant correlations between variables. A number of interesting relationships were identified, including a relationship between Hours of Sleep and Post ESS (r = −0.34), BMI and O2 Nadir (r = −0.44).and Pretreatment AHI and O2 Nadir (r = −0.44). Other relationships between MDA and AHI are explained because AHI is a component in the equation for MDA.

SECONDARY OUTCOME VARIABLES

Assessments of Pretreatment and Post-treatment PROMs

To determine if there was an effect of treatment on survey scores, a series of paired samples t-tests were conducted to compare the pretreatment survey scores to the post-treatment survey scores for the ESS, PRAQ, and SAQLI. Repeated measures indicated statistically significant differences for comparisons between pretreatment and post-treatment survey scores. Pre-ESS versus post-ESS (t (118) = 9.43, $P < .001$), pre-PRAQ and post-PRAQ (t (118) = −4.32, $P < .001$), and pre-SAQLI and post-SAQLI (t (118) = −4.23, $P < .001$) were significantly different following intervention, demonstrating improved quality of life for patients following the intervention.

Further analyses were conducted on the post-treatment and pretreatment scores independently (Table 7). An ANOVA analysis was conducted to

Table 4. MULTIPLE REGRESSION MODEL OF TREATMENT GROUP VERSUS MDA ADJUSTED FOR POTENTIAL COVARIATES

Source	B	SE	β	t	*P*
Treatment group	7.770	1.090	0.390	7.130	<.001
Age	0.226	0.093	0.124	2.434	.017
Sex	−2.462	2.484	−0.056	−0.991	.324
BMI	−0.144	0.246	−0.032	−0.585	.560
SES	1.385	1.086	0.081	1.275	.205
Highest education	−2.122	1.534	−0.091	−1.383	.170
Race	5.521	1.496	0.200	3.692	<.001
O2 nadir	0.100	0.152	0.039	0.653	.515
Hours of sleep	2.786	0.921	0.154	3.026	.003
Pre-Tx AHI	0.569	0.056	0.618	10.095	<.001

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determine if there was a statistically significant effect of treatment type on post-treatment scores for the 3 survey measures ESS, PRAQ, and SAQLI, to determine if there were differences across treatment groups following intervention. The ANOVA revealed a statistically significant effect of treatment type for post-ESS scores (F (3, 115) = 3.094, P = .03) and post-PRAQ scores (F (2,115) = 11.906, P < .001). No statistically significant effect was found for SAQLI scores (P = .483). Post hoc analyses revealed a statistically significant difference between CPAP and MMA (t = 2.83, P = .05) for post-ESS scores, with patients with greater daytime sleepiness undergoing MMA as compared to CPAP. In other words, patients who received MMA had lower post treatment ESS than those who were treated with CPAP, indicating less daytime sleepiness. For the post-PRAQ scores, statistically significant differences were identified between UAS and CPAP (t = −1.50, P = .001), UAS and MAD (t = −1.71, P < .001), and UAS and MMA (t = −1.80, P < .001). Patients treated with UAS reported higher quality of life as assessed by this survey compared to the other 3 groups.

Survey Measures as Predictors of MDA

A difference score was calculated for each of the survey measures, subtracting the post-treatment survey scores from the pretreatment survey scores for the ESS, PRAQ, and SAQLI. Each of these scores, the 3 different PROMs, were submitted to a regression analysis and only ESS difference scores were significantly predictive of MDA (t = −3.544, P < .0001). Survey responses were not consistent with MDA results. Patients did not show changes in quality of life in conjunction with improvements in MDA. Patients who showed improvement in MDA did not necessarily show improvement with the survey measures. A correlation analysis comparing difference scores from pretreatment and post-treatment ESS and MDA was statistically significant, with r = −0.259,

Table 5. SECONDARY OUTCOMES

Treatment Groups	Treatment Efficacy (%) Mean (SD)	Adjusted Compliance (%)* Mean (SD)	Remaining AHI Mean (SD)
CPAP	6.40 (17.18)	89.14 (18.02)	26.14 (22.63)
UAS	27 (15.37)	85.33 (17.57)	10.08 (9.99)
MAD	7.70 (9.68)	90.48 (17.27)	10.83 (11.15)
MMA	39.40 (29.08)	88.57 (16.09)	10.53 (11.75)
P value	<.00001	.664	.0001

Note: ++Adjusted compliance is not 100% for MAD, despite the fact that the surgery has 100% compliance, because of the mathematical calculations involved in the AC formula, which is average hours used per day/sleep divided by 7, converted to a percent.

Data represent mean and standard deviation.

Abbreviation: SD, standard deviation.

* Adjusted compliance = (hours of use per night/7) *100, where 7 is used as an estimate of normal hours of sleep per night.

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Table 6. PRIMARY OUTCOME VARIABLE (MDA) FOR TREATMENT GROUPS

Tx Type	MDA
CPAP	
Mean	5.00
SD	14.80
MAD	
Mean	6.80
SD	8.13
UAS	
Mean	22.88
SD	13.16
MMA	
Mean	36.08
SD	28.56

Abbreviation: SD, standard deviation.

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P = .002. This indicates that as MDA improves ESS is lower. Lower scores are consistent with less daytime sleepiness, which indicates success of treatment. However, other survey measures were not associated with MDA.

Discussion

This study was conducted to directly compare the effectiveness of 4 treatments for OSA to aid clinicians in determining which treatment may be most suitable for their patients with OSA. The investigators hypothesized that there would be statistically significant differences in MDA among all 4 types of treatment, there would be statistically significant differences in patient adherence among all 4 types of treatment, and there would be statistically significant differences in patients' subjective ratings of the success of therapy among all 4 types of treatment. Specifically, the researchers proposed that the surgical methods would be more effective, especially for patients with severe OSA. The specific aims of the study were to compare a cohort of patients treated with CPAP, MAD, UAS, or MMA surgery to examine whether there are statistically significant differences in MDA, patient adherence, and patients' subjective ratings of success of therapy and measures of daytime sleepiness. The most prominent key finding was that statistically significant improvements in MDA were found among patients who had undergone surgical procedures—MMA and UAS (see Table 3). Specifically, while all of the treatments showed alleviation of disease symptoms, the 2 surgical interventions were associated with better outcomes. These results support the first hypothesis. However, most of the patients who were offered the MMA procedure also had more severe preintervention assessment measures, such as higher AHI and lower O2 nadir. After controlling for pretreatment effects, the main effect of the selected treatment was still statistically significant, with MAD and UAS showing the best improvement in symptoms as assessed by the MDA. These findings highlight that MMA and UAS were the more effective in reducing symptoms and can act as a guide to clinicians when seeking the most appropriate OSA treatment option for their patients.

Table 7. MEANS OF PROMS

	Pre-ESS	Pre-PRAQ Avg	Pre-SAQLI Avg	Post-ESS	Post-PRAQ Avg	Post-SAQLI Avg
CPAP (n = 25)						
Mean	8.60	3.33	3.89	7.06	3.89	4.26
SD	5.09	1.48	1.75	4.40	1.11	1.28
UAS (n = 37)						
Mean	10.87	2.68	4.16	6.43	2.39	4.53
SD	4.70	1.31	1.51	4.38	1.46	0.87
MAD (n = 27)						
Mean	10.89	2.63	3.62	6.85	4.10	4.77
SD	5.58	1.25	1.45	3.07	1.51	0.99
MMA (n = 30)						
Mean	10.90	2.73	3.58	4.23	4.20	4.40
SD	4.51	0.72	1.01	3.53	1.47	1.63
Total (n = 119)						
Mean	10.40	2.82	3.84	6.11	3.55	4.50
SD	5.09	1.23	1.45	4.08	1.62	1.22

Abbreviation: SD, standard deviation.

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There was no support for the hypothesis that adjusted compliance would be different across the 4 treatment types or predictive of the success of the treatments. Furthermore, reduced compliance has been shown to impact OSA outcomes, including symptoms and QOL.[24] The findings in the current study could be because the patients in the CPAP group were more compliant than what is commonly identified. Adjusted compliance for all 4 groups was over 88 percent, which showed more compliance than other studies have indicated, particularly for CPAP and MAD. Studies have shown that after 60 to 90 days of CPAP use, compliance declines.[24] This difference in compliance in this study when compared to other studies is likely because the first 60 to 90 days is critical for determining insurance coverage, which leads to increased adherence, and all of the patients in the current study were within that insurance coverage window. There were 3 meaningful results from the 3 QOL surveys—ESS, SAQLI and PRAQ. The first major finding was that there was a major effect of treatment regardless of type, consistently found on all 3 surveys. Postintervention assessments showed improvements when compared to pretreatment assessments for all 3 PROM measures, which supports that all 4 treatment methods improve both daytime sleepiness and QOL. Another key finding was that there was no consistent effect of treatment type on QOL surveys. However, there was some evidence that the MMA treatment type resulted in more positive improvements in QOL compared to the other 3 procedures of CPAP, UAS, and MAD. The third result from the surveys was that the ESS showed a statistically significant improvement difference when compared between CPAP and MMA, with MMA reducing sleepiness better. With the exception of ESS, which showed more improvement with MMA than with other procedures, no patterns were clearly identified. This makes logical sense, in that patients reported less daytime sleepiness if the treatment was more successful, and MMA was clearly the most effective treatment in improving OSA symptoms. Also demonstrated by the findings in this study was a potential relationship between the SES of a patient and the treatment that they elected to undergo. This is displayed by the increased likelihood of UAS for those of the higher SES classes of $150,000 or more. The cost of UAS is over $35,000 and not all third-party payers reimburse for the service. While the sample size is not large (29 patients falling into the $150,000 or more category), and no insurance data was available, these findings may deem further research into the SES impact on choice of treatment to be necessary in identifying an SES gap in modern health care. Similarly, patients with higher education appeared to be more likely to have surgical interventions. This may be related to higher SES, but may also be related to more educated patients actively searching for alternatives. More exploration of these variables is clearly warranted. One of the most interesting findings of this study involves the factor of race. This study's findings demonstrated that White patients appeared to be more likely to undergo surgical alternatives (UAS or MMA) for OSA when compared to non-White patients who tended to elect the nonsurgical route (CPAP or MAD). Implications of this finding may be important when examining issues of access. This finding might be influenced by insurance, income, or SES, however, as previously mentioned, the existing data was not sufficient to investigate potential relationships (no insurance data was available, and the number of participants for each racial group was not large enough to investigate potential patterns with respect to SES). More research is needed to further ascertain the reasons behind this disparity between White patients and those from minority groups with respect to what treatment alternatives may be offered. There were 90 (75.6%) White patients as compared to the 29 (24.4%) non-White patients included in this study. Thus, the impact of race is inconclusive in this research due to small sample sizes, but again, these results do indicate that further studies need to be done on what treatments are offered to patients, and how race and financial issues may impact those treatments.

In conclusion, this study was developed to evaluate the comparative effectiveness and patient-reported outcomes of CPAP, MAD, UAS, and MMA surgery for OSA. There is a vast current literature on the effectiveness of CPAP, MAD, UAS, and MMA as treatments for OSA.[5,8,13] However, there are very few studies available that examine and compare the effectiveness of the 4 treatment options, especially regarding their impacts on OSA patient outcomes.[16] This is one of the first studies to directly compare all 4 treatment methods. These 4 groups were then compared, utilizing the MDA concept to evaluate overall control of disease and treatment efficacy for the 4 chosen treatment modalities. While the current study did support previous research that each of these 4 methods can be used to effectively address issues of OSA,[5,9-13] the current study shows that patients who receive surgical interventions demonstrate greater disease alleviation. However, many times these methods are reserved for patients with more severe OSA symptoms, so further research is needed to better compare the 4 methods.

There were multiple statistically significant findings from this study. First, there was a statistically

significant effect of treatment type on MDA, with the most improvement found with MMA and UAS. Next, there was a statistically significant difference in clinical pretreatment measures across treatment groups. Third, patients who received MMA had the most severe pretreatment AHI and O2 nadir, while patients with higher BMI were more likely to be offered CPAP as opposed to other interventions. After controlling for those pretreatment effects, the main effect of treatment was still statistically significant, again with MAD and UAS showing the best improvement in OSA symptoms, with MMA as the most effective. We also found that White patients and patients who belong to a higher SES were more likely to have surgical alternatives offered to them, which may be a factor of income or insurance. And, lastly, there was a predictive effect of demographics and preclinical variables on MDA measures, including: treatment type, race, BMI, age, hours of sleep and pretreatment AHI. Together, these results suggest potential for further studies, to examine how these variables may impact MDA for patients seeking treatment for OSA.

Furthermore, there was a statistically significant effect of treatment on all 3 survey measures. All 3 surveys showed improvements following treatment. While there was no consistent effect of treatment type on QOL surveys, it should be noted that the MMA treatment led to more improvements in QOL than other procedures. Consistently, MMA was found to reduce sleepiness better than other procedures. These findings support the notion that surgical procedures are most useful for patients with moderate to severe OSA.

The current study also indicates that not only are the MMA and UAS procedures as effective as both the CPAP and MAD, but they are also significantly more effective, particularly for patients who are diagnosed with severe OSA. Because OSA can be genuinely debilitating, not only affecting quality of life but also causing issues with sleepiness, OSA can also affect the ability to work and complete activities of daily living. For this reason, the findings of this study suggest that offering surgical alternatives sooner to patients, particularly those with severe OSA, may be a logical next step in formulating more effective treatment guidelines.

Finally, many of the current treatment guidelines focus on AHI as the single measure of severity of OSA. Despite the fact that the current study did not find an impact of treatment on QOL or daily sleepiness measures, all of the 4 methods demonstrated an improvement in quality of life and daytime sleepiness for most of the patients. For this reason, including assessments of QOL, daytime sleepiness, and impact of OSA on daily life might be beneficial in constructing a more useful set of treatment guidelines.

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