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Cost-Utility of Mandibular Advancement Devices in Mitigating Sleepiness and Traffic Accident Risk in Obstructive Sleep Apnea

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Abstract

Objectives: Mandibular advancement devices (MADs) are an effective alternative treatment for obstructive sleep apnea (OSA), improving daytime symptoms and enhancing quality of life. However, evidence on the cost-effectiveness of MAD for OSA treatment remains limited. This study aimed to conduct a cost-utility analysis comparing MAD treatment for OSA to no treatment in Thailand.

Methods: A social perspective was adopted to evaluate the cost-utility of MAD compared to no treatment using a Markov model with a lifetime horizon in OSA patients with excessive daytime sleepiness (EDS). Input parameters were drawn from international and national sources, including published literature, national databases, and local expert consultations. Costs were presented in the United States dollar (USD), and a 3% discount rate was applied to both costs and outcomes, in accordance with Thailand's National HTA Guidelines.

Results: The base case analysis indicated that using MAD resulted in an increase in QALYs by 0.85, with additional costs of 3,308 USD. This resulted in an ICER of 3,891 USD, which is slightly lower than the willingness-to-pay threshold in Thailand, set at 4,526 USD per QALY. MAD was found to be cost-effective, with a probability of cost-effectiveness of 51.9%. Parameters influencing cost-effectiveness were identified and the most sensitive parameters affecting changes in the incremental cost-effectiveness ratio (ICER) were examined through the one-way sensitivity analysis.

Conclusions: MAD therapy appeared marginally cost-effective in Thai settings for OSA patients with EDS. The considerable uncertainty revealed in sensitivity analyses suggests that further research is needed to clarify key parameters and inform decision-making.

Keywords: cost-effectiveness analysis, cost-utility analysis, economic evaluation, mandibular advancement devices, obstructive sleep apnea, road traffic accidents

Introduction

Obstructive sleep apnea (OSA) is a common sleep-related breathing disorder characterized by the relaxation of pharyngeal muscles, which leads to recurrent episodes of upper airway obstruction during sleep. As a protective mechanism, the brain triggers an arousal to awaken the individual, tightening the upper airway muscles and reopening the airway to resume breathing.[1,2] Repeated sleep disruptions and awakenings can result in various symptoms and health complications.[3] OSA significantly increases the risk of accidents, especially road traffic accidents (RTAs), due to excessive daytime sleepiness (EDS).[4-11] Individuals with OSA are particularly vulnerable to microsleep episodes and decreased alertness, particularly in monotonous driving conditions. Microsleep, a brief lapse in attention, is among the most hazardous outcomes of untreated OSA and contributes to a 2-to-7-fold increase in crash risk among affected drivers compared to the general population.[4,7] In Thailand, the prevalence of OSA with EDS is approximately 4.4% of the total population.[12]

Treatment options for OSA vary depending on the severity of the condition and the patient's needs. Continuous positive airway pressure (CPAP) therapy is considered the gold standard. This device provides a continuous flow of air through the nose and/or mouth to keep the airways open during sleep. CPAP has demonstrated effectiveness in reducing EDS and lowering the risk of RTAs.[3,13] Specifically, adherence to CPAP for more than four hours per night has been associated with a 67.1% to 81% reduction in RTAs[14], with noticeable improvements in driving performance within 2 to 7 days of treatment initiation.[3,13]

Despite its efficacy, CPAP adherence remains a major challenge. Globally, only about 50% of OSA patients maintain consistent CPAP use.[1,2,15] In Thailand, access to CPAP is further hindered by cost barriers. The device, which costs approximately 566 USD, is not currently covered under the Thai Universal Health Coverage (UHC) scheme, requiring patients to pay out-of-pocket.[16] Consequently, many patients either forgo therapy or seek alternative treatments. Therefore, Mandibular advancement device (MAD) provides a viable alternative, especially for patients with mild to moderate OSA. These devices function by repositioning the mandible forward relative to the upper jaw, helping to maintain an open airway and preventing the collapse of soft tissues. MAD treatment effectively reduces EDS and improves daytime functions, such as driving performance and it was reported to have better patient compliance than CPAP.[17-20]

Although MADs provide health benefits compared to no treatment, they also incur costs, necessitating justification for inclusion in the public program. Using a societal perspective, this study aims to conduct a cost-utility analysis comparing MADs with the no-treatment. The findings of this study may support policy considerations for including MADs in the Thai UHC benefit package, particularly in light of the affordability challenges associated with CPAP.

Methods

Economic model

This was a cost-utility analysis designed to estimate the expected costs and health gains associated with the use of MAD treatment versus no treatment in OSA patients with EDS. The study modeled OSA patients with EDS driving vehicles and transitioning into four health stages: OSA no event (OSA patients without any specific RTAs), RTA alive (OSA patients surviving an RTA), RTA disability (OSA patients disabled due to an RTA), and death. It was assumed that OSA patients surviving an RTA would drive similarly to OSA no event, meaning this group could continue driving vehicles and could experience RTAs again (Figure 1).

The model simulated scenarios for OSA patients starting at the age of 39 years, which represents the average age of OSA diagnosis in Thailand.[12] with a cycle-length of 1 year and a lifetime time horizon.

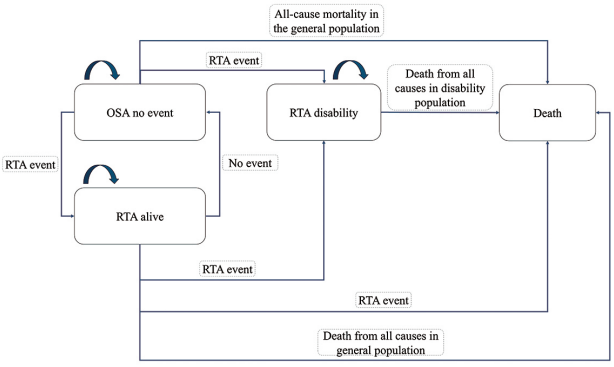

Figure 1: Structure of the Markov model.

Model input

Transition probabilities

In the no-treatment scenario, the probabilities of transitioning from OSA no event to RTA alive, RTA disability, and death from RTAs per year were calculated using the following data: the number of RTA injuries, the number of RTA injuries resulting in disability, and the number of RTA-related deaths per year reported by the Thai Road Safety Collaboration.[21]; the number of licensed drivers reported by the department of land transport, Thailand[22]; and an odds ratio of 2.36 (SE of 0.5255), derived from a meta-analysis of car crashes involving patients with and without OSA conducted by Luzzi *et al*.[23] The resulting probability was 0.060740 (0.015593) for OSA no event to RTA alive, 0.00012 (0.000233) for OSA no event to RTA disability, and 0.001012 (0.000053) annual probability of death from RTAs. This study assumed that OSA patients who survived an RTA would drive similarly to OSA patients in the no event group. Therefore, the probability of transitioning from RTA alive to RTA disability was assumed to be the same as the probability of transitioning from OSA no event to RTA disability.

The probability of death for patients disabled due to RTAs in OSA patients with EDS per year was assumed to be comparable to that of patients with cervical spinal injuries. Based on a report by Middleton *et al*.,[24] which indicated a 40-year survival rate of 47% for cervical spinal injury patients (most of whom were injured in motor vehicle accidents), the annual probability of death was calculated to be 0.0187 (0.0144).

The probability of a patient in the OSA no event group transitioning to death from general causes per year was assumed to be similar to the mortality rate of the general population, obtained from the 2014 Thailand's life table.[25]

In the MAD-treated scenario, the probability of RTAs was reduced based on treatment adherence and its relative risk. The relative risk comparing MAD-treated and untreated groups was calculated according to the data reported by Quinnell *et al*.[18] This study conducted an open label, randomized, controlled, crossover trial in adults with OSA, comparing four weeks of MAD treatment with four weeks of no treatment. The secondary outcomes were ESS scores, quality of life, and questionnaire-based evaluation of driving-related sleepiness. The questionnaire revealed that 11 out of 73 patients in the no-treatment group reported pulled off the road, compared to 4 out of 72 patients in the MAD-treated group. Statistical analysis yielded a relative risk of 0.3687 (0.205). This reduction was extrapolated to estimate a corresponding decrease in RTA probability.

Treatment adherence data were obtained from Uniken *et al*.,[26] who reported that 34 out of 51 patients-maintained MAD usage after a 10-year follow-up period, resulting in an annual adherence rate of 0.958 (0.0280).

The relative risk and adherence rates were subsequently used to calculate the probabilities of RTAs and associated outcomes (survival, mortality, and disability) in MAD-treated patients. For non-compliant patients, the probability of RTAs was assumed to be the same as that of the no-treatment scenario.

After accounting for treatment adherence and relative risk, the following probabilities were calculated for the MAD-treated scenario: transition from OSA no event to RTA alive: 0.023386 (0.013416), transition from OSA no event to RTA disability: 0.000390 (0.000219), transition from OSA no event to death from RTAs: 0.000005 (0.000003), transition from OSA no event to death from general causes and death from disability due to RTAs assumed to be the same as in the no-treatment group. The raw data calculated probabilities within this study are presented in Table 1.

Costs

Under societal viewpoint, the costs analyzed in this study included both direct medical expenses and direct non-medical costs, with the majority of the data obtained through comprehensive literature review and questionnaire surveys.

Direct medical costs

Medical costs including expenses such as cost of a visit to a dentist and cost of a visit to a doctor, were obtained from Thai Standard Cost List for Health Technology Assessment.[27] RTA-related costs such as cost of outpatient medical treatment for RTA patients, cost of inpatient medical treatment for RTA patients were derived from an analysis of the economic costs of road traffic injuries from the perspective of the Thailand Social Security System.[28] Additionally, the cost of MAD, the cost of sleep test and the number of patients visiting a doctor and dentist were obtained from the questionnaires collected from 15 qualified dentists in dental sleep medicine and 9 qualified sleep medicine physicians in Thailand. The

Table 1: Variables, standard deviations, and distributions associated with probabilities used in this study.

Input parameters	Value	SD	Distributions	Sources
Average number of persons holding driving licenses (per year)	32,792,963	51516.24	gamma	Pradabboon K *et al*., 2021[27]
Average number of persons injured from accidents (per year)	843,996	107822.92	gamma	Riewpaiboon A, 2009[26]
Average number of persons dying from accidents (per year)	14,059	827.24	gamma	Riewpaiboon A, 2009[26]
Average number of persons disabled due to accidents (per year)	173	9.70	gamma	Riewpaiboon A, 2009[26]
Probability of death in C-spinal injury patients	0.0187	0.0144	beta	Thailand Consumer Price Index[29]
Odds ratio of OSA patients having accidents compared to 'no treatment'	2.360	0.5255[a]	gamma	Thailand Consumer Price Index[28]
Probability of OSA patients using MAD in the following year	0.958	0.028	beta	Currie CJ *et al*., 2005[32]
Relative risk of treating OSA patients with MAD compared to 'no treatment'	0.3687	0.205	beta	Middleton JW *et al*., 2024[23] and Jenkinson C *et al*., 1998[31]

SD, standard deviation
a Standard error

lifetime costs associated with the MAD were calculated under the assumption that the device would require replacement every five years, a timeframe consistent with that of acrylic complete dentures, which are covered by the Universal Coverage Scheme in Thailand.

Direct non-medical costs

Direct non-medical costs including expenses such as, cost of transportation expenses for hospital visits, cost of lost income for patients due to hospital visits, cost of lost income for relatives due to hospital visits, food expenses during hospital visits were obtained from Thai Standard Cost List for Health Technology Assessment.[27] Furthermore, the cost of damaged vehicles from accidents, cost of damaged government properties from accidents, were derived from an analysis of the economic costs of road traffic injuries from the perspective of the Thailand Social Security System.[28] All costs were converted to 2024 values using the Thai consumer price index and presented in USD (approximately THB 35.35=1 USD).[29]

Cost analysis for patients with no treatment

For patients without treatment, the cost of the OSA no-event health stage during the first-year cycle was equivalent to the cost of a single visit to a doctor. For subsequent years, it was assumed that no additional costs would be incurred until the end of life.

In terms of RTA-related costs, the total cost was determined by summing various expenses. These included the cost of a visit to a doctor, outpatient medical treatment for RTA patients, inpatient medical treatment for RTA patients, costs associated with vehicle damage from accidents, costs of damage to government property caused by accidents, transportation expenses for hospital visits, lost income for patients due to hospital visits, and food expenses during hospital visits. Each of these costs was calculated based on a single session, as the study assumed that an RTA would occur only once per cycle or year.

For the RTA alive health stage, the cost was similar to the RTA-related costs. However, in the RTA disability or death health stages, the cost was also similar to the RTA-related costs but was calculated only for the first year. For subsequent years, it was assumed that no additional costs would be incurred, as patients with disabilities or those who had died would no longer drive or require treatment.

For patients in the RTA alive health stage, the costs were equivalent to the RTA-related expenses. However, for patients in the RTA disability or RTA death health stages, the costs were also similar to the RTA-related expenses but were calculated only for the first year. For subsequent years, it was assumed that no additional costs, as patients with disabilities or those who had died would no longer drive.

Cost analysis for patients with MAD treatment

For patients receiving MAD treatment, the study assumed that the lifespan of the MAD was five years, meaning that patients would need to replace the device every five years. The cost of the OSA no-event health stage during the first year of MAD treatment was calculated by considering several factors. These included the Number of visits a patient sees the doctor during the first year multiplied by the cost of a doctor's visit, the Number of visits a patient sees the dentist during the same period multiplied by the cost of a dentist's visit, the cost of one session of a hospital sleep test, the number of follow-up hospital sleep tests during the first year multiplied by the cost of a hospital sleep test, the number of follow-up home sleep tests during the first year multiplied by the cost of home sleep tests, and the cost of the MAD itself.

For subsequent years (years 2 to 5), the cost of the OSA no-event health stage was calculated similarly. This included the Number of visits a patient sees the doctor per year multiplied by the cost of a doctor's visit, the Number of visits a patient sees the dentist per year multiplied by the cost of a dentist's visit, the number of hospital sleep tests per year multiplied by the cost of a hospital sleep test, and the number of home sleep tests per year multiplied by the cost of home sleep tests.

In the sixth year, the MAD would need to be replaced. The cost for this year was similar to the costs for years 2 to 5 but included the additional cost of the MAD and three times the cost of a dentist's visit to account for the process of creating a new MAD. For years 7 to 10, the costs were similar to those for years 2 to 5. This cycle of costs (years 6 to 10) was repeated until the end of life, with the MAD being replaced every five years.

The costs associated with the RTA alive health stage were determined by adding the cost of MAD treatment in each year to the RTA-related costs. For the RTA disability and RTA death health stages, the costs were similar to those for the RTA alive health stage during the first year. However, for subsequent years, it was assumed that no additional costs would be incurred, as patients with disabilities or those who had died could no longer be involved in RTAs or use MAD treatment.

This study did not account for productivity losses due to morbidity and premature mortality from RTA, as this could result in double counting alongside the utility losses associated with disability and mortality outlined below. The raw data calculated costs within this study are presented in Table 2.

Health utility

In the no-treatment group, the utility value of OSA no event was reported as 0.74, based on the study by Sadatsafavi *et al*.,[30] which utilized data collected by Jenkinson *et al*.[31] This data was derived using the 36-item Short Form Health Survey (SF-36), the Patient Generated Index (PGI), and the EuroQol EQ-5D questionnaire in OSA patients from United Kingdom. The utility value of RTA alive as 0.62, according to the study by Sadatsafavi *et al*.,[30] which utilized data from Currie *et al*.[32] This data was collected and analyzed from patients treated at the Cardiff and Vale National Health Service Hospitals Trust in the United Kingdom. The utility value of RTA disability was reported as 0.19, as derived from the study by Graham *et al*.[33] This study collected and analyzed data from the Application of the Functional Capacity Index to NASS CDS Data, conducted by the National Highway Traffic Safety Administration, USA. The utility value of death in OSA patients was reported as 0.

In the MAD-Treated group, utility value of OSA no event after MAD treatment was calculated as 0.767. This value was derived by adding the baseline utility value of OSA no event in no treatment group as 0.74 to the difference in the ESS score before and after treatment, multiplied by 0.01. The reduction in ESS scores was derived from a single clinical study with a randomized crossover design conducted in Thailand.[34] This study provided baseline ESS scores (no treatment) and post-intervention ESS scores (MAD treatment). The results demonstrated a reduction in mean ESS scores from 11.20 to 8.49 following MAD intervention.[34]

This adjustment is based on findings that a 1-point reduction in the ESS score leads to a 0.01 (0.004) increase in the utility value of the EQ-5D-3L, as determined by analyses involving the ESS, SF-6D, and EQ-5D instruments.[35] The utility value RTA alive, RTA disability, and RTA death after MAD treatment were assumed to be the same as in the no-treatment group. The raw data calculated health utilities within this study are presented in Table 3

Base-case analysis

The primary outcomes of interest were the differences in the number of OSA no events, RTA alive, RTA deaths, and RTA disabilities from driving a vehicle, as well as the total costs and quality-adjusted life years (QALYs)

Table 2: Variables, standard deviations, and distributions associated with cost used in this study.

Input parameters	Value	SD	Distributions	Sources
Number of visits a patient sees the doctor during the first year of MAD treatment	3.202	0.87	gamma	survey
Number of visits a patient sees the dentist during the first year of MAD treatment	6.011	1.44	gamma	survey
Number of visits a patient sees the doctor per year during years 2 to 5 of MAD treatment	1.033	0.26	gamma	survey
Number of visits a patient sees the dentist per year during years 2 to 5 of MAD treatment	1.133	0.46	gamma	survey
Number of hospital sleep test for follow-up in the first year of MAD treatment	0.571	0.47	gamma	survey
Number of home sleep test for follow-up during the first year of MAD treatment	0.711	0.79	gamma	survey
Number of hospital sleep test per year during years 2 to 5 of MAD treatment	0.192	0.24	gamma	survey
Number of home sleep tests per year during years 2 to 5 of MAD treatment	0.193	0.05	gamma	survey
Cost of MAD	231	102.86	gamma	survey
Cost of hospital sleep test per session	248	27	gamma	survey
Cost of home sleep tests per session	83	19	gamma	survey
Cost of a visit to a dentist per session	8	1.88[b]	gamma	Chaikledkaew U *et al*., 2014[36]
Cost of a visit to a doctor per session	8	1.88[b]	gamma	Chaikledkaew U *et al*., 2014[36]
Cost of outpatient medical treatment for RTA patients per session	38	7.55[b]	gamma	Banhiran W *et al*., 2018[34]
Cost of inpatient medical treatment for RTA patients per session	555	111[b]	gamma	Banhiran W *et al*., 2018[34]
Cost of damaged vehicles from accidents per session	277	55[b]	gamma	Banhiran W *et al*., 2018[34]
Cost of damaged government properties from accidents per session	94	18.71[b]	gamma	Banhiran W *et al*., 2018[34]
Cost of transportation expenses for hospital visits per session	4.72	0.33[a]	gamma	Chaikledkaew U *et al*., 2014[36]
Cost of lost income for patients due to hospital visits per session	2.66	0.39[a]	gamma	Chaikledkaew U *et al*., 2014[36]
Cost of lost income for relatives due to hospital visits per session	3.17	1.00[a]	gamma	Chaikledkaew U *et al*., 2014[36]
Food expenses during hospital visits per session	1.75	0.15[a]	gamma	Chaikledkaew U *et al*., 2014[36]

The cost was reported in USD.
a Standard error, b Standard error assumed, 20%.
SD, standard deviation

in the no-treatment and MAD-treated groups. The reduction in the number of RTA alive, RTA deaths, and RTA disabilities caused by driving, along with the reduction in the ESS in RTA alive and OSA events, could lead to gains in QALYs for the MAD-treated groups. Future benefits, including the costs and QALYs gained, were discounted at 3%, as recommended by the Thai HTA guidelines.[36]

The incremental cost-effectiveness ratio (ICER) in USD per QALY gained for each policy option was presented to assess the cost-effectiveness of the technology. To be considered cost-effective in Thailand, MAD had to provide an additional unit of health gain at or below a willingness-to-pay (WTP) threshold of 160,000 THB (approximately 4,526 USD) per QALY.[15]

Table 3: Variables, standard deviations, and distributions associated with health utilities used in this study.

Input parameters	Value	SD	Distributions	Sources
ESS of 'no treatment'	11.2	3.5	gamma	McDaid C *et al*., 2009[41]
ESS of MAD treatment	8.49	0.7	gamma	McDaid C *et al*., 2009[41]
Increased utility value per 1 ESS reduction	0.01	0.0040[a]	gamma	Jenkinson C *et al*., 1998[31]
Utility value of OSA patients	0.74	0.1590[a]	beta	Van Haesendonck G *et al*., 2015[38]
Utility value of disabled patients	0.19	0.0560[a]	beta	Ou YH *et al*., 2023[39]
Utility value of RTA patients	0.62	0.27	beta	Ou YH *et al*., 2024[40]

SD, standard deviation
a Standard error

Uncertainty analysis

This study conducted a one-way sensitivity analysis, a probabilistic sensitivity analysis (PSA), and scenario analyses to assess the impact of model assumptions and parameter uncertainty. In the one-way sensitivity analysis, parameters were adjusted within their 95% confidence intervals. However, for certain cost-related parameters such as the cost of a dental visit, the cost of a doctor visit, the cost of outpatient treatment for RTA patients, the cost of inpatient treatment for RTA patients, the cost of vehicle damage from accidents, and the cost of damage to government property from accidents. The standard error was assumed to be 20 %. The most influential variables were presented using a tornado diagram.

For the PSA, parameter distributions were assigned following the guidelines of Briggs *et al*.[37] A beta distribution was applied to parameters such as relative risk, probabilities, and utility values, while a gamma distribution was used for cost-related parameters, number of persons holding driving licenses, number of persons injured from accidents, number of persons dying from accidents, number of persons disabled due to accidents . Random values were sampled from these distributions using Monte Carlo simulation with 1,000 iterations. The findings were summarized and displayed through cost-effectiveness acceptability curves.

For the scenario analyses, several parameters were varied to reflect different assumptions, including the following: home sleep tests were performed annually for follow-up, hospital sleep tests were performed annually for follow-up, the utility value of RTA survivors was assumed to be equal to that of OSA patients without events, MAD adherence was assumed to be 70%, MAD was assumed to have no effect on preventing RTAs, and the cost of the MAD was adjusted. The results revealed differences in the ICERs across scenarios.

Result

Base-case analysis

The result of base-case analysis comparing MAD with no treatment for OSA patients in Thailand is presented in Table 4. The analysis revealed that MAD treatment resulted in a lifetime cost of 4,675 USD compared with 1,367 USD for no treatment, yielding an incremental cost of 3,308 USD. In terms of health benefits, MAD was associated with 17.08 QALYs, whereas no treatment yielded 16.23 QALYs, resulting in an incremental gain of 0.85 QALYs. Consequently, the ICER was calculated to be 3,891 USD per QALY gained. According to the WTP threshold, MAD appears to represent a cost-effective intervention relative to no treatment.

Uncertainty analysis

The results of one-way sensitivity analysis indicated that the variables which had a highly significant impact on the base case ICER (more than 100% of ICER) were utility value of RTA patients, number of hospital sleep test per year during years 2 to 5 of MAD treatment, increased utility value per 1 ESS reduction. Other variables that had a significant impact on the base case ICER are shown in Figure 2. The remaining parameters are not presented in the tornado diagram, as they were unlikely to have a substantial impact on the ICER (less than 10%). The PSA results (Figure 3) revealed that at the current Thai WTP threshold, the MAD treatment was cost-effective with a 51.9%. No treatment was cost-effective if WTP was below 3,253 USD.

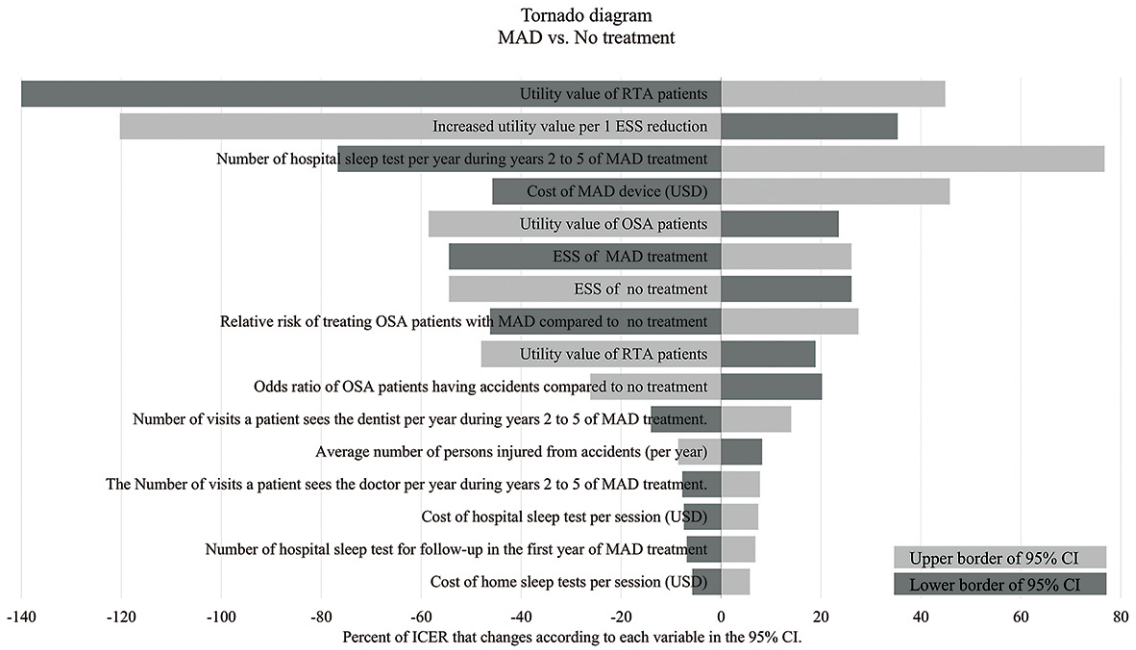

Figure2: Tornado diagram showing the variables affecting an ICER greater than 10%.

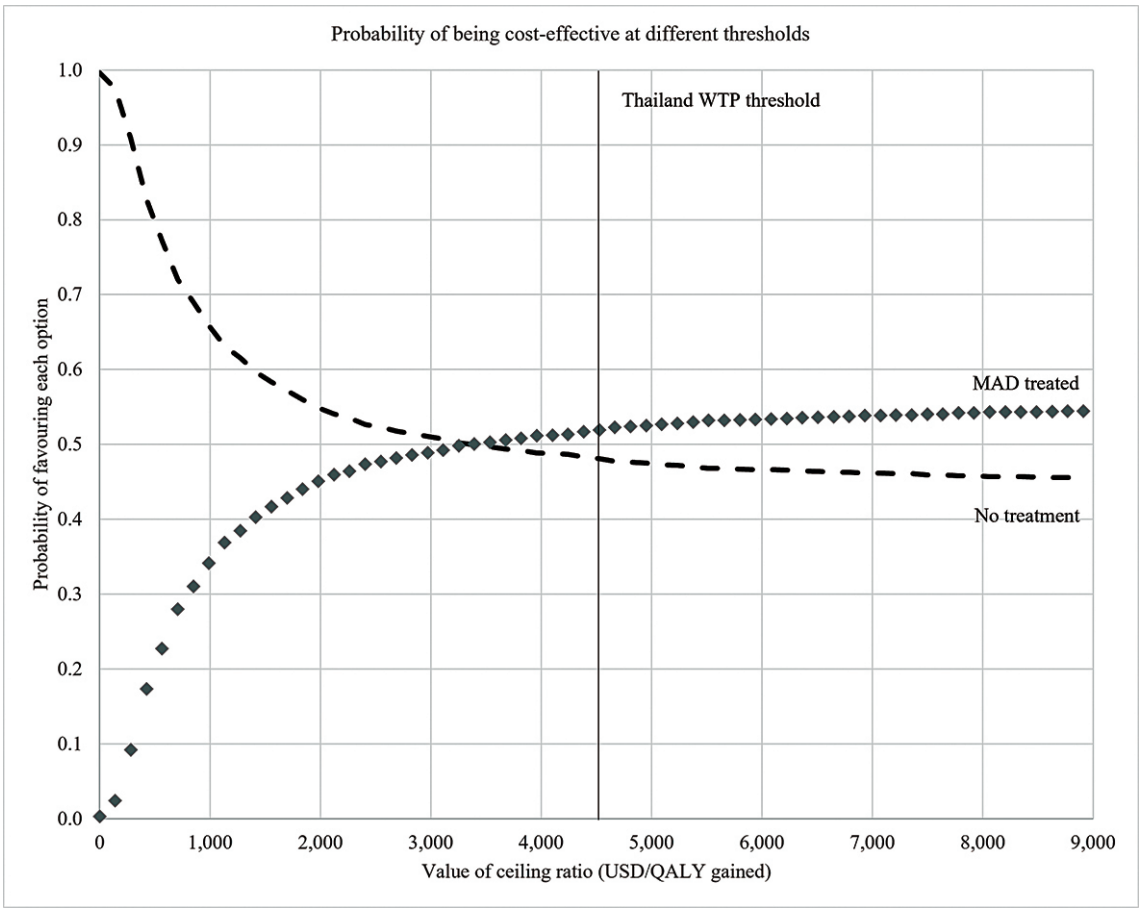

Figure 3: Cost-effectiveness acceptability curves in the different thresholds.

Table 4: Analyses of cost, QALY and ICER in different scenarios.

Scenario	MAD		No treatment		ICERs (USD/ QALY)
	Cost (USD)	QALY	Cost (USD)	QALY	
Base case analysis	4,675	17.08	1,367	16.23	3,891
If home sleep test is performed annually for follow-up	4,664	17.08	1,367	16.23	3,879
If hospital sleep test is performed annually for follow-up	8,680	17.08	1,367	16.23	8,604
If utility value of 'RTA alive' equals 'OSA no event'	4,675	17.15	1,367	16.39	4,353
If MAD adherence is 70%	4,884	17.01	1,367	16.23	4,509
If MAD has no effect on preventing RTA	5,446	16.80	1,367	16.23	7,156
If the cost of MAD is 339.46 USD (12,000 THB)	5,206	17.08	1,367	16.23	4,516

The results of the scenario analyses are summarized in Table 4. When follow-up was assumed to be conducted annually using only a hospital-based sleep test, the ICER increased substantially to 8,604 USD per QALY, reflecting significantly higher healthcare costs. In contrast, follow-up using only a home sleep testing yielded an ICER of 3,879 USD per QALY, comparable to the similar to the base-case estimation.

Altering the utility value of RTA patients to equal that of OSA patients without events resulted in an ICER of 4,353 USD. Reducing MAD adherence to 70% increased the ICER to 4,509 USD. When MAD had no effectiveness in reducing RTA incidence, the ICER rose substantially to 7,156 USD per QALY, highlighting the importance of treatment efficacy. Lastly, increasing the cost of the MAD to 339.46 USD (12,000 THB) resulted in an ICER of 4,516 USD per QALY.

Discussion

Our model indicates that MAD yields an ICER of 3,891 USD, which is slightly lower than the WTP threshold for the Universal Health Care Coverage Scheme in Thailand. These findings suggest that, compared to the no-treatment option, MAD is cost-effective in the Thai setting. However, one-way sensitivity and probabilistic sensitivity analyses highlight significant parameter uncertainty, rendering the results inconclusive. While MAD appears to have a higher probability of being cost-effective at Thailand's WTP threshold, there remains a 48% probability that the no-treatment option could be more cost-effective than MAD. These results underscore the need for further research to refine key parameters identified in the one-way sensitivity analysis.

In comparison, a US study by Sadatsafavi *et al*.,[30] that evaluated MAD against no treatment reported an ICER of 2,984 USD, which is lower than the ICER observed in this study (2,984 vs. 3,891 USD). The lower ICER in that study was attributed to the clinical benefits associated with the prevention of RTAs, stroke, and coronary artery disease. These additional benefits may have contributed to the higher incremental QALY observed in the treatment group compared to our study. Although the prevention of stroke and coronary artery disease could make MAD therapy more advantageous, this study excluded cerebrovascular and cardiovascular diseases from the economic model due to the numerous factors influencing their onset, recovery, and progression. Despite evidence suggesting that MAD may have beneficial effects on cardiovascular comorbidities in OSA patients, studies comparing MAD to CPAP therapy have shown similar effects.[19,38-40]

Regarding the ICER, a previous study conducted in the UK, which included the prevention of RTAs, stroke, and coronary artery disease in its economic model, reported an ICER of approximately 17,003 USD. In the UK, the WTP threshold ranges from 20,000 to 30,000 GBP.[35] The ICER in the UK study was higher than that observed in our study. These differences can be explained by variations in the cost of treatment between the two countries. For instance, in this study, the cost of MAD was 231 USD, whereas in the UK, it was 678 USD. Additionally, this study assumed a lifespan of 5 years for MAD, while the UK study assumed a lifespan of only 2 years.

The present study had some limitations. First, the costs associated with caregivers for patients with RTA-related disabilities were not included, which may have led

to an underestimation of the costs in the RTA disability health stage. Second, some variables, were not obtained from Thai population such as the odds ratio of traffic accidents in OSA patients could differ from those in other countries.[30,35,41-43] The relative risk of RTAs following MAD treatment, compared to the no-treatment group, was analyzed based on questionnaire data from the UK[35], which asked OSA patients about instances of pulling off the road. However, this may cause the relative risk to not accurately reflect reality. Not all cases of pulling off the road due to sleep while driving result in traffic accidents, as other factors, such as the safety of the car and the traffic environment, may also play a role. While safer cars may help prevent traffic accidents, they are often more expensive. However, this study used a higher relative risk, indicating that it may prevent accidents less effectively compared to the UK study, which calculated the risk using the ratio of ESS treatment effects (0.37 vs. 0.17).[41] In addition, OSA can cause various health problems beyond EDS and RTAs, which were not included in the model. These problems include sleepiness while driving, nodding off behind the wheel, cardiovascular diseases, depression, lower work performance, poorer sleep quality for bed partners, heart disease, trouble with thinking, and diabetes.[44] If research is done on how effective MAD is in treating or preventing these issues, it could help create a more detailed Markov model that affects cost calculations and increasing utility values, making it more likely that MAD will be seen as cost-effective. Lastly, this study compared only MADs and no treatment; other available treatments for OSA, such as CPAP, maxillomandibular advancement surgery, and myofunctional therapy, were not included, even though some of these treatments may be more cost-effective than MAD.

This study focuses on the economic aspects of including MAD in the Thai health benefit package, without addressing feasibility and implementation challenges. For instance, dentists who fabricate MADs are not authorized to provide definitive diagnoses for OSA patients. Therefore, successful implementation of this policy requires multidisciplinary collaboration among physicians, qualified dentists, sleep technicians, and other health professionals to ensure improved quality of life and effective treatment for OSA.

Conclusions

Given the limited data on RTA related to OSA in Thailand, MAD may demonstrate limited cost-effectiveness within the Thai healthcare context, as the probability of cost-effectiveness was marginal (51.9%). Both one-way and probabilistic sensitivity analyses identified substantial uncertainty across several key model parameters, thereby rendering its cost-effectiveness inconclusive. This pronounced parameter uncertainty constrains the degree of confidence in healthcare decision-making based on the current evidence base. Nevertheless, these findings highlight the imperative for further empirical research aimed at refining critical clinical and economic inputs, minimizing parameter uncertainty, and enhancing the methodological robustness of subsequent cost-effectiveness analyses.

Abbreviations

CPAP	Continuous positive airway pressure
EDS	Excessive daytime sleepiness
ESS	Epworth Sleepiness Scale
ICER	Incremental cost-effectiveness ratio
MAD	Mandibular advancement device
OR	Odds ratio
OSA	Obstructive sleep apnea
QALY	Quality-adjusted life years
WTP	Willingness-to-pay
SD	Standard deviation
UK	United Kingdom

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Ethics Approval and Consent to Participate

Ethical approval for this study was obtained from the Center for Ethics in Human Research, Khon Kaen University, Thailand (Approval No. HE651157).

Competing Interests

The authors declare no competing interests.

References

1. Kryger Meir, Roth T, Dement WC. Principles and Practice of Sleep Medicine. Philadephia:Saunders;2017.
2. Dempsey JA, Veasey SC, Morgan BJ, O'Donnell CP. Pathophysiology of sleep apnea. Physiol Rev. 2010;90(1):47-112.
3. Morsy NE, Farrag NS, Zaki NFW, Badawy AY, Abdelhafez SA, El-Gilany AH, *et al*. Obstructive sleep apnea: personal, societal, public health, and legal implications. Rev Environ Health. 2019;34(2):153-69.
4. Karimi M, Eder DN, Eskandari D, Zou D, Hedner JA, Grote L. Impaired vigilance and increased accident rate in public transport operators is associated with sleep disorders. Accid Anal Prev. 2013;51:208-14.
5. Philip P, Sagaspe P, Lagarde E, Leger D, Ohayon MM, Bioulac B, *et al*. Sleep disorders and accidental risk in a large group of regular registered highway drivers. Sleep Med. 2010;11(10):973-9.
6. Celikhisar H, Ilkhan GD. Association of presence and severity of obstructive sleep apnoea syndrome with accident risk in city bus drivers. J Pak Med Assoc. 2020; 70(12(A)):2184-9.
7. Tregear S, Reston J, Schoelles K, Phillips B. Obstructive sleep apnea and risk of motor vehicle crash: systematic review and meta-analysis. J Clin Sleep Med. 2009;5(6): 573-81.
8. Zhang T, Chan AH. Sleepiness and the risk of road accidents for professional drivers: a systematic review and meta-analysis of retrospective studies. Saf Sci. 2014;70:180-8.
9. Bioulac S, Micoulaud-Franchi JA, Arnaud M, Sagaspe P, Moore N, Salvo F, *et al*. Risk of motor vehicle accidents related to sleepiness at the wheel: a systematic review and meta-analysis. Sleep. 2017;40(10): doi: 10.1093/sleep/zsx134.
10. Amra B, Dorali R, Mortazavi S, Golshan M, Farajzadegan Z, Fietze I, *et al*. Sleep apnea symptoms and accident risk factors in Persian commercial vehicle drivers. Sleep Breath. 2012;16(1):187-91.
11. Howard ME, Desai AV, Grunstein RR, Hukins C, Armstrong JG, Joffe D, *et al*. Sleepiness, sleep-disordered breathing, and accident risk factors in commercial vehicle drivers. Am J Respir Crit Care Med. 2004;170(9):1014-21.
12. Neruntarat C, Chantapant S. Prevalence of sleep apnea in HRH Princess Maha Chakri Srinthorn Medical Center, Thailand. Sleep Breath. 2011;15(4):641-8.
13. Tregear S, Reston J, Schoelles K, Phillips B. Continuous positive airway pressure reduces risk of motor vehicle crash among drivers with obstructive sleep apnea: systematic review and meta-analysis. Sleep. 2010;33(10):1373-80.
14. Cassel W, Ploch T, Becker C, Dugnus D, Peter JH, Von Wichert P. Risk of traffic accidents in patients with sleep-disordered breathing: Reduction with nasal CPAP. Eur Respir J. 1996;9(12):2606-11.
15. Sawunyavisuth B, Ngamjarus C, Sawanyawisuth K. A meta analysis to identify factors associated with CPAP machine purchasing in patients with obstructive sleep apnea. Biomed Rep. 2022;16(6):1-9.
16. Hoekema A, Stegenga B, Bakker M, Brouwer WH, de Bont LG, Wijkstra PJ, *et al*. Simulated driving in obstructive sleep apnoea–hypopnoea; effects of oral appliances and continuous positive airway pressure. Sleep Breath. 2007;11(3):129-38.
17. Quinnell TG, Bennett M, Jordan J, Clutterbuck-James AL, Davies MG, Smith IE, *et al*. A crossover randomised controlled trial of oral mandibular advancement devices for obstructive sleep apnoea-hypopnoea (TOMADO). Thorax. 2014;69(10):938-45.
18. Ramar K, Dort LC, Katz SG, Lettieri CJ, Harrod CG, Thomas SM, *et al*. Clinical practice guideline for the treatment of obstructive sleep apnea and snoring with oral appliance therapy: an update for 2015: an American academy of sleep medicine and american academy of dental sleep medicine clinical practice guideline. J Clin Sleep Med. 2015;11(7):773-827.
19. Gottlieb DJ, Punjabi NM. Diagnosis and management of obstructive sleep apnea: a review. JAMA. 2020 ;323(14): 1389-400.
20. Road Safety Collaboration. ThaiRSC [Internet]. [cited 2022 Feb 2]. Available from: https://www.thairsc.com/
21. Transport Statistics Sub-Division PDD of LTT. The Number of Driving Licences and Transport Personnel Licences [Internet]. 2022. Available from: https://web.dlt.go.th/statistics/
22. Luzzi V, Mazur M, Guaragna M, Di Carlo G, Cotticelli L, Magliulo G, *et al*. Correlations of obstructive sleep apnea syndrome and daytime sleepiness with the risk of car accidents in adult working population: a systematic review and meta-analysis with a gender-based approach. J Clin Med. 2022;11(14):3971.
23. Middleton JW, Dayton A, Walsh J, Rutkowski SB, Leong G, Duong S. Life expectancy after spinal cord injury: a 50-year study. Spinal Cord. 2012;50(11):803-11.
24. Sittimart M, Butani D, Poonsiri C, Korakot M, Nalongsack M, Chalermkitpanit P, *et al*. Cost-utility analysis of radiofrequency ablation among facet joint-related chronic low back pain patients in Thailand. Pain Physician. 2024 Sep;27(7):E761–73.
25. Uniken Venema JA, Doff MH, Joffe-Sokolova D, Wijkstra PJ, van der Hoeven JH, Stegenga B, *et al*. Long-term obstructive sleep apnea therapy: a 10-year follow-up of mandibular advancement device and continuous positive airway pressure. J Clin Sleep Med. 2020;16(3):353-9.
26. Riewpaiboon A. Standard Cost List for Health Technology Assessment [Internet]. 2009 [cited 2022 Feb 2]. Available from: costingmenu.hitap.net

27. Pradabboon K, Phanthunane P, Pratoomsoot C. The economic cost of road traffic injuries among people receiving social security benefits. BEC Journal. 2011;9(2):109-23.
28. Thailand Consumer Price Index. Available online: https://www.price.moc.go.th/price/cpi/index_new.asp (accessed on 2 Feb 2022).
29. Thailand Consumer Price Index. Available online: https://www.price.moc.go.th/price/cpi/index_new.asp (accessed on 2 Feb 2022).
30. Sadatsafavi M, Marra CA, Ayas NT, Stradling J, Fleetham J. Cost-effectiveness of oral appliances in the treatment of obstructive sleep apnoea–hypopnoea. Sleep Breath. 2009;13:241-52.
31. Jenkinson C, Petersen S, Stradling J. How should we evaluate health status? a comparison of three methods in patients presenting with obstructive sleep apnoea. Qual Life Res. 1998;7:95-100.
32. Currie CJ, McEwan P, Peters JR, Patel TC, Dixon S. The routine collation of health outcomes data from hospital treated subjects in the Health Outcomes Data Repository (HODaR): descriptive analysis from the first 20,000 subjects. Value Health. 2005;8(5):581-90.
33. Graham JD, Thompson KM, Goldie SJ, Segui-Gomez M, Weinstein MC. The cost-effectiveness of air bags by seating position. JAMA. 1997;278(17):1418-25.
34. Banhiran W, Assanasen P, Nopmaneejumrudlers C, Nujchanart N, Srechareon W, Chongkolwatana C, *et al*. Adjustable thermoplastic oral appliance versus positive airway pressure for obstructive sleep apnea. Laryngoscope. 2018;128(2):516-22.
35. Sharples L, Glover M, Clutterbuck-James A, Bennett M, Jordan J, Chadwick R, *et al*. Clinical effectiveness and cost-effectiveness results from the randomised controlled Trial of Oral Mandibular Advancement Devices for Obstructive sleep apnoea-hypopnoea (TOMADO) and long-term economic analysis of oral devices and continuous positive airway pressure. Health Technol Assess. 2014;18(67):1-296.
36. Chaikledkaew U, Kittrongsiri K. Guidelines for health technology assessment in Thailand (second edition)-the development process. J Med Assoc Thai. 2014;97(Suppl 5):S4-9.
37. Briggs A, Sculpher M, Claxton K. Decision modelling for health economic evaluation. Oxford: OUP; 2006.
38. Van Haesendonck G, Dieltjens M, Kastoer C, Shivalkar B, Vrints C, Van De Heyning CM, *et al*. Cardiovascular benefits of oral appliance therapy in obstructive sleep apnea: a systematic review. J Dent Sleep Med. 2015;2(1):9-14.
39. Ou YH, Colpani JT, Chan SP, Loke W, Cheong CS, Kong W, *et al*. Mandibular advancement device versus CPAP in lowering 24-hour blood pressure in patients with obstructive sleep apnoea and hypertension: the CRESCENT trial protocol. BMJ Open. 2023;13(5):e072853.
40. Ou YH, Colpani JT, Cheong CS, Loke W, Thant A tar, Shih EC, *et al*. Mandibular advancement vs CPAP for blood pressure reduction in patients with obstructive sleep apnea. J Am Coll Cardiol. 2024;83(18):1760-72.
41. McDaid C, Griffin S, Weatherly H, Duree K, Van der Burgt M, Van Hout S, *et al*. Continuous positive airway pressure devices for the treatment of obstructive sleep apnoea-hypopnoea syndrome: a systematic review and economic analysis. Health Technol Assess. 2009; 13(4): doi: 10.3310/hta13040.
42. Giannopoulou A, Burgers LT, van Bruggen MP, de Vries N, Redekop WK, Rijnsburger A. Economic evaluation of mandibular advancement device to treat obstructive sleep apnea. Value Health. 2013;16(7):A373.
43. Poullié AI, Cognet M, Gauthier A, Clementz M, Druais S, Späth HM, *et al*. Cost-effectiveness of treatments for mild-to-moderate obstructive sleep apnea in France. Int J Technol Assess Health Care. 2016;32(1-2):37-45.
44. Andre F, AJ HA, Nurit F, Najib A, Ismail L. The public health burden of obstructive sleep apnea. Sleep Sci. 2021;14(3):257–65.