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The Predictive Value of the Triponderal Mass Index in Adult Obstructive Sleep Apnea Severity

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ABSTRACT

Objective: Obesity is the main risk factor for obstructive sleep apnea (OSA). While body mass index (BMI) is the most reliable indicator of obesity, it may not fully reflect metabolic status. This study investigated the predictive value of the triponderal mass index (TMI), which better reflects metabolic rate and obesity in both children and adults, for OSA severity.

Materials and Methods: Medical records of 507 adult patients with clinical suspicion of OSA were retrospectively reviewed. After applying exclusion criteria, 487 records were included. Both BMI and TMI were assessed. The relationships of TMI and BMI with the oxygen desaturation index (ODI), minimum oxygen saturation (minSpO_2), mean oxygen saturation (meanSpO_2), and apnea-hypopnea index (AHI) were analyzed.

Results: The median BMI was 32.1 (20.0–59.9) kg/m^2, and the median TMI was 19.3 (11.4–47.4) kg/m^3. A positive correlation was found between median TMI and OSA severity (r=0.218, p<0.001). BMI showed a significant positive correlation with AHI (r=0.2017, p<0.001), and a similarly strong positive correlation was observed between TMI and AHI (r=0.2441, p<0.001). Receiver operating characteristic curve analysis for predicting severe OSA revealed that BMI (cut-off: 31.28) had a sensitivity of 65.57% and specificity of 63.27%, whereas TMI (cut-off: 17.20) demonstrated higher sensitivity (77.05%) but lower specificity (44.39%).

Conclusion: This is the first study to demonstrate that TMI predicts OSA severity in adults. TMI exhibits high sensitivity for identifying severe OSA, whereas BMI provides a more balanced specificity. These findings pave the way for further research into the role of OSA in children and the significance of TMI in obesity hypoventilation syndrome.

Keywords: Apnea, body mass index, metabolic syndrome, obesity, triponderal mass index (TMI).

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INTRODUCTION

Obstructive sleep apnea (OSA) is a common sleep disorder characterized by collapse of the upper airways and is often accompanied by desaturation and arousal. The apnea-hypopnea index (AHI) is the most critical parameter for diagnosing this condition and for assessing its severity. The primary risk factors for OSA in adults include an increased body mass index (BMI) >30 kg/m^2, advanced age, and a wider neck circumference (>43 cm in men and >38 cm in women).[1] However, OSA can also occur in individuals without these risk factors. Studies have reported that sleep apnea may be associated with dyslipidemia, hypertension, increased body surface area, and impaired glucose tolerance, independent of obesity.[2,3]

Obesity, a chronic disease caused by excessive fat accumulation, leads to various health issues, including altered organ function, particularly in the lungs. Chronic inflammation in adipose tissue may be responsible for the development of OSA, particularly in cases of obesity-related metabolic dysfunction. Obesity significantly affects lung function, explaining its association with lung diseases, particularly OSA and obesity hypoventilation syndrome (OHS).[4,5] BMI, a widely used measure for diagnosing obesity, is associated with AHI in OSA. Additionally, a BMI>30 is a diagnostic criterion for OHS, a clinical condition coexisting with OSA in approximately 90% of cases. However, BMI does not differentiate between fat mass and lean mass or account for the percentage and distribution of fat mass, which are the most significant markers of cardiometabolic risks. Recently, the triponderal mass index (TMI) has been shown to more accurately predict body fat levels than BMI, particularly in adolescents and pediatric populations.[6] Recent studies have demonstrated the utility of TMI in diagnosing obesity in children.[7,8] In a rare study involving adults, TMI was found to significantly predict metabolic syndrome, similar to other indices.[9]

In this study, we aimed to evaluate the effectiveness of TMI in predicting the severity of OSA and to compare its predictive ability with that of BMI.

MATERIALS AND METHODS

This was a retrospective observational study. Patient records of individuals who underwent polysomnography due to suspicion or symptoms of obstructive sleep apnea in the field of chest diseases were analyzed. Polysomnography results of 507 patients over the age of 18 years with clinical suspicion of OSA, evaluated at an adult pulmonology clinic between August 2017 and September 2021, were reviewed. This study complies with the Declaration of Helsinki, and ethics committee approval was obtained from Erciyes University Hospital (ethics committee meeting date: 18.01.2023, decision no: 2023/49).

Anthropometric Measurements

Weight and height were measured under post-void fasting conditions, with patients wearing minimal clothing and no shoes, and standing with feet together. Patients were categorized based on BMI as follows: BMI<25 (normal), BMI 25–29.9 (overweight), and BMI≥30 (obese).[10] TMI was calculated by dividing weight by the cube of height (kg/m^3).

KEY MESSAGES

- This study demonstrates the predictive value of TMI for OSA severity in adults.
- TMI shows superior specificity over BMI, offering more precise screening potential.
- TMI and BMI are correlated with AHI, supporting their relevance in OSA evaluation and metabolic assessment.

Polysomnographic Measurements

Polysomnographic monitored and recorded several physiological indicators, including four-channel electroencephalography (EEG), airflow, body position, submandibular and tibial electromyograms, electrooculograms, electrocardiography, respiratory effort, and arterial oxyhemoglobin saturation (measured via fingertip pulse oximetry) (SpO_2). The sleep studies were conducted using the 64-channel Compumedics E-Series polysomnography (PSG) system (Victoria, Australia).

Patients' minimum oxygen saturation, average oxygen saturation, AHI, and oxygen desaturation index (ODI) were recorded for evaluation. The diagnosis of OSA was made according to the criteria in the International Classification of Sleep Disorders, Third Edition.[11] Patients were categorized into the following groups based on AHI: mild OSA (5/hour ≤ AHI < 15/hour), moderate OSA (15/hour ≤ AHI ≤ 29/hour), and severe OSA (AHI ≥30/hour). The ODI was calculated by dividing the total number of desaturation events by the total sleep time and multiplying the result by 60.

Statistical Methods

Statistical analyses were performed using SPSS software, version 15.0 (Statistical Package for the Social Sciences, SSPS Inc., Chicago, IL, USA). The data distribution was assessed using Shapiro-Wilk test statistics, histograms, and Q-Q plots. Data were presented as mean±standard deviation or as median with minimum–maximum range. Categorical variables were expressed as frequencies and percentages. The Mann-Whitney U test and Kruskal-Wallis test were used to compare data by BMI and TMI for mild, moderate, and severe OSA groups. Receiver operating characteristic (ROC) curve analysis was conducted to evaluate BMI and TMI, with calculations of the area under the curve (AUC), sensitivity, and specificity for predicting OSA severity. Pearson correlation analysis was used to determine associations between variables. A p value below 0.05 was considered statistically significant. Linear regression analyses were also conducted to examine the impact of BMI and TMI on AHI. Separate regression models were developed for each predictor variable, with BMI and TMI treated as independent variables and AHI as the dependent variable.

Table 1. Clinical and demographic variables

	OSA severity			
	Mild (n=60)	Moderate (n=147)	Severe (n=280)	p
Age, mean (SD)	43.7 (9.5)[a]	50.3 (11.5)[b]	54.4 (12.0)[c]	<0.001[A]
Gender				0.383χ^2
Male, n (%)	35 (12.6)	77 (27.7)	166 (59.7)	
Female, n (%)	25 (12.0)	70 (33.5)	114 (54.5)	
BMI, median (min–max)	29.5 (20.0–50.2)[a]	31.2 (20.5–71.1)[b]	33.3 (20.7–59.9)[c]	<0.001[B]
TMI, median (min–max)	17.2 (11.4– 33.0)[a]	19.1 (11.8–47.4)[b]	19.9 (11.7–41.3)[c]	<0.001[B]
AHI, median (min–max)	9.35 (5.4–14.7)[a]	19.7 (15.1–29.9)[b]	62.6 (30–127.8)[c]	<0.001[B]
ODI, median (min–max)	10.9 (3.1–41.8)[a]	23.7 (1.7–50.6)[b]	70.3 (6.6–163.5)[c]	<0.001[B]
Mean SpO_2, median (min–max)	92 (88–96)[a]	92 (81–98)[a]	90 (70–97)[b]	<0.001[B]
Min SpO_2, median (min–max)	85 (63–92)[a]	82 (56–90)[b]	74 (35–95)[c]	<0.001[B]
Obesity status				<0.001χ^2
Normal, n (%)	34 (19.7)	62 (35.8)	77 (44.5)	
Obese, n (%)	26 (8.3)	85 (27.1)	203 (64.6)	

Superscript letters indicate comparisons between groups: identical letters denote no statistically significant difference between the groups, whereas different letters denote statistically significant differences between the groups. BMI: Body mass index; MinSpO_2: Minimum oxygen saturation; MeanSpO_2: Mean oxygen saturation; min: Minimum; max: Maximum; TMI: Triponderal mass index; AHI: Apnea-hypopnea index; ODI: Oxygen desaturation index; OSA: Obstructive sleep apnea; A: Analysis of variance (ANOVA); B: Kruskal-Wallis Test; χ^2: Chi-Square Test; t: t-test.

RESULTS

Demographics

All patients were included in the study except those diagnosed with central apnea, upper airway resistance syndrome (UARS), or AHI<5, resulting in the exclusion of 20 patients. A total of 487 individuals with OSA were included in the study. The mean age of the participants was 51.8±12 years, with 57% being male. There were no significant differences between genders regarding body weight, AHI averages, and ODI values (p=0.054, p=0.261, and p=0.845, respectively). However, the mean age was higher in women than in men (55.3±9.97 vs. 49.2±12.83 years, respectively; p<0.001). The study population included 60 patients with mild OSA, 147 with moderate OSA, and 280 with severe OSA. The median BMI was 32.1 (20.0–59.9) kg/m^2, the median TMI was 19.3 (11.4–47.4) kg/m^3, and the median AHI was 44.1 (5.4–127.8) events/hour. The moderate and severe OSA groups had higher mean ages than the mild OSA group (53.0, 51.3, and 43.7 years, respectively; p<0.001). The median ODI value was higher in the moderate and severe OSA groups than in the mild OSA group (70.3, 23.7, and 10.9, respectively; p<0.001) (Table 1).

BMI and TMI

The groups with moderate and severe OSA had higher median BMI values compared to the mild group [moderate: 31.2 (20.5–71.1), severe: 33.3 (20.7–59.9), mild: 29.5 (20.0–50.2); p<0.001]. Similar to BMI, the mean TMI value was higher in women [21.9 (±5.7)] than in men [17.4 (±3.2)] (p<0.001). The median TMI values were also higher in the moderate and severe OSA groups compared to the mild group [moderate: 19.9 (11.7–41.3), severe: 19.1 (11.8–47.4), mild: 17.2 (11.4–33.0); p<0.001] (Table 1). The ROC analysis was conducted for both BMI and TMI to predict severe OSA (Fig. 1). The ROC analysis for predicting severe OSA showed that BMI, with a cutoff value of 31.28, had a sensitivity of 65.57%, a specificity of 63.27%, positive predictive value (PPV) of 73.53%, and negative predictive value (NPV) of 54.15%. In comparison, TMI, with a cutoff value of 17.20, demonstrated a higher sensitivity of 77.05% but a lower specificity of 44.39%, with PPV of 68.31% and NPV of 55.41%. While TMI was more sensitive in detecting severe OSA, BMI provided better-balanced specificity, making both indices useful but not definitive on their own (Table 2).

The post hoc power analysis for the t-test, performed using G*Power 3.1.9.4, showed a power of 0.9999 with an effect size of 0.49 and sample sizes of 196 and 305. This indicates that the study was highly powered to detect differences in TMI between the severe and non-severe OSA groups (Table 3).

There was a positive, weak, and statistically significant correlation between TMI and ODI (r=0.2828, p<0.001). A negative, moderate, and statistically significant correlation was observed between TMI and mean oxygen saturation (meanSpO_2) (r=-

Table 2. Sensitivity, specificity, PPV, and NPV of BMI and TMI in predicting severe OSA

Variable	Cut-off	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
BMI	31.28	65.57	63.27	73.53	54.15
TMI	17.20	77.05	44.39	68.31	55.41

OSA: Obstructive sleep apnea; BMI: Body mass index; TMI: Triponderal mass index; PPV: Positive predictive value; NPV: Negative predictive value.

Table 3. Post-power test results of the study

Test	Effect size (d)	Sample size (severe OSA)	Sample size (non-severe OSA)	Power
t-test	0.49	196	305	0.9999

OSA: Obstructive sleep apnea.

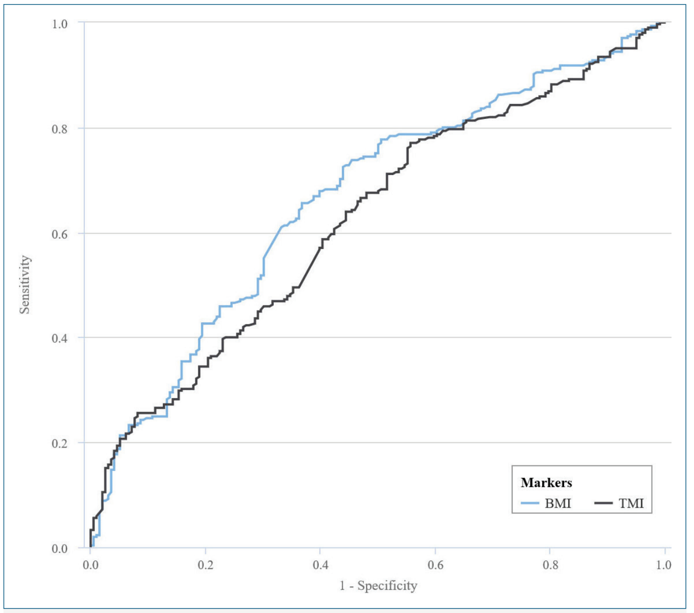

Figure 1. Specificity and sensitivity of the triponderal mass index (TMI) and body mass index (BMI) in the severe obstructive sleep apnea (OSA) group, as determined by receiver operating characteristic (ROC) analysis.

0.4414, $p<0.001$) and minSpO_2 ($r=-0.3944$, $p<0.001$). Similarly, a negative and statistically significant correlation was found between BMI and meanSpO_2 ($r=-0.4582$, $p<0.001$) and minSpO_2 ($r=-0.4025$, $p<0.001$). Additionally, a positive and statistically significant correlation existed between BMI and AHI ($r=0.2017$, $p<0.001$). Like BMI, TMI also showed a positive and statistically significant correlation with AHI ($r=0.2441$, $p<0.001$).

To further investigate the effects of BMI and TMI on AHI, linear regression analyses were performed. The model for BMI demonstrated that each unit increase in BMI was associated with an average increase of 1.42 units in AHI (coefficient =1.42). Similarly, the model for TMI showed that each unit increase in TMI corresponded to an average increase of 1.74 units in AHI (coefficient =1.74) (Table 4). These findings indicate that both BMI and TMI positively influenced AHI, with TMI exerting a slightly stronger effect.

Correlation analysis revealed significant associations between TMI, BMI, and AHI, ODI, and oxygen saturation levels. Both TMI and BMI exhibited moderate positive correlations with AHI, whereas negative correlations were observed with mean and minimum SpO_2. Binary logistic regression further identified BMI, TMI, and ODI as independent predictors of OSA-related outcomes, with significant odds ratios underscoring their predictive value (Table 4).

DISCUSSION

This study found that TMI effectively correlated with BMI and indices such as ODI, minSpO_2, meanSpO_2, and AHI across all groups, offering better predictions of body fat levels in adults. While BMI showed slightly stronger correlations with minSpO_2 and meanSpO_2 values, TMI demonstrated a stronger correlation with AHI, reflecting its utility in assessing OSA severity.

Previous research has highlighted that changes in BMI have significant positive clinical effects on the cardio-metabolic risk factors of OSA.[1] Despite limited data, dietary modification, important determinants of “metabolic status” in OSA patients, are often emphasized. Studies report that approximately 60–70% of OSA patients fall into the obese category with a BMI greater than 30 kg/m^2.[12] Increasing BMI is predictive of increased AHI, indicating higher OSA severity.[12] A one-unit reduction in BMI can result in a decrease of more than 2.8 events/hour in AHI. Additionally, a 10% increase in body weight can elevate AHI by an average of 30%, whereas a 10–15% reduction in body weight may decrease AHI by up to

Table 4a. The correlation coefficients (r), p values, and regression coefficients show the relationships between TMI, BMI, and various parameters, including AHI, ODI, mean SpO_2, and minimum SpO_2

Variable	Correlation (r)	p	Regression coefficient
TMI vs ODI	0.2828	<0.001	–
TMI vs mean SpO_2	-0.4414	<0.001	–
TMI vs min SpO_2	-0.3944	<0.001	–
BMI vs mean SpO_2	-0.4582	<0.001	–
BMI vs min SpO_2	-0.4025	<0.001	–
BMI vs AHI	0.2017	<0.001	1.42
TMI vs AHI	0.2441	<0.001	1.74

Table 4b. Binary logistic regression analysis demonstrating the OR and 95% CI for BMI, TMI, ODI, mean SpO_2, and minimum SpO_2, along with their significance levels in predicting OSA-related outcomes

Variable	Binary logistic			Backward: Wald		
	OR	%95 CI	p	OR	%95 CI	p
BMI	0.941	0.915–0.969	<0.001	1.084	1.012–1.161	0.021
TMI	0.942	0.832–0.969	<0.001			
ODI	0.796	0.756–0.839	<0.001	0.784	0.740–0.830	<0.001
Mean SpO_2	1.507	1.365–1.664	<0.001			
Min SpO_2	1.191	1.149–1.234	<0.001			

OSA: Obstructive sleep apnea; TMI: Triponderal mass index; ODI: Oxygen desaturation index; meanSpO_2: Mean oxygen saturation; minSpO_2: Minimum oxygen saturation; BMI: Body mass index; AHI: Apnea-hypopnea index; OR: Odds ratio; CI: Confidence interval.

50%.[13] Currently, there is no published literature on the role of TMI in OSA. BMI increased rapidly after birth, peaked at 12 months, and gradually declined thereafter. Children's BMI reaches its lowest point between the ages of 3 and 8 years, after which it begins a second phase of increase toward adult BMI levels. For these reasons, TMI in children and adolescents has become a more established research topic.[14]

Recent data indicate that half of the individuals with OSA are obese, and sleep apnea affects about 40% of individuals who are moderately overweight.[15] In our study, 64.4% of patients had a BMI greater than 30 kg/m^2. The higher occurrence is attributed to the fact that polysomnographic assessments were conducted on symptomatic patients. A clear cutoff value for the TMI in obesity studies has not yet been established.

Although ODI, minSpO_2, and meanSpO_2 are commonly used metrics in research, AHI remains the most widely accepted parameter for assessing the severity of OSA. Our findings demonstrate that TMI is as sensitive as BMI in predicting OSA severity in this population. TMI, like BMI, appears to be effective in predicting disease severity in adults with OSA. In our study, although BMI demonstrated a stronger correlation with minSpO_2, meanSpO_2, and ODI based on the 'r' values compared to TMI, TMI exhibited a stronger correlation with AHI, which is considered the most accepted parameter for assessing OSA severity. This finding could be attributed to the continuing limitations of parametric indices in accurately reflecting the severity of OSA.

Although widely used, BMI is recognized as an inadequate measurement of obesity. As a result, improved measures of body composition and adiposity have been developed to better predict metabolic risk.[16] Obesity is a component of the metabolic syndrome (MetS), which encompasses a cluster of metabolic disorders. Metabolic syndrome is associated with high mortality and morbidity when at least three of the following conditions are present: central obesity, hypertension, low high-density lipoprotein cholesterol, hypertriglyceridemia, and elevated fasting plasma glucose.[17] MetS is also observed at a higher rate in obese individuals and OSA patients.[18] In a study investigating MetS in adults, the mean cutoff values defining the risk for MetS were BMI: 47.9 and TMI: 28.2. In this context TMI was found to be more predictive than the fat mass.[19] However, in our study, patients were not screened for MetS, which represents one of the limitations of our research.

With rising rates of cardiovascular disease among patients with OSA, potentially linked to dyslipidemia, a meta-analysis highlights the elevated cardiovascular risks, particularly stroke.[19,20] Our study did not evaluate cardiometabolic risks in patients, underscoring the need for research comparing the predictive value of TMI and BMI for such risks.

Despite numerous dietary studies, non-randomized behaviorally assisted therapies lack sufficient evidence, particularly in combination with positive airway pressure (PAP) therapy. Additionally, more data on the potential comorbidities affecting study subjects are needed. OSA outcomes may also vary by ethnicity; however, our study focused on the Asian population.

We used AHI, ODI, meanSpO_2, and minSpO_2 to assess the burden of sleep disturbances. Future studies should explore the relationship between TMI and cardiovascular risks. While a BMI>30 has become a diagnostic criterion for OHS, could a cut-off value for TMI be identified and incorporated into the diagnostic criteria? However, this requires further investigation.

Our study has certain limitations. Primarily, it is a retrospective, single-center investigation. The evaluation of whether patients had metabolic syndrome and the assessment of associated cardiovascular and endocrine conditions were not possible due to the lack of data.

CONCLUSION

This study is the first to demonstrate the potential of TMI in predicting OSA severity in adults. It paves the way for further research into the role of TMI in assessing OSA severity in obese children and its potential inclusion in the diagnostic criteria for OHS.

Ethics Committee Approval: The Erciyes University Clinical Research Ethics Committee granted approval for this study (date: 18.01.2023, number: 2023/49).

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