Sakarya Tıp Dergisi
Sakarya Med J

e-ISSN: 2146-409X
Publisher: Sakarya University

Vol. 15, No. 3, 218-226, 2025
DOI: http://doi.org/10.31832/smj.1698739

Research Article

The Clinical Role of the Thiol-Disulfide Balance as an Oxidative Stress Indicator in Patients with Obesity

Soner Yeşilyurt[1*], Osman Erinç[2], Türker Demirtakan[3], Almila Şenat[4], Esra Fırat Oğuz[5], Nihat Müjdat Hökenek[6], Özcan Erel[5]

[1] Taksim Education and Research Hospital, Internal Medicine Clinic, Istanbul, Türkiye, yesilyurtsoner@gmail.com, ror.org/05qvd2e93

[2] Kanuni Sultan Süleyman Education and Research Hospital, Internal Medicine Clinic, Istanbul, Türkiye, doctorerinc@gmail.com, ror.org/05jxvg504

[3] Taksim Education and Research Hospital, Emergency Medicine Clinic, Istanbul, Türkiye, turkerdemirtakan@gmail.com, ror.org/05qvd2e93

[4] Taksim Education and Research Hospital, Biochemistry Clinic, Istanbul, Türkiye, almilasenat@gmail.com, ror.org/05qvd2e93

[5] Yıldırım Beyazıt University, Department of Biochemistry, Ankara, Türkiye, dr_esrafirat@hotmail.com, erelozcan@gmail.com ror.org/05ryemn72

[6] Başakşehir Pine and Sakura City Hospital, Emergency Medicine Clinic, Istanbul, Türkiye, nihathokenek@gmail.com, ror.org/05grcz969

* Corresponding Author

Received: 14.05.2025
Accepted: 26.06.2025
Available Online: 15.09.2025

Objectives: Thiol-disulfide measurements will assess obesity-related oxidative stress.

Methods: A prospective observational study was done at two tertiary care centers. The participants were divided into three distinct categories based on their body mass index (BMI): The control group (Group 1) consisted of 116 individuals with a BMI ranging from 18 to 25 kg/m^2, while the overweight group (Group 2, n = 89) included those with a BMI between 25 and 30 kg/m^2. The obese group (Group 3, n = 39) comprised individuals with a BMI of 30 kg/m^2 or greater. This approach primarily utilizes the disulfide/native thiol ratio, disulfide/total thiol ratio, and native thiol/total thiol ratio as key metrics. All patients' demographics, waist circumference, hip circumference, height, weight, hemoglobin, hematocrit, white blood cell count, glucose, C-reactive protein, disulfide, native thiol (NT), total thiol (TT), lipid hydroperoxide radical (LOOH), and absolute ischemia-modified-albumin (ABSO) levels were recorded on calculations and records were made for disulfide to native and total thiol ratios.

Results: Thiol-disulfide equilibrium differed between the three groups. NT concentrations averaged 368.87 µmol/L across all individuals and were significantly higher in the normal-weight cohort (BMI 18-25 kg/m2) at 380.60 µmol/L, compared to overweight and obese populations (p<0.001). TT concentrations were higher in normal-weight individuals, with an average of 426.36±54.48 µmol/L, compared to 405.41±52.14 and 391.07±46.45 in overweight and obese individuals, respectively (p<0.001).

Conclusions: Reduced native and total thiol levels, along with altered disulfide concentrations in obese individuals, serve as indicators of oxidative stress.

Keywords: Thiol disulfide balance, Inflammatory markers, Oxidative stress, Obesity

1. INTRODUCTION

Obesity is characterized by an excessive accumulation of adipose tissue that negatively affects health, as defined by the World Health Organization (WHO).[1] This condition has escalated into a significant global public health challenge, with a rapidly increasing prevalence worldwide.[2] In the United States, obesity prevalence reached 42.4% during the period from 2017 to 2020, and this trend has been rising steadily.[3] Moreover, in 2019, approximately 5 million deaths globally were attributed to complications associated with obesity.[4] Projections indicate that by 2030, obesity could affect up to 50% of the global population.[5]

The assessment of obesity is predominantly determined by the Body Mass Index (BMI). Obesity is primarily evaluated using the BMI, which is calculated by dividing an individual's weight in kilograms by the square of their height in meters. The WHO classifies BMI as follows: A BMI ranging from 18.5 to 24.9 is deemed normal weight, 25 to 29.9 is defined as overweight (pre-obesity), and a BMI of 30 or more is categorized as obese.[6] However, BMI does not account for variations in body fat distribution and can be misleading, particularly in individuals with high muscle mass.[7]

Current guidelines suggest incorporating additional anthropometric measurements, such as

Cite as: Yeşilyurt S, Erinç O, Demirtakan T, et al. The clinical role of the thiol-disulfide balance as an oxidative stress indicator in patients with obesity. *Sakarya Med J.* 2025;15(3):218-226. doi:10.31832/smj.1698739

waist circumference and waist-to-hip ratio, alongside BMI for a more comprehensive assessment of obesity. Waist circumference is particularly important for evaluating abdominal fat, which is a key indicator of metabolic risk associated with obesity. According to the 2020 guidelines from the American College of Cardiology and the American Heart Association (ACC/AHA), a waist circumference exceeding 102 cm in men and 88 cm in women is associated with an increased risk of cardiovascular disease and metabolic disorders.[8]

The accumulation of adipose tissue in obesity significantly elevates oxidative stress levels. Excessive adiposity induces increased generation of reactive oxygen species (ROS), causing cellular damage and inflammation.[9] This oxidative stress exacerbates insulin resistance and accelerates the onset of metabolic disorders related to obesity.[10] The chronic low-grade inflammation associated with obesity weakens antioxidant defense mechanisms, leading to the accumulation of oxidative damage.[11] Recent literature indicates that addressing obesity may reduce oxidative stress and enhance metabolic health.[12,13]

The thiol-disulfide system is essential for preserving cellular redox balance and controlling oxidative stress.[14] Thiol groups (-SH) are organic compounds containing a sulfur atom covalently bonded to a hydrogen atom, and are predominantly found in proteins. When these thiol groups encounter oxidative agents such as free radicals or ROS, they become oxidized, forming disulfide bonds (-S-S-) between two thiol groups.[15] This dynamic process helps maintain equilibrium and mitigate oxidative damage in both intracellular and extracellular spaces.[16]

The thiol-disulfide balance entails the oxidation of thiol groups into disulfide bonds under oxidative stress and their subsequent reduction back to thiol groups as oxidative stress subsides. This cycle reflects the cells' ability to manage oxidative stress and disruptions in this balance have been linked to metabolic disorders, inflammation and obesity.[17] Disruption of this balance results in heightened oxidative damage and inflammation, potentially contributing to the onset of various chronic diseases.[18]

Another oxidative stress biomarker, ischemia-modified albumin (IMA), forms through structural modifications in albumin molecules under ischemic conditions and holds a crucial role in assessing circulating oxidative stress levels.[19] Additionally, lipid hydroperoxides (LOOH) are lipid oxidation products resulting from oxidative stress, which compromise cell membrane integrity and negatively impact cellular functions.[20] These biomarkers are essential for identifying oxidative damage associated with obesity and for evaluating metabolic risks.[21]

The main objective of this study is to investigate the association between oxidative stress—evaluated through thiol-disulfide homeostasis, ischemia-modified albumin (IMA), and lipid hydroperoxides (LOOH)—and different Body Mass Index (BMI) categories in the context of obesity. Secondary outcomes include associations between thiol-disulfide homeostasis, IMA, and LOOH with waist circumference, waist-to-hip ratio, and waist-to-height ratio. This comprehensive approach will provide valuable insights into the oxidative mechanisms underlying obesity-related metabolic risks.

2. MATERIALS AND METHODS

The study was conducted as a prospective, multicenter observational investigation. The participating centers were Taksim Training and Research Hospital and Yıldırım Beyazıt University Hospital. Patients included in the study were enrolled over a six-month period, from November 2023 to April 2024. Approval from the Taksim Training and Research Hospital institution's ethics committee was obtained for the study (IRB date: 25.10.2023 no: 120).

2.1. Participants

The inclusion criteria were set as patients aged 18-99 without any chronic diseases. Patients who presented to the internal medicine outpatient clinic at Taksim Training and Research Hospital for routine check-ups, without any significant complaints and having fasted for 8-12 hours, were enrolled in the study. Patients with no findings of anemia, vitamin deficiency, or hormonal abnormalities in routine analyses were considered eligible. All patients were apprised

about the study and their informed consent was obtained. The exclusion criteria included pregnant women, those with a history of malignancy, patients who had undergone major surgery, and those with musculoskeletal deformities causing postural abnormalities.

Demographic data, waist circumference, hip circumference, height, weight, hemoglobin, hematocrit, white blood cell count, glucose, C-reactive protein, disulfide, native thiol (NT), total thiol (TT), lipid hydroperoxide radical (LOOH), and absolute ischemia-modified albumin (IMA_{ABSO}) levels of all patients were recorded on a data form. The ratios of disulfide to native thiol and disulfide to total thiol were also calculated and recorded. We categorized patients into three groups based on their BMI, following the guidelines established by the American Association of Clinical Endocrinologists: BMI categories include 18-25 kg/m^2, 25-29.9 kg/m^2, and over 30 kg/m^2.[22]

2.2. Sample collection and laboratory analysis

A 10 ml antecubital blood was taken following an 8-12 hour fasting period to evaluate thiol and disulfide levels. The samples underwent centrifugation at 1500 rpm for 10 minutes to isolate plasma and serum. Plasma samples were preserved at -80°C prior to analysis. The materials were thereafter transported through a cold route to the laboratory at XXX Hospital, in accordance with biological material transfer protocols. The thiol/disulfide measurement technique used in the study was developed by Erel et al. and is frequently cited in the current literature.[23] Thiol/disulfide levels were analyzed via Cobas 501, Roche analyzer and reported in micromoles per liter (µmol/L). This technique entails the conversion of dynamic disulfide bonds (-S-S-) into functional thiol groups (-SH) through reduction with sodium borohydride (NaBH4). Excess NaBH4 is neutralized with formaldehyde. Total thiol content is determined by modifying the Ellman reagent and measuring it spectrophotometrically at 415 nm. The concentration of native thiol is directly quantified using the modified Ellman substance, while the disparity between total thiol and native thiol is utilized to calculate the concentration of disulfide bonds (disulfide = [total thiol-native thiol] / 2). The key parameters obtained from this method are the ([-S-S-]/[-SH]), ([-S-S-]/ [total thiol]), and the ([-SH]/ [total thiol]).

IMA levels were measured using the albumin cobalt-binding (ACB) test, which assesses the reduced binding capacity of albumin to cobalt in ischemic conditions and were expressed in absorbance units (ABU).[24] LOOH concentrations were calculated with the ferrous oxidation-xylenol orange (FOX) test, a sensitive method for quantifying lipid hydroperoxides, and were expressed in micromoles per liter (µmol/L).[25]

2.3. Statistical analysis

Hypothesis tests were performed to compare variables among normal-weight, overweight, and obese groups. Categorical variables were expressed as frequencies and percentages. The Kolmogorov-Smirnov test was utilized to assess the normality of the data. Numerical variables following a normal distribution were reported as mean and standard deviation (SD), whereas those not normally distributed were presented as median and interquartile range (IQR). The Pearson Chi-square test was used to evaluate categorical variables. One-way ANOVA was applied for comparing normally distributed numerical variables. Post-hoc analyses were performed using either Dunnett or Tukey tests, depending on variance homogeneity. The Kruskal-Wallis test was employed for numerical variables that did not follow a normal distribution across the three groups, while the Mann-Whitney U test was used for pairwise comparisons. This study particularly examined the clinical significance of inflammatory biomarkers in obesity. Receiver operating characteristic (ROC) analysis was conducted to determine the sensitivity and specificity of inflammatory biomarkers in relation to obesity. The area under the curve (AUC) for each variable was assessed using ROC curves. All statistical analyses were performed at a 95% confidence interval with a significance level of 0.05. Data analysis was carried out using IBM SPSS Version 26 (IBM, Chicago, IL, USA).

3. RESULTS

A total of 244 patients were divided into three groups according to BMI: 116 patients between

18-25 kg/m^2 were classified as the control group (Group 1), 89 patients were overweight (Group 2), and those with a BMI of 30 kg/m^2 and above were classified as obese (Group 3, n=39). The average age of all study population was 36.95 (±12.78) years. A notable distinction was observed among the groups, with the average age of obese group 46.48 (±9.32) years, significantly higher than in other groups (p=0.001) (Table 1).

In the obese group (BMI ≥ 30), the average waist circumference was 101.64±11.72 cm, while it was 90.73±8.98 cm in group 2 and 75.32±8.34 cm in group 1 (p<0.001). Similarly, waist-to-hip and waist-to-height ratios also increased significantly with higher BMI. Fasting blood glucose levels were measured as 100.25±14.43 mg/dL across all patients (p=0.067). In terms of general inflammation markers, no significant differences in CRP or WBC levels were found among the groups (Table 1).

The average NT level across all patients was 368.87 μmol/L. In group, the NT level was significantly higher, at 380.60 μmol/L, compared to the overweight and obese groups (p<0.001). Similarly, TT values were higher in normal-weight individuals; the mean TT level in group 1 was 426.36±54.48 μmol/L, compared to 405.41±52.14 μmol/L in group 2 and 391.07±46.45 μmol/L in group 3 (p<0.001). Post-hoc analysis revealed that the TT level in the normal-weight group was significantly higher than in both the overweight and obese groups, although no difference was observed between the overweight and obese groups (Table 1).

Table 1.

Clinical characteristics, antropometric measurements, and oxidative biomarkers comparison of the study population

	Total N=244	**Group 1 n=116**	**Group 2 n=89**	**Group 3 n=39**	*P*
Age	36,95±12,78	31,07±11,23[2,3]	40,77±12,16[1,3]	46,48±9[1,2]	**0,001**
Female gender, n (%)	123 (50.4%)	59 (49.6%)	38 (44.2%)	26 (66.7%)	0,064
Weight, kg	72,95±16,52	61,86±9,66[2,3]	78,50±9,37[1,3]	94,53±18,04[1,2]	**<0.001**
Height, cm	168,51±9,61	168,71±9,15	168,72±9,49	165,51±10,95	0,162
Waistline, cm	84,96±13,61	75,32±8,34[2,3]	90,73±8,98[1,3]	101,64±11,72[1,2]	**<0.001**
Hip Circumference, cm	101,24±10,18	94,66±6,36[2,3]	103,91±5,61[1,3]	115,43±10,39[1,2]	**<0.001**
Waist/hip ratio	0,83±0,09	0,79±0,08	0,87±0,07	0,88±0,09	**<0.001**
Waist/height ratio	0,50±0,09	0,44±0,04	0,54±0,10	0,61±0,06	**<0.001**
Glucose, mg/dl	100,25±14,43	90,08±6,86	93,34±12,38	101,11±14,48	0,067
Hb, g/dl	13,61±1,70	13,54±1,80	13,89±1,63	13,40±1,50	0,218
CRP, mg/L	1,75 (1,83)	0,82 (1,41)	1,44 (1,53)	3,00 (2,56)	0,632*
WBC, 10^3/μL	7,37±1,93	7,30±2,17	7,39±1,75	7,56±1,50	0,757
NT, μmol/L	368,87±51,43	380,60±53,19[2,3]	360,84±48,22[1]	350,79±44,86[1]	**0,001**
TT, μmol/L	413,34±53,99	426,36±54,48[2,3]	405,41±52,14[1]	391,07±46,45[1]	**<0,001**
Disulfide, μmol/L	22,23±5,86	22,87±6,05[3]	22,28±5,67	20,14±5,39[1]	**0,040**
Disülfide/NT ratio	5,83±1,70	0,061±0,018	0,063±0,016	0,058±0,017	0,485
Disülfide/TT ratio	5,41±1,39	0,054±0,014	0,055±0,012	0,051±0,013	0,476
NT/TT ratio	89,16±2,78	0,89±0,29	0,88±0,25	0,89±0,27	0,475
IMA ABSO	0,90±0,22	0,94±0,21[3]	0,86±0,22	0,86±0,23[1]	**0,036**
LOOH	4,92±0,38	4,90±0,40	4,92±0,29	4,98±0,50	0,528

Hb: Hemoglobin; CRP: C reactive protein; WBC: white blood cell; NT: native thiol; TT: total thiol IMA ABSO: ischemia modified albümin absolute; LOOH: lipid hydroperoxides.

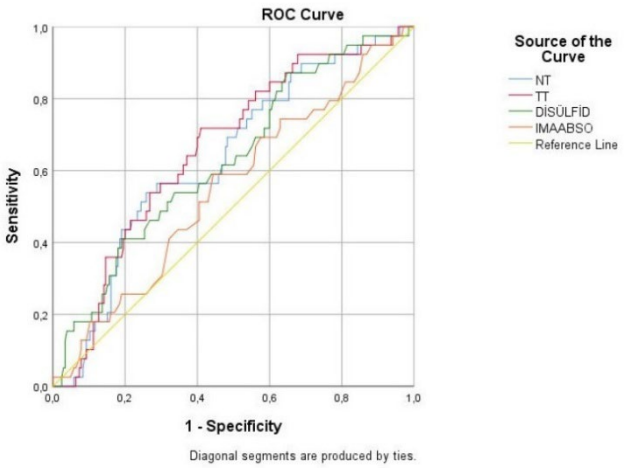
- * Kruskal-Wallis test was used to compare the group variables
- Other comparison were analysed with one-way ANOVA test
- [1]: Significant difference was detected with group 1 according to post-hoc tests
- [2]: Significant difference was detected with group 2 according to post-hoc tests
- [3]: Significant difference was detected with group 3 according to post-hoc tests

Disulfide levels were measured as 22.23±5.86 µmol/L across the study population. In group 1, the average disulfide level was 22.87±6.05 µmol/L, while it was 22.28±5.67 µmol/L in group 2 and 20.14±5.39 µmol/L in group 3. Significant differences in disulfide levels were found between the groups, with post-hoc analysis showing that the normal-weight group had significantly higher disulfide levels than the obese group (p=0.040). However, no significant differences were found between the groups regarding the disulfide/total thiol and disulfide/native thiol ratios.

Other biochemical markers, including IMA_{ABSO} and LOOH, were also examined. The average IMA ABSO value across all patients was 0.90±0.22, and the mean LOOH level was 4.92±0.38 µmol/L. IMA_{ABSO} levels differed significantly between the three groups, with values of 0.94±0.21, 0.86±0.22, and 0.86±0.23, respectively (p=0.036). However, no significant variations in LOOH levels were observed among the groups. ROC analysis supports these findings, with NT (AUC: 0.634, p=0.008), TT (AUC: 0.660, p=0.002), and disulfide (AUC: 0.629, p=0.010) values being significantly associated with obesity. Notably, lower NT, TT, and disulfide levels were more strongly related to obesity (Figure 1, Table 2).

Figure 1.

ROC curve and ROC analyses of the oxidative biomarkers



NT: Native Thiol, TT: Total Thiol, IMAABSO: Ischemia modified albümin

Table 2.

Area under curve of study variables

	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval Lower Bound	Upper Bound
NT	,634	,046	,008	,544	,725
TT	,660	,045	,002	,572	,747
Disulfide	,629	,048	,010	,536	,723
IMAabso	,550	,050	,319	,453	,648

The test result variable(s): NT: native thiol; TT: total thiol; IMA_{abso}: ischemia modified albümin.
a. Under the nonparametric assumption
b. Null hypothesis: true area = 0.5

4. DISCUSSION

This study clearly demonstrates that oxidative stress increases in obesity. The key outcome of our study indicates that an imbalance in the thiol/disulfide system is linked to heightened oxidative stress and a reduction in antioxidant capacity among obese individuals.

Of the total patients, 50.4% were female, and 49.6% were male, indicating a balanced gender distribution across groups. A notable variation was observed among the groups, with the obese group having a mean age of 46.48 (±9.32) years, which was significantly higher compared to the other groups (p=0.001). This result underscores the link between obesity and aging, indicating that the likelihood of obesity rises with advancing age.

Oxidative stress plays a major role in the development of chronic diseases and is further aggravated by conditions like obesity.[26] Oklu et al. demonstrated that the thiol-disulfide balance is impaired in obese individuals, with this disruption

becoming more evident as BMI increases.[27] Likewise, studies have shown that the thiol-disulfide balance is impaired in obese children, with this imbalance being inversely correlated with BMI.[28] These results are consistent with studies emphasizing the link between obesity and elevated oxidative stress. Moreover, oxidative stress has been reported to be linked to heightened adipokine secretion, further disturbing the oxidative balance.[29] Our study revealed a significant decline in native and total thiol levels as BMI increased, reinforcing the evidence that oxidative stress levels are elevated in obese individuals. These results suggest that the thiol-disulfide balance could serve as an early indicator of chronic diseases associated with obesity.

CRP levels have been closely linked to obesity in the literature and are considered a marker of inflammation. A positive association has been identified between visceral adipose tissue and CRP levels in obese individuals, indicating a link to heightened inflammation.[30] Van Wijk et al. also demonstrated that CRP is a biomarker of the inflammatory processes related to obesity, which are linked to cardiovascular risks.[31] However, in our study, no significant differences in CRP levels were observed among the groups. This suggests that the participants in our study might be in a stage where chronic inflammation has not yet become clinically apparent. Moreover, the fact that all participants were healthy individuals without any health problems other than obesity could explain this. Individual differences and the impact of genetic factors on the inflammatory response may also have contributed to this outcome.[32]

In our study, disulfide levels—another marker of oxidative stress—were assessed and found to be lower in the obese group. Mengen et al. identified reduced disulfide levels in obese individuals as a sign of heightened oxidative stress.[33] Similarly, Elkan et al. indicated that the reduction in disulfide levels in obese individuals suggests that the antioxidant defense systems are insufficient.[34] These findings highlight that disulfide levels could be an early marker of oxidative stress related to obesity.

Numerous studies have highlighted the significance of anthropometric measurements, including waist circumference, waist-to-hip ratio, and waist-to-height ratio, in relation to obesity. A meta-analysis by De Koning et al. established that an increase in waist circumference serves as a strong predictor of cardiovascular events and has a direct association with oxidative stress.[35] These findings underscore that obesity is not merely an increase in weight but is also associated with fat accumulation and changes in the metabolic functions of adipose tissue.[36] Likewise, in our study, these anthropometric measurements were notably higher in individuals with elevated BMI, correlating with oxidative stress. The literature extensively documents that an increase in visceral fat tissue stimulates oxidative stress by promoting the release of free fatty acids and inflammatory cytokines.[37] These findings demonstrate the marked increase in abdominal obesity with rising BMI, highlighting potential health risks associated with central fat accumulation.

Ischemia-modified albumin (IMA) is a commonly utilized biomarker for assessing oxidative stress. Piva et al. demonstrated that elevated oxidative stress in obese individuals results in alterations in IMA levels.[38] The study demonstrated that IMA levels were significantly reduced in obese individuals, emphasizing the potential impact of oxidative stress on albumin structure. Mehmetoglu et al. also indicated that IMA levels are associated with obesity, and increased oxidative stress in these individuals results in changes in albumin structure.[39]

This study possesses multiple shortcomings that warrant acknowledgment. The observational approach restricts the capacity to deduce causality between oxidative stress and obesity. Longitudinal studies are needed to establish a clear temporal relationship. Second, the sample size, while adequate for preliminary analysis, may not fully represent the diverse population affected by obesity, potentially limiting the generalizability of the findings. Additionally, the exclusion of individuals with chronic diseases may have led to a selection bias, as the inflammatory responses in these patients could differ significantly from those without such conditions. Moreover, using BMI as

the sole indicator of obesity overlooks differences in body composition and fat distribution. Incorporating additional metrics, such as body fat percentage or bioelectrical impedance analysis, could offer a more comprehensive evaluation. Finally, while the study utilized established laboratory techniques for measuring thiol and disulfide levels, variations in laboratory protocols and individual biological variability could affect the reproducibility of the findings.

5. CONCLUSIONS

In conclusion, this study highlights a significant association between obesity and oxidative stress, as evidenced by the disruption of thiol-disulfide balance among different BMI categories. The results indicate that decreased native and total thiol levels, along with modifications in disulfide levels, serve as markers of heightened oxidative stress in obese individuals. This imbalance may play a role in the development of various metabolic disorders linked to obesity, highlighting the necessity for further research to investigate thiol-disulfide balance as a potential biomarker for oxidative stress and inflammation. Given the rising global obesity epidemic, strategies aimed at reducing oxidative stress may be beneficial in preventing and managing obesity-related health complications. Future studies should investigate the efficacy of interventions targeting oxidative stress in improving metabolic health and mitigating the risks associated with obesity.

Article Information Form

Authors' Contribution

All authors jointly conceived and designed the study. SY, OE, AS, and EFO contributed to data collection. SY, TD, NMH, EFO, and OE were involved in data analysis and interpretation. The manuscript draft was written by SY, TD, and NMH. Technical and material support was provided by SY, OE, AS, and OE. All authors critically revised the content. Literature review was conducted by SY, OE, and AS. All authors reviewed the final results and approved the final version of the manuscript.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by authors.

The Declaration of Ethics Committee Approval

Approval from the Taksim Training and Research Hospital Ethics Committee was obtained for the study (IRB date: 25.10.2023, no: 120).

Artificial Intelligence Statement

No artificial intelligence tools were used while writing this article.

Copyright Statement

REFERENCES

1. World Health Organization (2024) Obesity and overweight.
2. World Health Organization (2014) Global status report on noncommunicable diseases 2014.
3. Hales CM, Carroll MD, Fryar CD, Ogden CL. Prevalence of obesity among adults and youth: United States, 2015-2016. *NCHS Data Brief.* 2017;(288):1-8.
4. Global Nutrition Target Collaborators. Global, regional, and national progress towards the 2030 global nutrition targets and forecasts to 2050: A systematic analysis for the Global Burden of Disease Study 2021. *Lancet.* 2025;404(10471):2543-2583.
5. Finkelstein EA, Khavjou OA, Thompson H, et al. Obesity and severe obesity forecasts through 2030. *Am J Prev Med.* 2012;42(6):563-570.
6. World Health Organization (2020). WHO guidelines on physical activity and sedentary behaviour.
7. Freigang R, Geier AK, Schmid GL, Frese T, Klement A, Unverzagt S. Misclassification of self-reported body mass index categories. *Dtsch Arztebl Int.* 2020;117(15):253-260.
8. American College of Cardiology, American Heart Association (2020) 2020 AHA/ACC guideline on the assessment of cardiovascular risk. Available from:

https://www.jacc.org/doi/full/10.1016/j.jacc.2020.09.018
9. Sies H. Oxidative stress: A concept in redox biology and medicine. *Redox Biol.* 2015;4:180-183.
10. Ahmed B, Sultana R, Greene MW. Adipose tissue and insulin resistance in obese. *Biomed Pharmacother.* 2021;137:111315.
11. Hotamisligil GS. Inflammation and metabolic disorders. *Nature.* 2006 Dec 14;444(7121):860-867.
12. Bosch-Sierra N, Grau-Del Valle C, Hermenejildo J, Hermo-Argibay A, Salazar JD, Garrido M, et al. The impact of weight loss on inflammation, oxidative stress, and mitochondrial function in subjects with obesity. *Antioxidants (Basel).* 2024;13(7):870.
13. Kanikowska D, Kanikowska A, Swora-Cwynar E, Grzymisławski M, Sato M, Bręborowicz A, et al. Moderate caloric restriction partially improved oxidative stress markers in obese humans. *Antioxidants (Basel).* 2021;10(7):1018.
14. Jones DP. Redox theory of aging. *Redox Biol*. 2015;5:71-79.
15. Turell L, Radi R, Alvarez B. The thiol pool in human plasma: The central contribution of albumin to redox processes. *Free Radic Biol Med.* 2013;65:244-253.
16. Winterbourn CC. Are free radicals involved in thiol-based redox signaling? *Free Radic Biol Med.* 2015;80:164-170.
17. D'Alessandro A, Di Felice G, Manco M, Pastore A, Pezzi S, Mariani M, et al. Study of the association between thiols and oxidative stress markers in children with obesity. *Nutrients*. 2022;14(17):3637.
18. Keaney JF Jr, Larson MG, Vasan RS, Wilson PW, Lipinska I, Corey D, et al. Framingham Study. Obesity and systemic oxidative stress: Clinical correlates of oxidative stress in the Framingham Study. *Arterioscler Thromb Vasc Biol.* 2003;23(3):434-439.
19. Shevtsova A, Gordiienko I, Tkachenko V, Ushakova G. Ischemia-modified albumin: Origins and clinical implications. *Dis Markers*. 2021;2021:9945424.
20. Ayala A, Muñoz MF, Arguelles S. Lipid peroxidation: Production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. *Oxid Med Cell Longev*. 2014;2014:360438.
21. Sulekova M, H. The role of oxidative stress and thiol-disulfide balance in obesity and metabolic disorders. *Obes Rev.* 2022:23(5):e13456.
22. Garvey WT, Mechanick JI, Brett EM, Garber AJ, Hurley DL, Jastreboff AM, et al. Reviewers of the AACE/ACE obesity clinical practice guidelines. *Endocr Pract.* 2016;22(7):842-884.
23. Erel O, Neselioglu S. A novel and automated assay for thiol/disulfide homeostasis. *Clin Biochem.* 2014;47(18):326-332.
24. Resano-Barrio P, Alfaro E, Solano-Pérez E, Coso C, Cubillos-Zapata C, Díaz-García E, et al. On Behalf of The Spanish Sleep Network. Analysis of the ischemia-modified albumin as a potential biomarker for cardiovascular damage in obstructive sleep apnea patients with acute coronary syndrome. *Int J Mol Sci.* 2023;24(10):9019.
25. Xie Y, Wu Z, Qin Z, Wu B, Lv X, Wei F, et al. Methods of lipidomic analysis: Extraction, derivatization, separation, and identification of lipids. *Adv Exp Med Biol.* 2021;1280:173-187.
26. Feelisch M, Cortese-Krott MM, Santolini J, Wootton SA, Jackson AA. Systems redox biology in health and disease. *EXCLI J.* 2022;21:623-646.
27. Oklu E, Alhan M, Erdal E (2023) The role of thiol/disulfide balance in obesity: A clinical study. *J Obes Res.* 2023;45(2):123-130.
28. Elmas B, Karacan M, Dervisoglu P, Kösecik M, Isguven SP, Bal C. Dynamic thiol/disulfide homeostasis as a novel indicator of oxidative stress in obese children and its relationship with inflammatory-cardiovascular markers. *Anatol J Cardiol.* 2017;18(5):361-369.
29. Fernández-Sánchez A, Madrigal-Santillán E, Bautista M, Esquivel-Soto J, Morales-González A, Esquivel-Chirino C, et al. Inflammation, oxidative stress, and obesity. *Int J Mol Sci.* 2011;12(5):3117-3132.
30. Carbone S, Del Buono MG, Ozemek C, Lavie CJ. The association between circulating C-reactive protein levels and both epicardial

and visceral fat depots in women meeting metabolic syndrome criteria. *J Clin Med.* 2019;8(11):1838.
31. van Wijk DF, Boekholdt SM, Arsenault BJ, Ahmadi-Abhari S, Wareham NJ, Stroes ES, et al. C-Reactive protein identifies low-risk metabolically healthy obese persons: The european prospective investigation of cancer-norfolk prospective population study. *J Am Heart Assoc.* 2016;5(6):e002823.
32. Li X, Morel JD, Benegiamo G, Poisson J, Bachmann A, Rapin A, et al. Genetic and dietary modulators of the inflammatory response in the gastrointestinal tract of the BXD mouse genetic reference population. *Elife.* 2023;12:RP87569.
33. Mengen E, Ucakturk SA, Kocaay P, Kaymaz O, Neselioglu S, Erel ÖO. The significance of thiol/disulfide homeostasis and ischemia-modified albumin levels in assessing oxidative stress in obese children and adolescents. *J Clin Res Pediatr Endocrinol.* 2020;12(1):45-54.
34. Elkan H, Karateke F, Taskin S, Celik H, Yuksekyayla B, Uzunkoy A. Comparison of preoperative and postoperative serum thiol/disulfide levels in patients undergoing laparoscopic sleeve gastrectomy for morbid obesity. *Eur Rev Med Pharmacol Sci.* 2024;28(2):757-762.
35. De Koning L, Merchant AT, Pogue J, Anand SS. Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: Meta-regression analysis of prospective studies. *Eur Heart J.* 2007;28(7):850-856.
36. Powell-Wiley TM, Poirier P, Burke LE, Després JP, Gordon-Larsen P, Lavie CJ, et al. Obesity and cardiovascular disease: A scientific statement from the American Heart Association. *Circulation.* 2021;143(21):e984-e1010.
37. Bluher M. Adipose tissue dysfunction in obesity. *Exp Clin Endocrinol Diabetes.* 2009;117(6):241-250.
38. Piva SJ, Duarte MM, Da Cruz IB, Coelho AC, Moreira AP, Tonello R, et al. Ischemia-modified albumin as an oxidative stress biomarker in obesity. *Clin Biochem.* 2011;44(4):345-347.
39. Mehmetoglu I, Kurban S, Yerlikaya FH, Polat H. Obesity is an independent determinant of ischemia-modified albumin. *Obes Facts*. 2012;5(5):700-709.