ISSN: 2320-9267

Indian Journal of Pharmaceutical and Biological Research (IJPBR)

Journal homepage: www.ijpbr.in

RESEARCH ARTICLE

Salivary Biochemical Alterations Across Body Mass Index Categories: A Cross-Sectional Study of Oxidative Stress and Antioxidant Defense

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ABSTRACT

Background: Body mass index (BMI) may be associated with changes in oral biochemical homeostasis, including oxidative damage and antioxidant defense. Saliva offers a non-invasive matrix for investigating these changes.**Objectives**:To compare salivary alkaline phosphatase (ALP), superoxide dismutase (SOD), lipid peroxidation, and ferric reducing antioxidant power (FRAP) across four BMI groups.**Materials and Methods**:This cross-sectional study included 72 apparently healthy adults, with 18 participants in each BMI group: underweight (<18.5 kg/m²), normal BMI (18.5-22.9 kg/m²), BMI 25.0-29.9 kg/m², and BMI ≥30 kg/m². Unstimulated whole saliva was collected and analyzed using spectrophotometric/colorimetric methods. Group differences were assessed by one-way analysis of variance (ANOVA) with post hoc comparisons. The reported significance threshold was P<0.05.**Results**:Mean ALP increased from 38.42±7.15 U/L in the underweight group to 61.34±10.12 U/L in the BMI ≥30 group (F=23.48, P<0.001). SOD was highest in the normal-BMI group (7.46±1.35 U/mL) and lowest in the BMI ≥30 group (4.91±1.05 U/mL; F=18.62, P<0.001). Lipid peroxidation was lowest in the normal-BMI group (1.74±0.39 nmol/mL) and highest in the BMI ≥30 group (3.72±0.71 nmol/mL; F=42.15, P<0.001). FRAP was highest in the normal-BMI group (526.78±74.16 µmol Fe^{2+}/L) and lowest in the BMI ≥30 group (371.64±58.27 µmol Fe^{2+}/L; F=21.74, P<0.001).**Conclusion:**The BMI groups differed significantly in all four salivary measures. The combination of higher ALP and lipid peroxidation with lower SOD and FRAP in the highest-BMI group suggests an association between BMI and salivary biochemical status. The cross-sectional design does not establish causality.

Keywords: Body Mass Index; Saliva; Oxidative Stress; Antioxidants; Alkaline Phosphatase

Indian J. Pharm. Biol. Res. (2026): https://doi.org/10.30750/ijpbr.14.4.69

INTRODUCTION

Saliva is a biologically active fluid containing enzymes, proteins, electrolytes, antimicrobial molecules, metabolites, and antioxidant compounds. Its continuous interaction with teeth, gingiva, oral mucosa, microorganisms, and gingival crevicular fluid makes its composition responsive to local oral conditions. At the same time, several salivary constituents may originate from systemic circulation, supporting the use of saliva as a non-invasive medium for investigating oral-systemic biological interactions.[1-4]Oxidative stress develops when reactive oxygen species generation exceeds the capacity of endogenous antioxidant systems to neutralize them. Persistent oxidative imbalance can damage lipids, proteins, nucleic acids, and cellular structures and may contribute to chronic inflammatory processes.[5-6] The oral cavity is particularly exposed to oxidative challenges because microbial activity, inflammatory cell responses, dietary factors, and environmental exposures can contribute to reactive oxygen species production.[7-8]Saliva possesses both enzymatic and non-enzymatic antioxidant systems. Superoxide dismutase (SOD) constitutes an important enzymatic component by catalyzing the conversion of superoxide radicals into hydrogen peroxide and oxygen. Other salivary antioxidants include uric acid, ascorbic acid, glutathione, albumin, and peroxidase systems. Consequently, assessment of a single antioxidant marker may provide only a limited representation of the salivary redox state.[9-10]Lipid peroxidation provides complementary information because it reflects oxidative damage to membrane-associated lipids. Malondialdehyde and related thiobarbituric acid-reactive substances are commonly used as biochemical indicators of lipid oxidation. Increased lipid peroxidation has been described in inflammatory and oxidative stress-associated oral conditions.[11-12]Ferric reducing antioxidant power (FRAP) measures the reducing capacity of a biological sample. It principally reflects the ability of antioxidants to reduce ferric ions to ferrous ions and therefore provides an integrated estimate of reducing antioxidant potential.[13] However, FRAP does not represent every component of antioxidant defense and is best interpreted alongside specific antioxidant enzymes and oxidative damage markers.Alkaline phosphatase (ALP) is an enzyme involved in phosphate metabolism and is associated with mineralization, tissue turnover, and inflammatory processes. Salivary ALP may originate from several oral sources, including salivary glands, epithelial cells, leukocytes, microorganisms, gingival crevicular fluid, and periodontal tissues. Altered salivary ALP has been investigated particularly in relation to periodontal inflammation and tissue destruction.[14-15]BMI is a simple anthropometric measure calculated from body weight and height. Increasing BMI is associated with metabolic abnormalities, chronic low-grade inflammation, altered lipid metabolism, and oxidative stress.[16-19] Adipose tissue is metabolically active and can contribute to inflammatory signaling and reactive oxygen species generation. These systemic changes may influence the oral environment and may interact with periodontal and salivary biochemical processes.[20-21]

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How to cite this article: Amita Rupesh Thakur Sahil Dhonde, Yatindra Kumar. Salivary Biochemical Alterations Across Body Mass Index Categories: A Cross-Sectional Study of Oxidative Stress and Antioxidant Defense. Indian J. Pharm. Biol. Res. 2026;14(4):472-479

Source of support: Nil. **Conflict of interest:** None.

Received: 01.10.2026 Revised: 14.10.2026 Accepted: 22.10.2026

The relationship between obesity and periodontal health has received considerable attention. Excess body weight has been associated with periodontal disease in systematic reviews, although the relationship may also be influenced by oral hygiene, diet, smoking, diabetes, and other lifestyle factors.[22-23] These considerations are particularly important when interpreting salivary ALP because the enzyme is influenced by local oral inflammatory activity.Previous research has examined salivary antioxidants, oxidative stress, and ALP in different oral and systemic conditions. However, simultaneous evaluation of ALP, SOD, lipid peroxidation, and FRAP across distinct BMI categories may provide a more integrated biochemical picture. The present study therefore investigated the salivary biochemical profile of apparently healthy adults distributed across four BMI categories.

Materials and Methods

Study Design and Participants

A laboratory based cross-sectional observational study was conducted among apparently healthy adult participants. The study included 72 participants distributed equally among four BMI categories, with 18 participants in each group. The inclusion of adults aged 18 years or older who were willing to provide written informed consent and saliva samples.The study population was divided into the following groups:

- Group I: Underweight, BMI <18.5 kg/m²
- Group II: Normal BMI, 18.5-22.9 kg/m²
- Group III: BMI 25.0-29.9 kg/m²
- Group IV: BMI ≥30.0 kg/m²

Participants were analyzed in the four BMI ranges used in the source dataset: <18.5, 18.5-22.9, 25.0-29.9, and ≥30.0 kg/m².

Eligibility Criteria

Participants were required to be adults and apparently healthy at the time of sample collection. Individuals with known systemic disorders such as diabetes mellitus, chronic liver or kidney disease, autoimmune disorders, active infection, or malignancy were intended to be excluded. Participants receiving antioxidant supplements, anti-inflammatory drugs, antibiotics, or long-term medications capable of altering salivary composition were also excluded. Tobacco use, smoking, alcohol abuse, active oral lesions, severe periodontal disease, and recent dental treatment were included among exclusion considerations.

Anthropometric Assessment

Body weight and height were measured using a calibrated weighing scale and stadiometer, respectively. BMI was calculated using the standard equation:

BMI = Body weight (kg) / Height² (m²)

Participants were subsequently assigned to one of the four predefined BMI groups.

Saliva Collection and Processing

Unstimulated whole saliva was collected under standardized conditions. Participants were instructed to refrain from eating, drinking, chewing gum, tooth brushing, or using mouthwash for approximately 60-90 minutes before collection. Participants gently rinsed the mouth with distilled water and were allowed to rest before sample collection.Approximately 2-5 mL of unstimulated saliva was collected by passive drooling into sterile, labelled collection tubes. Samples were placed on ice and transported for laboratory processing. The samples were centrifuged at approximately 3000 rpm for 10-15 minutes to remove cellular debris and insoluble material. The resulting clear supernatant was transferred to sterile microcentrifuge tubes and either analyzed immediately or stored at -20°C until analysis. Repeated freeze-thaw cycles were avoided

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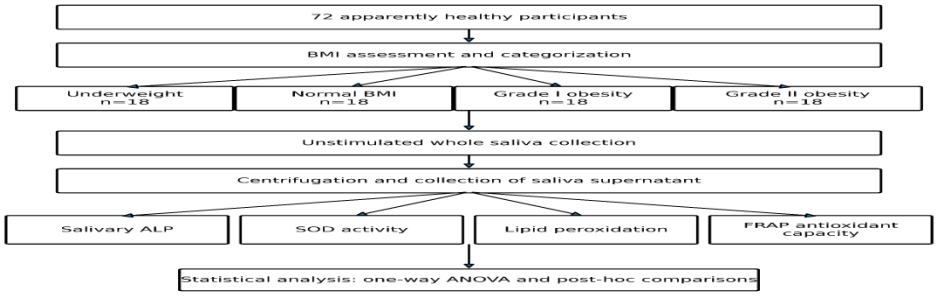


Figure 1: Study design and salivary biomarker assessment

Biochemical Analysis

Salivary biochemical parameters were assessed using spectrophotometric/colorimetric methods and commercially available reagent kits according to the respective assay procedures.

Salivary Alkaline Phosphatase

ALP activity was estimated using an alkaline phosphatase assay based on enzymatic hydrolysis of p-nitrophenyl phosphate to p-nitrophenol under alkaline conditions. The resulting color intensity was measured spectrophotometrically, with ALP activity expressed as U/L.

Salivary Superoxide Dismutase

SOD activity was determined using a spectrophotometric assay based on inhibition of a superoxide-mediated color reaction. Results were expressed as U/mL according to the assay procedure.

Lipid Peroxidation

Lipid peroxidation was estimated using a spectrophotometric assay based on malondialdehyde/thiobarbituric acid-reactive substances. The results were expressed as nmol/mL.

Ferric Reducing Antioxidant Power

FRAP was used to estimate salivary reducing antioxidant capacity. The assay is based on reduction of ferric ions to ferrous ions by reducing substances present in the saliva. Results were expressed as μmol Fe^{2+}/L.[13]

Statistical Analysis

Descriptive statistics were used to summarizebiochemical measurements. Differences in salivary ALP, SOD, lipid peroxidation, and FRAP among the four BMI groups were evaluated using one-way analysis of variance (ANOVA), followed by post hoc comparisons where appropriate. Statistical significance was defined as $P < 0.05$.

Results

Distribution of Participants

A total of 72 participants were included. Each BMI category contained 18 participants, representing 25% of the study population. The equal distribution allowed direct comparison of salivary biochemical parameters across BMI categories.

Table 1. Distribution of participants according to BMI category

BMI group	BMI category	BMI range	n	Percentage
I	Underweight	<18.5 kg/m²	18	25.0
II	Normal BMI	18.5–22.9 kg/m²	18	25.0
III	BMI 25.0–29.9	25.0–29.9 kg/m²	18	25.0
IV	BMI ≥30	≥30.0 kg/m²	18	25.0
Total			**72**	**100**

Salivary Alkaline Phosphatase

Salivary ALP demonstrated a progressive increase across BMI categories. The mean ALP concentration was 38.42 ± 7.15 U/L in the underweight group, 43.86 ± 8.24 U/L in the normal BMI group, 52.73 ± 9.68 U/L in BMI 25.0-29.9 group, and 61.34 ± 10.12 U/L in BMI ≥30 group.

One-way ANOVA demonstrated a statistically significant difference among the four groups ($F = 23.48$, $P < 0.001$). Post hoc analysis showed significant differences between underweight and BMI 25.0–29.9 group, underweight and BMI ≥30 group, normal BMI and BMI 25.0-29.9 group, normal BMI and BMI ≥30 group, and Grade I versus BMI ≥30 group. The difference between underweight and normal BMI was not statistically significant.

Salivary Superoxide Dismutase

SOD activity demonstrated a different pattern. The normal BMI group showed the highest mean activity (7.46 ± 1.35 U/mL), followed by BMI 25.0-29.9 group (6.38 ± 1.28 U/mL), underweight participants (5.82 ± 1.12 U/mL), and BMI ≥30 group (4.91 ± 1.05 U/mL).

The overall difference among BMI categories was statistically significant ($F = 18.62$, $P < 0.001$). The significantly lower SOD activity in BMI ≥30 group compared with the normal BMI and BMI 25.0-29.9 group groups.

Lipid Peroxidation

Lipid peroxidation demonstrated a marked increase in the higher-BMI groups. The mean values were 2.18 ± 0.46 nmol/mL in underweight participants, 1.74 ± 0.39 nmol/mL in the normal BMI group, 2.86 ± 0.58 nmol/mL in BMI 25.0–29.9 group, and 3.72 ± 0.71 nmol/mL in BMI ≥30 group.

The overall difference was statistically significant (F = 42.15, P < 0.001). Post hoc analysis demonstrated significant differences between underweight and BMI 25.0-29.9 group, underweight and BMI ≥30 group, normal BMI and BMI 25.0-29.9 group, normal BMI and BMI ≥30 group, and Grade I versus BMI ≥30 group. The underweight versus normal BMI comparison was not statistically significant.

Ferric Reducing Antioxidant Power

FRAP antioxidant capacity was highest in the normal BMI group and lowest in BMI ≥30 group. Mean FRAP values were 412.35 ± 62.48 µmol Fe^{2+}/L for underweight participants, 526.78 ± 74.16 µmol Fe^{2+}/L for normal BMI participants, 463.92 ± 69.85 µmol Fe^{2+}/L for BMI 25.0–29.9 group, and 371.64 ± 58.27 µmol Fe^{2+}/L for BMI ≥30 group. One-way ANOVA showed a statistically significant difference among groups (F = 21.74, P < 0.001). Post hoc testing demonstrated significant differences between normal BMI and BMI 25.0-29.9 group, normal BMI and BMI ≥30 group, and Grade I versus BMI ≥30 group. The difference between underweight and normal BMI was also significant.

Table 2. Salivary biochemical parameters across BMI categories

BMI category	N	ALP (U/L), mean ± SD	SOD (U/mL), mean ± SD	Lipid peroxidation (nmol/mL), mean ± SD	FRAP (µmol Fe^{2+}/L), mean ± SD
Underweight	18	38.42 ± 7.15	5.82 ± 1.12	2.18 ± 0.46	412.35 ± 62.48
Normal BMI	18	43.86 ± 8.24	7.46 ± 1.35	1.74 ± 0.39	526.78 ± 74.16
BMI 25.0–29.9	18	52.73 ± 9.68	6.38 ± 1.28	2.86 ± 0.58	463.92 ± 69.85
BMI ≥30	18	61.34 ± 10.12	4.91 ± 1.05	3.72 ± 0.71	371.64 ± 58.27

Table 3. Overall statistical comparison among BMI groups

Salivary parameter	Statistical test	F value	P value
ALP	One-way ANOVA	23.48	<0.001
SOD	One-way ANOVA	18.62	<0.001
Lipid peroxidation	One-way ANOVA	42.15	<0.001
FRAP	One-way ANOVA	21.74	<0.001

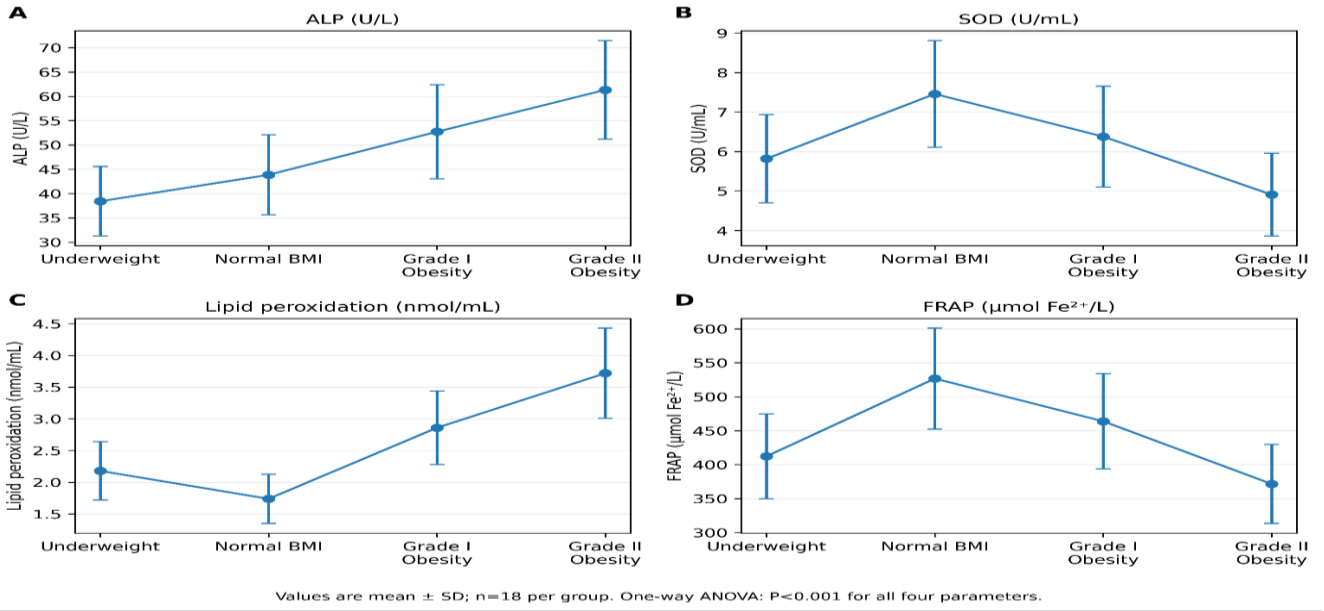


Figure 2. Salivary biochemical parameters across BMI categories. (A) ALP, (B) SOD, (C)

lipid peroxidation, and (D) FRAP. Values are expressed as mean ± SD. Overall group differences were statistically significant by one-way ANOVA ($P < 0.001$ for all parameters).

Discussion

The present study demonstrates a consistent alteration in the salivary biochemical profile across BMI categories. The most prominent pattern was the simultaneous increase in ALP and lipid peroxidation and the reduction of SOD activity and FRAP antioxidant capacity in the higher BMI groups, particularly BMI ≥30 group. Rather than relying on a single biochemical indicator, the study examined four complementary parameters representing enzymatic activity, enzymatic antioxidant defense, oxidative damage, and total reducing antioxidant capacity.

The rise in salivary ALP across BMI categories is noteworthy. ALP is associated with phosphate metabolism, mineralization, tissue turnover, and inflammatory processes. Within the oral environment, salivary ALP may be contributed by periodontal tissues, gingival crevicular fluid, epithelial cells, leukocytes, microorganisms, and salivary glands.[14-15] Previous studies have reported increased salivary ALP in periodontal inflammation, supporting the possibility that changes in ALP may reflect altered oral tissue activity.[14-15]

The present results cannot establish that obesity itself caused the increase in ALP. Nevertheless, the progressive increase from 38.42 U/L in underweight participants to 61.34 U/L in BMI ≥30 group suggests that body-weight status may be associated with a measurable change in salivary enzymatic activity. This interpretation is biologically plausible because obesity is characterized by low grade inflammation and metabolic disturbances that may influence oral inflammatory pathways.[20-21]

The oxidative stress findings provide a second dimension to this association. Lipid peroxidation was lowest in the normal BMI group and increased substantially in the two higher BMI groups. The BMI ≥30 group demonstrated a mean value more than twice that observed in the normal BMI group. The statistically significant group differences are consistent with the concept that increased adiposity is associated with greater oxidative burden.[17-18]

Obesity associated oxidative stress may arise from several interconnected mechanisms, including mitochondrial dysfunction, increased free fatty acid availability, chronic inflammatory signaling, altered cellular metabolism, and impaired antioxidant responses.[17-18] These processes may influence systemic redox status and could potentially be reflected in saliva. However, because saliva is also influenced by local oral factors, the observed increase in lipid peroxidation cannot be interpreted as a direct measurement of systemic oxidative stress.

The SOD findings complement the lipid peroxidation results. SOD activity was highest among normal BMI participants and declined to its lowest level in the BMI ≥30 group, reaching the lowest value in BMI ≥30 group. SOD is a first-line enzymatic antioxidant that converts superoxide radicals into hydrogen peroxide and oxygen. Altered salivary SOD has previously been described in oxidative and periodontal conditions.[9,12]

The combination of higher lipid peroxidation and lower SOD activity in BMI ≥30 group is particularly important. An isolated change in SOD could potentially represent either compensation or impairment. In the present dataset, however, the decrease in SOD occurred alongside increased lipid peroxidation, providing a pattern more compatible with an unfavourable oxidative balance.

FRAP provided complementary information about total reducing antioxidant potential. The highest FRAP value was observed in the normal BMI group, whereas the lowest value occurred in BMI ≥30 group. The significant reduction in FRAP between normal BMI and BMI ≥30 group suggests that increasing BMI may be accompanied by diminished salivary reducing capacity.

FRAP should nevertheless be interpreted cautiously. It measures reducing capacity rather than the complete antioxidant system and does not directly quantify individual antioxidant enzymes such as SOD or catalase.[13] Salivary uric acid is a major contributor to antioxidant capacity, and metabolic alterations may influence its concentration. Thus, the present FRAP findings are most informative when considered alongside SOD and lipid peroxidation rather than interpreted independently.

The normal BMI group demonstrated the most favourable combined profile: relatively low lipid peroxidation together with the highest SOD activity and FRAP capacity. In contrast, BMI ≥30 group demonstrated the highest ALP and lipid peroxidation together with the lowest SOD and FRAP values. This convergence of four independent biochemical dimensions strengthens the biological interpretation of an altered salivary redox environment in participants with higher BMI.

The findings are also relevant from an oral-systemic perspective. Saliva receives contributions from oral tissues, gingival crevicular fluid, microorganisms, immune cells, and systemic circulation.[1-4] Consequently, alterations in saliva may arise from either local oral processes or systemic metabolic changes. Obesity has been associated with

periodontal disease, although the relationship is influenced by multiple behavioural and metabolic factors.[22-23]

The elevated ALP observed in the higher-BMI groups could therefore reflect increased tissue turnover or inflammatory activity, but the current study did not include detailed periodontal measurements such as plaque index, gingival index, probing depth, clinical attachment loss, or bleeding on probing. This is an important limitation because oral inflammation could independently influence both ALP and oxidative stress markers.

Another consideration is the influence of diet. Dietary antioxidant intake can affect antioxidant status, while dietary patterns associated with obesity may influence oxidative stress.[24] The present study did not provide detailed dietary intake data. Similarly, salivary flow rate was not quantitatively incorporated into the reported analysis. Differences in salivary flow can alter analyte concentration and should therefore be considered in future studies.

The study has several strengths. First, the sample was evenly distributed across four BMI categories, facilitating direct group comparison. Second, four biochemical parameters were evaluated rather than relying on a single oxidative stress marker. Third, saliva provided a non-invasive and readily accessible biological material. Finally, the findings demonstrated statistically significant differences across BMI categories for all four measured parameters.

The principal limitation is the cross-sectional design. The findings demonstrate association rather than causation. It cannot be determined whether increased BMI directly produces the observed salivary changes or whether unmeasured factors contribute to both obesity and altered oral biochemistry. The sample size was also relatively modest and was drawn from a defined institutional setting, limiting generalizability.

The absence of detailed periodontal assessment is another important limitation. Similarly, serum metabolic markers, inflammatory cytokines, dietary intake, salivary flow rate, and waist circumference were not incorporated into the reported analysis. The lipid peroxidation assay should also be interpreted cautiously because TBARS-based approaches may lack complete specificity for malondialdehyde.[8,10] Salivary ALP has also been examined in relation to smoking, diabetes-associated oral changes, and periodontal disease, reinforcing the need to account for these potential confounders.[25-28]

An additional limitation concerns the original study objective of assessing correlations between BMI and salivary biomarkers. Although the methodology described Pearson or Spearman correlation testing, the available results report groupwise comparisons without numerical correlation coefficients.

Despite these limitations, the findings provide a useful preliminary biochemical profile. The results suggest that salivary ALP, SOD, lipid peroxidation, and FRAP may collectively capture different dimensions of the relationship between body-weight status and oral biochemical homeostasis. Future studies should combine these markers with comprehensive periodontal examination, salivary flow measurements, dietary assessment, fasting glucose, HbA1c, lipid profile, inflammatory biomarkers, and corresponding serum oxidative stress markers.

Longitudinal studies will be particularly valuable. If weight reduction, dietary modification, physical activity, or periodontal treatment produces parallel changes in salivary ALP, SOD, lipid peroxidation, and FRAP, this would provide stronger evidence for a biologically meaningful relationship. Such investigations may ultimately determine whether saliva can contribute to non-invasive screening approaches linking metabolic and oral health.

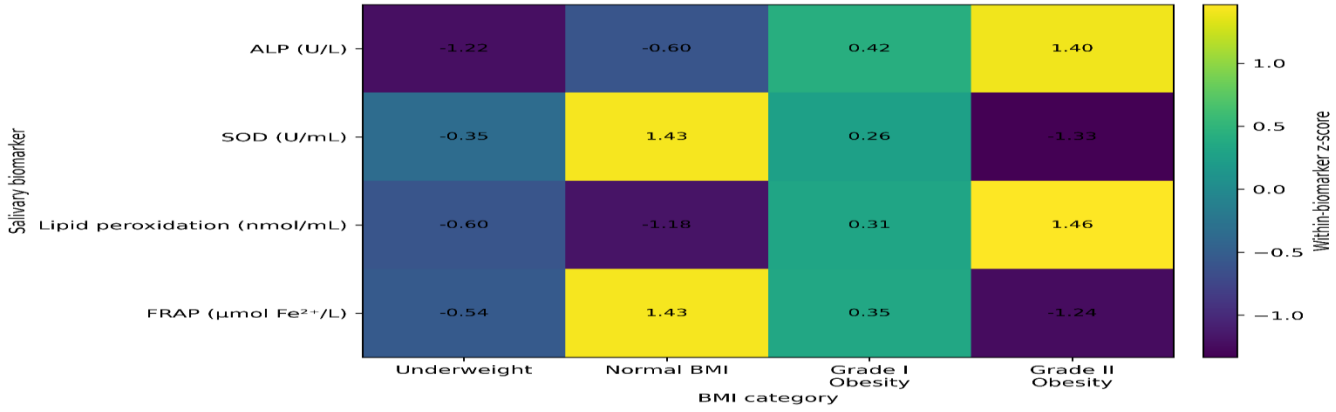


Figure 3. Standardized heat map illustrating the relative salivary biochemical profile across BMI categories.

Conclusion

This cross-sectional study identified significant differences in salivary biochemical parameters across BMI categories. Increasing BMI was accompanied by progressively higher salivary ALP and lipid peroxidation, while SOD activity and FRAP antioxidant capacity were comparatively reduced in obese participants, particularly those with BMI ≥30 group.

The simultaneous elevation of an enzymatic tissue response marker and an oxidative damage marker, together with reduced enzymatic and reducing antioxidant measures, suggests a shift in the salivary biochemical environment toward greater oxidative burden with increasing BMI.

Saliva therefore represents a promising non-invasive medium for investigating interactions between metabolic status and oral biochemical homeostasis. However, the observed associations should not be interpreted as evidence of causality or as a substitute for established metabolic or periodontal assessment. Larger, multicenter and longitudinal studies incorporating detailed oral, metabolic, inflammatory, dietary, and salivary flow variables are required to determine the clinical significance of these salivary signatures.

ACKNOWLEDGEMENTS

The authors sincerely express their gratitude to the Department of Life Sciences and Biotechnology, Chhatrapati Shivaji Maharaj University, Panvel, Maharashtra, India, for providing the necessary academic guidance, infrastructure, and laboratory facilities that enabled the successful completion of this research. The authors are also thankful to Inventum Research and Diagnostic Pvt. Ltd for their valuable technical support and assistance in sample collection, processing, and laboratory investigations. Finally, the authors extend their heartfelt appreciation to all the study participants for their enthusiastic cooperation and invaluable contribution, without which this study would not have been possible.

Declarations

Ethics approval:

The study was reviewed and approved by the Institutional Ethics Committee of Chhatrapati Shivaji Maharaj University, Panvel, Maharashtra, India, prior to the commencement of the study. Written informed consent was obtained from all participants before enrollment. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki, and participant confidentiality and anonymity were maintained throughout the study. regarding the publication of this study.

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