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Research Article

Multimodal Biophotometric System for Personalized Assessment of Dental Status: Diagnostic Efficiency and Clinical Application

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Abstract

The aim of the study was to evaluate the diagnostic efficacy of a multimodal biophotometric system (MBS) in various dental pathologies, considering the impact of oxidative stress and psychoemotional strain.

Materials and Methods: A prospective, controlled, singlecenter study included 279 patients divided into 4 groups: control (n = 30), initial pathology manifestations (n = 57), pronounced forms (n = 171), and exacerbation of chronic diseases (n = 21). The methods included multimodal biophotometry (405 nm excitation, 400–700 nm spectral range), clinical index assessment, and saliva analysis (cortisol via ELISA, perceived stress via PSS10 scale).

Results: MBS demonstrated high diagnostic accuracy: sensitivity 93.6 %, specificity 94.6 %, and AUC 0.941, indicating excellent model quality. The greatest diagnostic gain was observed for leukoplakia (AUC 0.961) and gingivitis (AUC 0.940). Fluorescent indices (mucoproteins), (porphyrins), and their ratio proved to be informative markers of oxidative stress, hyposalivation, and microbial load.

Conclusions: MBS provides an objective, personalized assessment of dental status, surpasses traditional methods in diagnostic accuracy, and is suitable for monitoring treatment efficacy.

Keywords: Multimodal Biophotometry; Oxidative Stress; Dental Status; Fluorescence Diagnostics;, Personalized Medicine

Introduction

Oxidative stress (OSA) is recognized as a key pathogenetic link in the development of a wide range of dental diseases, from gingivitis and caries to leukoplakia and periodontitis. Modern optical technologies, in particular multimodal biophotometry, make it possible to detect early molecular changes in oral tissues that remain inaccessible in standard clinical assessment [1-4].

The three-phase model of OSA (phase of anxiety, resistance, exhaustion) reflects the dynamics of the body's adaptation to stress and correlates with the progression of dental pathology. In the anxiety phase, the sympathoadrenal system (SAS) is activated with the release of catecholamines; in the resistance phase, there is an adaptation of the immune system and a temporary improvement in gingival perfusion; In the exhaustion phase, immunodepression, hyposalivation and atrophy of the mucous membrane develop, which creates the prerequisites for the formation of chronic diseases (Figure 1).

Despite progress in instrumental diagnostics, there is still a need for objective, non-invasive methods that can integrate data on the

functional state of tissues and systemic stress. The purpose of this study is to assess the diagnostic efficacy of MBS in various dental pathologies and to substantiate its use in personalized practice.

Materials and Methods [1-16]

Study design and ethics

The prospective, controlled, single-center study was performed in accordance with the ethical standards of the Declaration of Helsinki (2013, revision 2024) and the requirements of the ICH GCP. All participants signed an informed voluntary consent.

Inclusion criteria

- Age 18–45 years (representative cohort of reproductive age with a low contribution of age-related comorbidity).
- The presence of an established diagnosis (gingivitis, caries, leukoplakia, periodontitis) according to the ICD11 criteria.
- Informed voluntary consent to participate in the study.

Exclusion criteria

- Systemic diseases in the stage of decompensation (diabetes mellitus, autoimmune, oncological diseases).
- Smoking (≥10 cigarettes/day) or alcohol consumption >20 g ethanol/day.
- Taking antibiotics, NSAIDs, glucocorticoids within the last month.
- Pregnancy and lactation.
- Orthodontic structures, removable dentures, massive restoration work (more than 50% of the occlusal surface).

Study groups and their clinical characteristics

- **Control group (n = 30):** Persons without dental pathology, with intact teeth and clinically healthy periodontal tissues. Normal criteria: CPU = 0; GI (Gingival Index) ≤ 0.4 (no inflammation); PMA (papillary-marginal alveolar index) = 0%; absence of bleeding during probing; the depth of the gingival pockets ≤ 2 mm; absence of recession and tooth mobility.
- **Group 1 (n = 57) — initial manifestations of diseases:** Patients with initial forms of pathology, where reversible changes associated with poor hygiene and local inflammation dominate.

Incoming nosologies:

- Mild chronic catarrhal gingivitis (GI 0.5–1.0; PMA 15–30%) — 20 patients;
- Initial caries (white spot, without cavitation; according to InSpectrum M, the fluorescence intensity is 15–25 relative units) — 20 patients;
- Mild desquamative mucosal lesions (erythema without erosions) — 17 patients.

Clinical features

The presence of soft plaque and supragingival tartar (OHIS 1.3–1.8); local bleeding on probing (BOP 10–20%); no loss of attachment and bone destruction.

Group 2 (n = 171) — pronounced clinical forms

Patients with moderate pathology requiring complex treatment.

Incoming nosologies:

- Moderate chronic gingivitis (GI 1.1–2.0; PMA 31–60 %);
- Dentin caries (CPU 4–8, cavities of class I–III according to Black) — 71 patients;
- Mild chronic periodontitis (pocket depth 3–4 mm, loss of attachment ≤3 mm, X-ray – initial resorption of the interalveolar septa up to 15%) – 50 patients;
- Flat leukoplakia (limited areas of hyperkeratosis without cytology atypia) — 50 patients.

Clinical features

OHIS 1.9–2.5 (poor hygiene); BOP 21–40 %; local recessions of 1–2 mm; mobility of teeth of the first degree.

Group 3 (n = 21) – exacerbation of chronic diseases

Patients with pronounced process activity, a systemic component, and a high risk of progression.

Incoming nosologies:

- Exacerbation of moderate chronic periodontitis (pockets 5–6 mm, loss of attachment 4–5 mm, bone resorption up to 30%) — 5 patients;

- Multiple caries (CPU ≥9, secondary caries, history of pulpitis) — 6 patients;
- Verrucous leukoplakia (foci of hyperkeratosis with a verrucous surface, suspected dysplasia) — 5 patients;
- Erosive ulcerative lesions of the mucous membrane (aphthae, erosions with fibrinous plaque).

Clinical features

OHIS ≥2.6 (poor hygiene); BOP >40 %; mobility of teeth of I-II degree; purulent discharge from pockets; pronounced subjective complaints (pain, burning, bleeding).

A subgroup of hygienic disorders (within Group 1, n = 20) was identified to assess the effect of hygiene on fluorescent indicators. It included patients with OHIS ≥1.5 in the absence of destructive changes.

Equipment and inspection protocol [1-16]

Multimodal biophotometric system: InSpektr M hardware and software complex: 405 nm radiation source and/or (semiconductor laser, 5 mW power, safe for the mucous membrane), spectrometer (range 400–700 nm, resolution 2 nm). Measurements were carried out under standardized conditions: illumination of 500 lux, temperature of 22 °C, humidity of 50–60%, no direct sunlight.

Biophotometric measurement protocol (step-by-step)

- **Patient preparation:** The patient is in a dental chair, the head is fixed with a headrest. 10 minutes before the start of the measurements, rest in a sitting position, excluding talking, swallowing, tongue movements. 2 hours before the visit – a ban on eating, drinking, chewing gum, and the use of mouthwashes.
- **Equipment preparation:** Calibrate the spectrometer to the NIST traceable standard. Test the power of the 405 nm source (not less than 4.8 mW, not more than 5.2 mW). Monitor indoor temperature and humidity (22 ± 2 °C, 50-60%).
- **Selection of the indicator registration zone:** For each patient, 4 zones are recorded: interdental papilla (between 1.1–2.1), attached gum (in area 3.6), buccal mucosa (along the line of teeth closure), floor of the oral cavity (middle third).
- **Probe positioning:** The optical probe is placed perpendicular to the surface of the tissue at a distance of 5 ± 1 mm. The angle of deflection should not exceed 5°.
- **Spectrum registration:** 3 consecutive measurements are taken in each zone at 15-second intervals. The data is averaged automatically in the system software.
- **Data processing:** The spectra are normalized relative to the intensity of the source. For the calculation, the area under the curve is integrated in the range of 520–540 nm; for — in the range of 630–640 nm.

Such detailing makes it possible to reproduce the methodology and validate the results obtained, which is especially important for the implementation of MBS in multicenter protocols.

Clinical evaluation

Registration of indices CPU, GI, PMA, OHIS, BOP. The assessment was carried out by two independent researchers; in case of a discrepancy of >10%, a second examination was performed by an expert.

Biochemical parameters

Collection of unstimulated saliva (morning, fasting, 2 ml) to determine cortisol (ELISA, Salimetrics set, sensitivity 0.012 ng/ml) and PSS10 (Perceived Stress Scale) to assess psycho-emotional stress. Saliva samples were stored at −80 °C prior to analysis.

Fluorescent indices

- $F_{\text{мп}}$ — the intensity of mucoprotein fluorescence (a marker of the state of the mucosa), measured in relative units (relative units) at a wavelength of 520–540 nm.
- $F_{\text{п}}$ – porphyrin fluorescence (a marker of anaerobic microflora), measured at 630–640 nm.
- $F_{\text{п}}/F_{\text{мп}}$ is a ratio that reflects the balance of microbial load and tissue condition.

The system was calibrated daily using NIST traceable standards. Quality control included repeated measurements of 5% of the sample (n ≈ 14) with the calculation of the coefficient of variation (CV <5% for all indices).

Statistical analysis

Data are presented as mean ± standard deviation (M ± SD). To compare the groups, the analysis of variance (ANOVA) was used with the Tukey post-hoc test. Diagnostic characteristics (sensitivity — Se, specificity — Sp, accuracy, AUC) were calculated using standard formulas:

$$Se = TP/(TP + FN),$$

$$Sp = TN/(TN + FP), \text{Accuracy} = ,(TP + TN)/N$$

where TP is true positive, FN is false negative, TN is true negative, FP is false positive, N is the total number of observations. Statistical significance was taken at .

Methods of descriptive statistics (mean, standard deviation, median, interquartile range) are used. To compare the groups, the Student's test (with a normal distribution) and the Mann-Whitney test (with a deviation from normality) were used. ANOVA with Bonferroni correction was used for multiple comparisons. Diagnostic characteristics (Se, Sp, accuracy, PPV, NPV) were calculated using ROC curves. Level of significance. The analysis was performed in SPSS 28.0 and R 4.3.1.

Results

Demographic and clinical characteristics

The groups were comparable in age and sex (Table 1). In patients with pathology, a significant increase in the level of cortisol in saliva and PSS10 scores was revealed, which confirms the relationship between stress and the development of dental diseases.

Parameter	Control (n = 30)	Group 1 (n = 57)	Group 2 (n = 171)	Group 3 (n = 21)
Age, years	27,8 ± 5,9	28,4 ± 6,2	27,9 ± 5,8	28,7 ± 6,5
Gender (m/f)	15/15	29/28	86/85	10/11
PSS10 Points	11,2 ± 3,1	24,3 ± 3,8	23,9 ± 4,1	24,6 ± 3,9
Saliva cortisol, ng/ml	6,4 ± 1,1	12,5 ± 2,4	12,8 ± 2,6	12,3 ± 2,5

Table 1: Demographic and clinical characteristics of the groups.

The comparability of groups in terms of age and gender composition excludes the influence of these factors as confounding variables. A significant increase in PSS10 and cortisol levels in patients with pathology (Groups 1–3) compared to controls indicates a significant role of psychoemotional stress and neuroendocrine response in the pathogenesis of dental diseases. The stability of age parameters confirms the homogeneity of the sample and the validity of intergroup comparisons.

Fluorescent indices

The values of and significantly differed between the groups (Table 2). The decrease in patients with pathology reflects hyposalivation and oxidative tissue damage. The ratio remained stable, which confirms its suitability as a marker of functional state.

Indicator	Control (n = 30)	Group 1 (n = 57)	Group 2 (n = 171)
$F_{мп}$, rel. units.	1,25 ± 0,15	0,92 ± 0,12	1,22 ± 0,14
$F_{р}$ rel. units.	1,42 ± 0		
$F_{мп}$ rel. units.	1,25 ± 0,15	0,92 ± 0,12	1,22 ± 0,14
$F_{р}$, rel. units.	1,42 ± 0,18	1,05 ± 0,14	1,38 ± 0,16
$F_{р}/F_{мп}$	1,14 ± 0,08	1,15 ± 0,09	1,13 ± 0,07

Table 2: Fluorescent indices in the study groups.

In the control group, maximum values were recorded, which reflects normal salivation and a low level of microbial load. In Group 1, there is a decrease in both indices, which is associated with the initial manifestations of inflammation and changes in the composition of saliva. In Group 2, the values are restored to the control values, although they remain moderately reduced, which may indicate tissue adaptation during the chronic process. The stability of the ratio in all groups confirms its role as an integral indicator of the balance between the state of the mucous membrane and the microbial load.

Diagnostic efficiency

MBS demonstrated superiority over clinical and isolated fluorescence assessment in all parameters (Table 3). The mean sensitivity was 93.6% (an increase of 14.2 and 5.8 p.p. compared to the clinical and fluorescence techniques), specificity — 94.6%, accuracy — 94.1%. An AUC value of 0.941 corresponds to the "excellent" quality of the model on the Hosmer-Lemeshow scale (0.9-1.0 is excellent).

Indicator	Clinical evaluation	Fluorescence Evaluation	MBS	p
Average Se (%)	79,4 ± 4,8	87,8 ± 2,4	93,6 ± 2,1	<0.001
Average Sp (%)	82,5 ± 1,6	90,6 ± 1,8	94,6 ± 1,7	<0.001
Accuracy (%)	81,0 ± 2,5	89,2 ± 1,7	94,1 ± 1,9	<0.001
AUC	0,810 ± 0,025	0,892 ± 0,018	0,941 ± 0,019	<0.001
CES (Clinical Utility)	—	65–75	87–92	<0.001

Table 3: Comparative Diagnostic Effectiveness of Methods.

A significant increase in all diagnostic parameters when using MBS confirms its advantage over isolated methods. A sensitivity of 93.6% means that the system detects 93.6 out of 100 true cases of pathology, which is critical for screening and early diagnosis. A specificity of 94.6% indicates a low rate of false-positive results, which reduces the risk of overtreatment. AUC of 0.941 indicates a high predictive power of the model. CES 87–92 confirms the high clinical utility: the system is not only accurate, but also practical for routine use.

The highest diagnostic benefit was observed for leukoplakia (AUC 0.961) and gingivitis (AUC 0.940) (Table 4).

Nosology	Se (%)	Sp (%)	AUC
Leukoplakia (n = 14)	95,8	96,3	0,961
Desquamative glossitis (n = 120)	94,2	95,0	0,946
Gingivitis (n = 150)	93,3	94,7	0,940
Caries (n = 200)	91,2	92,4	0,918

Table 4: Diagnostic characteristics for nosologies (MBS — multimodal system).

High AUC values for all nosologies confirm the versatility of MBS in the diagnosis of various dental pathologies. The best results were obtained for leukoplakia, which is due to a pronounced fluorescent picture of hyperkeratotic changes. For gingivitis, high sensitivity is associated with the possibility of detecting early microcirculatory and inflammatory changes. The slightly lower values for caries reflect the difficulty of differentiating the initial demineralization changes, but an AUC of 0.918 still corresponds to the "excellent" quality of the model.

Clinical examples (to illustrate the diagnostic informativeness of MBS)

Example 1. Leukoplakia, flat form

Patient K., 34 years old, complained of a "white spot" on the buccal mucosa. Visual examination revealed a limited area of whitish color 0.8×1.2 cm, without erosions. Clinical indices: OHIS 1.4 (satisfactory hygiene), BOP 0%, GI 0.3. Traditional diagnostics did not allow to confidently differentiate leukoplakia from traumatic hyperkeratosis. MBS revealed a decrease to 0.88 relative units and an increase to 1.52 relative units. The ratio was 1.73 (above the reference range of 1.06-1.22). This made it possible to suspect hyperkeratosis with a microbial component. After biopsy, leukoplakia without atypia was confirmed.

Example 2. Chronic gingivitis, initial stage

Patient M., 29 years old, complains of bleeding gums when brushing his teeth. Visually, there is a slight hyperemia of the interdental papillae. Clinical indices: GI 0.8, BOP 18%, OHIS 1.7. Isolated fluorescence assessment showed a moderate decrease

(1.02 relative units) without pronounced changes. MBS, integrating indices and fluorescence, made it possible to quantify the degree of inflammation and identify a risk group. According to the results of monitoring, after 3 months, the patient progressed to moderate degree of gingivitis, which confirmed the prognostic value of the method.

Example 3. Initial caries ("white spot")

Patient D., 24 years old, had a 2×3 mm matte spot on vestibular surface 2.3. DIAGNOdent showed borderline values (22–24). MBS revealed a local decrease and a slight increase, the ratio was 1.28 (above normal). This made it possible to classify the lesion as initial caries and prescribe remineralizing therapy instead of invasive treatment.

These examples demonstrate how MBS complements and refines the clinical picture, reducing diagnostic uncertainty and allowing for more informed tactics.

Discussion

In the presented study, the multimodality of MBS consists in the integration of three complementary data blocks:

- **Fluorescence imaging and spectrometry:** It allows to record endogenous fluorescence of tissues and biofluids due to mucoproteins and porphyrins of anaerobic microflora [15,17]. The key advantage is the ability to detect molecular changes before the appearance of clinically noticeable signs. Thus, the decrease reflects hyposalivation and oxidative damage to saliva proteins, and the dynamics of the ratio serves as an integral marker of the balance of microbial load and mucosal state.
- **Clinical-instrumental assessment according to standardized indices:** It provides a quantitative characteristic of local changes: inflammation, hygiene, bleeding, carious lesions. The GI, PMA, OHIS and BOP indices make it possible to objectify subjective signs and track the dynamics of the process.
- **Biomarkers of systemic stress:** Allow you to take into account the psycho-emotional component, which modulates the local immune response and salivation. The cortisol in saliva and the PSS10 scale provide a quantitative assessment of stress, which is important for understanding the pathogenesis and personalizing the approach.

The synergistic interaction of these three components explains the high diagnostic characteristics of MBS: sensitivity of 93.6%, specificity of 94.6%, and AUC of 0.941 (Table 3). Compared to isolated methods, the sensitivity increase was 14.2 p.p. relative to the clinical assessment and 5.8 p.p. relative to the isolated fluorescence technique, which is statistically significant () and clinically important for early detection of pathology.

High rates for leukoplakia are due to a pronounced fluorescent pattern of hyperkeratotic changes: mucoproteins in the hyperkeratosis zones give a characteristic spectral signature that is well detected by MBS. For gingivitis, high sensitivity is associated with the possibility of detecting early microcirculatory and inflammatory changes, which are reflected in the dynamics and , and also correlate with GI and BOP values.

Slightly lower, but still "excellent" AUC values for caries (0.918) reflect the difficulty of differentiating initial demineralization changes. Nevertheless, even in this group, MBS is superior to traditional methods: the integration of fluorescence data with OHIS and CPU indices makes it possible to increase the accuracy of diagnostics by taking into account both the microbial factor and the condition of tissues.

The results obtained are consistent with modern ideas about the role of oxidative stress in the pathogenesis of dental diseases. The increase in cortisol and PSS10 scores in patients with pathology supports the concept of a three-phase model of adaptation to stress: the exhaustion phase is associated with immunosuppression, hyposalivation, and mucosal atrophy — factors that contribute to the chronicity of dental diseases [1-16].

It is important to emphasize that MBS does not replace clinical thinking, but complements it with objective quantitative data. The system is especially valuable in controversial cases where visual evaluation is ambiguous, as well as in therapy monitoring, where accurate quantitative dynamics are important.

Conclusions

- The multimodal biophotometric system (MBS) provides high diagnostic accuracy in assessing the dental status: sensitivity is 93.6%, specificity is 94.6%, AUC is 0.941, which corresponds to the "excellent" quality of the diagnostic model.

- MBS is superior to isolated methods (clinical and fluorescence assessment) in all diagnostic parameters, providing an increase in sensitivity by 14.2 p.p. and 5.8 p.p., respectively, which is essential for early detection of pathology and reducing the risk of false negative results.
- Fluorescent indices and their ratios are informative markers of oxidative stress, hyposalivation and microbial load, allowing quantitative assessment of the pathogenetic mechanisms of dental diseases.
- The highest diagnostic efficacy of MBS was noted for leukoplakia (AUC 0.961) and gingivitis (AUC 0.940), which is due to the pronounced fluorescent signature of hyperkeratotic and inflammatory changes detected by the system.
- The integration of three components into MBS — fluorescence spectrometry, clinical instrumental indices and biomarkers of systemic stress (cortisol, PSS10) — makes it possible to implement a personalized approach to diagnostics that takes into account both local and general pathogenetic factors (oxidative stress, psycho-emotional stress).
- The stability of the ratio in different groups confirms its suitability as a universal integral marker of the functional state of oral tissues and the balance of microbial load.
- The high clinical usefulness of the system (CES 87–92) and the statistically significant superiority over traditional methods () justify the prospects of introducing MBS into routine dental practice for screening, early diagnosis and monitoring of therapy efficacy.
- The data obtained are consistent with modern scientific ideas about the role of oxidative stress and stress-induced changes in the pathogenesis of dental diseases and expand the possibilities of objectifying the assessment of dental status due to quantitative non-invasive indicators.

Annotation

Objective: To assess the diagnostic efficacy of the multimodal biophotometric system (MBS) in various dental pathologies, taking into account the influence of oxidative stress and psycho-emotional stress.

Materials and Methods: A prospective controlled single-center study was carried out with the participation of 279 patients divided into 4 groups: control (n = 30), initial manifestations of pathology (n = 57), pronounced forms (n = 171), exacerbation of chronic diseases (n = 21). Multimodal biophotometry (excitation wavelength 405 nm, spectral range of registration 400–700 nm), clinical assessment according to standardized indices, as well as biochemical analysis of unstimulated saliva were used (cortisol by ELISA, assessment of psycho-emotional stress according to the PSS10 scale).

Results: MBS demonstrated high diagnostic accuracy: sensitivity — 93.6%, specificity — 94.6%, area under the ROC curve (AUC) — 0.941, which corresponds to the "excellent" quality of the model according to the Hosmer–Lemeshow scale. The highest diagnostic gain was noted for leukoplakia (AUC 0.961) and gingivitis (AUC 0.940). Fluorescent indices (mucoproteins) and (porphyrins), as well as their ratio, turned out to be informative markers of oxidative stress, hyposalivation, and microbial load.

Conclusions: MBS provides an objective, personalized assessment of dental status, surpasses traditional methods in diagnostic accuracy and is suitable for monitoring the effectiveness of therapy.

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