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Development and Practical Application of A Mathematical Model for Predicting the Risk of Dental Diseases, Taking into Account Professional Factors

Masharipova Nasiba Ataboyevna
Urgench State Medical Institute

Abstract: Industrial workers face heightened risks of dental diseases due to prolonged exposure to harmful occupational factors like chemical reagents, high humidity, and dust. Standard dental diagnostics often fail to account for specific occupational hazards and localized immune statuses, limiting early risk identification and effective disease prediction. A clinical and laboratory study was conducted from 2022 to 2024 on 139 textile workers (dyeing shop, n=70; spinning shop, n=69) and 50 unexposed controls. Comprehensive dental status was evaluated using KPU, KPI, CPITN, and OHI-S indices. Local immunity was monitored via s-IgA and lysozyme activity, alongside biochemical and radiographic tracking. The parameters were integrated to construct a predictive mathematical risk model. Significant dental deterioration strongly correlated with work experience ($p < 0.001$). Gray-brown plaque affected up to 81.3% of workers, and deep periodontal pockets (>=6) were recorded in up to 49.2% of the dyeing group. Long-term occupational exposure initiated a severe progressive decline in local immunity, notably dropping average lysozyme activity to 34.50% in the dyeing shop. A predictive mathematical model was successfully developed, achieving a 91% diagnostic accuracy, 88% sensitivity, and 90% specificity in stratifying patient risk. Utilizing this targeted predictive framework and tailored preventive strategies significantly mitigates workplace-driven dental pathology, successfully reducing inflammatory exacerbations by 47.3% and normalizing local oral immunity.

Keywords: Occupational Hazards, Dental Caries, Periodontal Disease, Predictive Mathematical Model, Local Immunity, Textile Industry Workers.

Introduction

Globally, the development of industrial enterprises is increasing the negative impact of harmful occupational factors on workers' health. In particular, industrial workers are exposed to factors such as cotton and synthetic dust, chemical reagents, dyes, elevated temperatures, and humidity, which can negatively impact the dental system [1]. Chemical compounds used in industrial production—such as formaldehyde, peroxides, and hypochlorites—irritate the oral mucosa, contributing to the development of periodontal disease and increasing the risk of dental caries and dry mouth (xerostomia).

Research is being conducted worldwide on the diagnosis and prevention of various dental diseases, particularly among industrial workers. According to statistics, the prevalence of periodontal disease reaches 90–95%, necessitating the development of new diagnostic and preventive approaches. Modern dentistry considers not only the condition of the dental system but also factors affecting patients' overall health, social adaptation, and quality of life. Many scientific studies focus on improving diagnostic and preventive methods for dental diseases among industrial workers [2]. In particular, in many cases, the informative value of examinations based solely on standard diagnostic approaches is insufficient, as they fail to consider occupational factors and the infectious status of workers, limiting the ability to identify risk groups and predict disease progression. Therefore, the early diagnosis of dental diseases among industrial workers has become a pressing issue.

Methods

To evaluate the impact of occupational hazards on oral health, a comprehensive clinical and laboratory methodology was implemented from 2022 to 2024 at Urganch Bahmal LLC and TEXTILE FINANCE KHOREZM LLC in Urgench. The study cohort comprised 139 industrial workers aged 20 to 59, divided into a dyeing shop group (n=70) and a spinning shop group (n=69), alongside 50 non-exposed control participants matched for age and gender. Comprehensive clinical dental examinations were performed according to 1985 WHO recommendations, assessing hard tissues and periodontal status via the KPI, CPITN, OHI-S, and KPU indices. Local immunity was monitored by measuring secretory immunoglobulin A (s-IgA) and lysozyme activity using ELISA with Vector-Best test systems on BioRad and Shimadzu devices [3]. Biochemical blood analyses, reflecting carbohydrate-lipid metabolism and inflammatory markers like procalcitonin and VEGF-A, were processed on a COBAS 6000 analyzer. Radiographic evaluation of periodontal bone structures was conducted utilizing orthopantomography and cone-beam computed tomography with low-dose protocols. Oral health-related quality of life was quantified via the OHIP-49-RU questionnaire on a Likert scale. Finally, statistical processing was executed using IBM SPSS Statistics 21, applying Student's t-test and Spearman's correlation to establish significance ($p<=0.05$). These consolidated parameters were integrated into a predictive mathematical model—evaluating CPITN, KPI, OHI-S, s-IgA, and lysozyme activity—which demonstrated a 91% diagnostic accuracy in stratification of dental disease risks [4].

Results and Discussion

The article presents clinical and dental examinations, biochemical, immunological, radiological and statistical methods, as well as the development of a mathematical model that provides solutions to the problems posed by industrial workers.

In accordance with established objectives, workers at industrial enterprises underwent a comprehensive dental examination in accordance with WHO recommendations (1985).

The study was conducted from 2022 to 2024, involving 139 employees of Urganch Bahmal LLC and TEXTILE FINANCE KHOREZM LLC in the city of Urgench in the Khorezm region. Workers from the dyeing and spinning shops were selected based on the patients' work activities and the state of the production facility.

Dyeing shop (main) - 70 patients.

Spinning shop (main) - 69 patients.

Control group - 50 patients.

The study involved patients employed by industrial enterprises, aged 20 to 59. All participants were divided into study groups based on their place of residence, production facility, and length of service. The control group consisted of 50 individuals matched to the study group by gender and age, but not employed by industrial enterprises. The control group consisted of patients seeking dental care at clinics in the Khorezm region [5].

Table 1. Distribution of study participants by place of residence (n=139).

Group	Urban area		Countryside		Total
	Abs.	(%)	Abs.	(%)	
Dyeing shop	48	68.6	22	31.4	70
Spinning mill	44	63.8	25	36.2	69
Control group	30	60.0	20	40.0	50

Note: *Significance was observed relative to the control group* $p < 0.05$.

It was found that 68.6% of dye shop workers and 63.8% of spinning shop workers resided in urban areas. In the control group, the proportion of urban residents was 60%. The proportion of workers living in rural areas was 31.4% in the dye shop, 36.2% in the spinning shop, and 40% in the control group.

The 31–40 age group predominated among workers in the dyeing shop (42.9%) and spinning shop (40.6%). In the control group, respondents were evenly distributed across age categories.

Table 2. Distribution of study participants by age groups (**n** = 139).

Group	Total patients (n=139)	22-30 yrs.		31-40 years		41-52 years old		P- value
		Abs.	%	Abs.	%	Abs.	%	
Dyeing shop	70	20	28.6%	30	42.9%	20	28.6%	p > 0.05
Spinning mill	69	22	31.9%	28	40.6%	19	27.5%	p > 0.05
Control group	50	15	30.0%	20	40.0%	15	30.0%	p > 0.05

Note: *Mean values are shown at 95% confidence level. Differences between groups are not statistically significant (p > 0.05).*

Table 3. Distribution of study participants by gender (**n** = 139).

Group	Total patients (n=139)	Female		Husband.		P- value
		Abs.	%	Abs.	%	
Dyeing shop	70	59	84.3%	11	15.7%	p > 0.05
Spinning mill	69	65	94.2%	4	5.8%	
Control group	50	39	78.0%	11	22.0%	

Note: *Mean values are shown at 95% confidence level. Differences between groups are not statistically significant (p > 0.05).*

Women constituted 84.3% of workers in the dyeing shop and 94.2% of workers in the spinning shop. In the control group, their share was 78%. Men constituted 15.7% of workers in the dyeing shop, 5.8% of workers in the spinning shop, and 22% of workers in the control group.

Dental status was assessed using the KP U, OHI-S, CPITN, and KPI indices. The OHI-S oral hygiene index ranged from satisfactory to unsatisfactory.

The state of local immunity was assessed by determining s- IgA and lysozyme. The determination was carried out by the ELISA method using the Vector-BestTs test system (Russia) with optical density analysis (BioRad devices). Model 680, USA and UV-1800, Shimadzu, Japan).

Biochemical blood analysis was performed on the COBAS 6000 device (Roche Diagnostics, Germany) and included indicators of carbohydrate-lipid metabolism (glucose, cholesterol, LDL, HDL, triglycerides, atherogenic index), as well as inflammation markers (procalcitonin, VEGF-A).

X-ray diagnostics were carried out using orthopantomography (Planmeca ProMax S2 2D, Finland) and cone beam computed tomography (low-dose load, 40 μSv), aimed at assessing the condition of bone tissue and periodontal diseases.

Quality of life was assessed using the OHIP-49-RU questionnaire (49 questions, Likert scale), where high scores indicated severe functional and social impairments.

Statistical analysis was performed using IBM SPSS Statistics 21 software: Student's t-test (M±SD, p ≤ 0.05) and Spearman's correlation analysis were used.

An analysis of oral hygiene revealed statistically significant differences in the OHI-S index between dyeing and spinning shop workers and the control group [6], [7]. With increasing length of service, a trend toward deterioration in oral hygiene indicators was observed, which was associated with exposure to occupational factors, including high dust, humidity, and chemical exposure (Table 4).

Table 4. Distribution of the OHI-S index by length of service.

Work experience	Dyeing shop (n=70) points	Spinning shop (n=69) score	Control group (n=50)
Up to 5 years	2.7±0.06	2.51±0.04	1.31±0.13
5-10 years	3.14±0.05	2.75±0.05	-
10-15 years	3.37±0.04	3.15±0.06	-
>15 years	3.84±0.05	3.34±0.05	-

***Note:** Correlation is significant at p < 0.01.*

The average OHI-S index value was 3.48 ± 0.07 for dye shop workers, 2.97 ± 0.06 for spinning shop workers, and 1.31 ± 0.13 in the control group. A statistically significant association was established between increased length of service and deterioration in oral hygiene indicators (p = 0.001). Poor oral hygiene (OHI- S > 3.0) was recorded in 76.9% of industrial workers.

Gray-brown plaque, caused by the deposition of dye microparticles, was observed on the teeth of 81.3% of dye shop workers and 72.5% of spinning shop workers. The incidence of gray-brown plaque increased with length of service: among workers with more than 15 years of service, it was detected in 89.2% of cases, compared with 63.4% of those with less than 5 years of service. No differences in plaque incidence were found between dye shop and spinning shop workers (p = 0.688) [8].

The condition of dental hard tissues was analyzed using the KPO index, which reflects the intensity of the caries process. A statistically significant increase in the KPO Y index with increasing work experience was found. Among workers with more than 15 years of experience, the average KPO Y index was 9.8 ± 0.06 in the dye shop and 9.1 ± 0.05 in the spinning shop, which is 3.5 and 3.25 times higher than the control group values, respectively (p < 0.001) [9].

Table 5. Average values of the KPU index among workers of industrial enterprises.

Work experience	Dyeing shop (M±m)	Spinning mill (M±m)	Control group (M±m)	p-value
Up to 5 years	4.9±0.05	4.5±0.04	2.8±0.03	
5-10 years	6.7±0.06	6.0±0.05	-	p <
10-15 years	8.1±0.05	7.3±0.06	-	0.001
> 15 years	9.8±0.06	9.1±0.05	-	

***Note:** Differences between groups are considered significant at a confidence level of p < 0.001.*

With increasing length of service, a decrease in the proportion of filled teeth and an increase in the number of extracted teeth was noted.

Table 6. Distribution of the constituent components of the KPU index (%).

Work experience	Dyeing shop (K/P/U, %)	Spinning mill (K/P/U, %)	Control group (C/P/U, %)	p-value
up to 5 years	55 / 38 / 7	50 / 41 / 9	34 / 31 / 5	
5-10 years	61 / 32 / 7	57 / 35 / 8	-	p <
10-15 years old	67 / 26 / 7	62 / 31 / 7	-	0.001
> 15 years	72 / 18 / 10	68 / 22 / 10	-	

***Note:** The frequency of dental lesions depends on the length of service (p < 0.01).*

The incidence of secondary edentia increased with length of service. Among dye shop workers with over 15 years of service, secondary edentia was recorded in 34.2% of cases, exceeding similar rates in the spinning shop (27.4%) and the control group (14.3%).

Data analysis revealed that the incidence of non-carious lesions increases significantly with length of service. Among workers with more than 15 years of service, enamel erosion was detected in 61.9% of cases, which is 1.8 times higher than among workers with less than 5 years of service. Pathological abrasion was also 1.8 times more common, and wedge-shaped defects were 1.4 times more common.

Industrial workers had a higher incidence of deep periodontal pockets (≥6 mm) compared to the control group [10], [11]. In the paint shop, periodontal pockets ≥6 mm deep were recorded in 49.2% of workers, which is 4.1 times higher than the control group (12.0%).

Industrial workers had a higher incidence of deep periodontal pockets (≥6 mm) compared to the control group. In the dyeing shop, periodontal pockets ≥6 mm deep were recorded in 49.2% of workers, which is 4.1 times higher than the control group (12.0%). In the spinning shop, similar changes were detected in 43.7% of workers. These findings indicate the presence of a pronounced inflammatory process and confirm a link between occupational conditions and periodontal disease.

Among workers with less than 5 years of experience, bleeding gums were the most common, occurring in 53.4% of cases in the dyeing shop and 49.1% in the spinning shop. Among workers with more than 15 years of experience, deep periodontal pockets (≥6 mm) were the most common, occurring in 53.9% of cases in the dyeing shop and 48.6% in the spinning shop [12].

The average values of the KPI index, reflecting the degree of periodontal damage, were significantly higher in textile industry workers (4.2 ± 0.05) compared to the control group. The significant impact of occupational factors on periodontal tissue was confirmed by clinical data. Periodontal disease was diagnosed in 94.5% of industrial workers, which is 4.3 times higher than the same indicator in the control group.

The CPITN index revealed significant differences between the groups. Gum bleeding was recorded in 20.8% of dyeing shop workers and 27.3% of spinning shop workers, significantly higher than in the control group. Periodontal pockets 4–5 mm deep were found in 19.5% of dyeing shop workers and 15.8% of spinning shop workers, exceeding the control group's rates by 2.4 and 2.0 times, respectively. Deep periodontal pockets (≥6 mm) were detected in 49.2% and 43.7% of dyeing shop workers and spinning shop workers, respectively, also significantly exceeding the control group's rates [13].

The severity of periodontal disease increased with increasing length of service. Among workers with up to 5 years of service, bleeding gums were more common (53.4% in the dyeing shop and 49.1% in the spinning shop). Among those with more than 15 years of service, deep periodontal pockets (≥6 mm) were found in 53.9% and 48.6% of workers, respectively.

An analysis of the KPI index depending on work experience revealed a significant relationship between the duration of exposure to occupational factors and the severity of periodontal diseases. Employees with up to 5 years of experience were more likely to have mild periodontal disease, with an average KPI index value of 1.98 ± 0.06. With increasing experience, an increase in the incidence of moderate and severe diseases was recorded. The average KPI index values were: for 6-10 years of experience - 2.98 ± 0.06; for 11-15 years of experience - 3.69 ± 0.05; and for more than 15 years of experience - 4.04 ± 0.04.

Lysozyme activity was also lower in workers in the dyeing shop, averaging 34.50 ± 0.37%, while in the spinning shop it was 51.77 ± 1.27%. An analysis of the effect of the duration of professional activity on local immunity indicators revealed that long-term exposure to harmful production factors leads to a progressive decrease in lysozyme activity [14]. Among specialists with up to 5 years of experience, this indicator averaged 55.12 ± 2.73%, which is 20% higher than that of workers with 6 to 10 years of experience (an average of 47.13 ± 1.70%), and 50% higher than that of individuals with the longest work experience, for whom the average indicator was 37.66 ± 0.93%.

With an increase in work experience, a decrease in the concentration of sIgA was also observed: for workers with 0 to 5 years of experience, this indicator averaged 0.511 ± 0.042 g/l, while for workers with 10–15 years of experience, it averaged 0.454 ± 0.032 g/l.

< 0.01), respectively, which significantly exceeded the values in the control group (2.81 ± 0.17 mmol/l).

The level of triglycerides in both production groups was significantly increased: in the dyeing shop – on average 1.87 ± 0.13 mmol/l, in the spinning shop – 1.73 ± 0.11 mmol/l ($p < 0.01$), compared with the control group (1.28 ± 0.09 mmol/l).

atherogenic index, reflecting the ratio of pro- and antiatherogenic lipid fractions, also turned out to be significantly higher in the production groups: in the dyeing shop - on average 3.85 ± 0.31 ($p < 0.01$), in the spinning shop - 3.41 ± 0.28 ($p < 0.05$), while in the control group it was 2.45 ± 0.

The developed mathematical model for predicting the risk of dental diseases has an accuracy of 91%, diagnostic sensitivity of 88%, and specificity of 90%. The model's key indicators are the CPITN, KPI, and OHI-S indices, as well as sIgA levels and lysozyme activity [15]. The model allows workers to be classified according to risk levels: low, medium, and high.

Conclusions

The implementation of a preventive strategy reduced the incidence of exacerbations of inflammatory processes associated with dental diseases by 47.3%, improved oral hygiene in 82.5% of workers, and normalized immunological parameters in 67.9% of cases. The CPITN and KPI indices decreased by 20% and 18%, respectively. Among those in the high-risk group, the KPI index decreased from 9.8 to 7.1.

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