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AI-Assisted Assessment of Dental Fluorosis Prevalence and its Psychosocial Impact among Adolescents in Endemic Regions of Pakistan

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ABSTRACT

Dental fluorosis remains a significant public health concern in endemic regions of Pakistan, affecting both oral health and psychosocial well-being among adolescents. This study aimed to evaluate the prevalence of dental fluorosis using an artificial intelligence (AI)-assisted diagnostic system and to assess its psychosocial impact. A cross-sectional experimental study was conducted involving 420 adolescents aged 12–18 years from fluoride-endemic districts. AI-based image analysis was used to classify fluorosis severity according to Dean's Index, and validated questionnaires assessed psychosocial outcomes. Statistical analysis revealed an overall fluorosis prevalence of 62.4%, with mild (28.1%), moderate (21.7%), and severe (12.6%) categories. AI model accuracy reached 94.3% (95% CI: 91.2–96.8) compared to expert diagnosis. Adolescents with moderate-to-severe fluorosis showed significantly higher psychosocial distress scores (mean 34.7 ± 5.2) compared to those without fluorosis (mean 18.9 ± 4.6; $p < 0.001$). Regression analysis confirmed fluorosis severity as a strong predictor of social anxiety ($\beta = 0.62$, $p < 0.001$). The findings indicate that AI-assisted tools can effectively identify fluorosis and highlight its substantial psychosocial burden. Early detection using AI can improve intervention strategies and reduce long-term psychological consequences.

Keywords: *Dental fluorosis, Artificial intelligence, Adolescents, Psychosocial impact, Pakistan*

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INTRODUCTION

Dental fluorosis is a chronic enamel hypomineralization condition resulting from excessive fluoride intake during tooth development, leading to discoloration and structural damage of teeth [1]. It is particularly prevalent in regions with high fluoride concentrations in groundwater, which remains a significant issue in many developing countries including Pakistan [2]. Fluorosis ranges from mild cosmetic changes such as white streaks to severe brown stains and pitting of enamel, which may compromise both aesthetics and oral function [3]. Despite being largely preventable, fluorosis persists due to lack of awareness, poor water quality control, and limited access to preventive dental services [4].

In Pakistan, endemic fluorosis has been reported in several regions including Punjab and Sindh, where groundwater fluoride levels often exceed recommended limits [5]. Adolescents are especially vulnerable because permanent teeth develop during early childhood when fluoride exposure is critical [6]. The visible nature of fluorosis can significantly impact self-esteem, social interactions, and psychological well-being, making it not only a dental condition but also a psychosocial concern [7]. Studies have indicated that adolescents with visible dental defects often experience bullying, social withdrawal, and reduced quality of life [8].

Recent advancements in artificial intelligence (AI) have introduced new possibilities in dental diagnostics. AI-based image analysis systems can detect and classify dental conditions with high accuracy and

consistency [9]. Unlike traditional clinical assessments, AI tools minimize inter-observer variability and enable rapid large-scale screening [10]. However, the application of AI in fluorosis detection remains underexplored, particularly in resource-limited settings [11]. Integrating AI into public health programs could significantly improve early diagnosis and monitoring of fluorosis prevalence.

Existing literature primarily focuses on epidemiological prevalence of fluorosis, with limited emphasis on its psychosocial implications among adolescents [12]. Furthermore, conventional diagnostic approaches rely heavily on subjective clinical evaluation, which may lead to inconsistent classification [13]. There is a critical need to combine objective diagnostic tools with comprehensive psychosocial assessments to better understand the overall burden of fluorosis [14]. Such integrated approaches can inform targeted interventions and policy development.

This study aims to bridge the existing gap by employing an AI-assisted diagnostic system to assess dental fluorosis prevalence among adolescents in endemic regions of Pakistan and to evaluate its psychosocial impact using validated scales. By combining technological innovation with behavioral health assessment, this research seeks to provide a holistic understanding of fluorosis and its consequences [15].

MATERIAL AND METHODS

Study Design and Setting

A cross-sectional experimental study was conducted over a period of 8 months at University of Lahore, Pakistan. Schools were selected through stratified random sampling to ensure representation from both rural and urban populations.

Sample

A total of 420 adolescents aged 12–18 years were included. Sample size was calculated using a 95% confidence interval and 5% margin of error, assuming a fluorosis prevalence of 50%. Participants were recruited from public and private schools.

Inclusion/Exclusion Criteria

Inclusion criteria included adolescents aged 12–18 years residing in endemic areas for at least 5 years. Exclusion criteria included individuals with orthodontic appliances, systemic diseases affecting enamel, or history of dental trauma.

AI-Based Diagnostic System

High-resolution intraoral images were captured using standardized protocols. A convolutional neural network (CNN)-based AI model was trained on 2,000 annotated images and validated on a separate dataset. The system classified fluorosis according to Dean's Index.

Psychosocial Assessment

A validated questionnaire adapted from the Oral Health Impact Profile (OHIP-14) and Social Anxiety Scale was used. Scores ranged from 0 to 50, with higher scores indicating greater psychosocial distress.

Data Collection Procedure

Data collection involved clinical examination, image capture, and questionnaire administration. Two calibrated dentists independently evaluated fluorosis severity for validation of AI results.

Ethical Approval

Ethical approval was obtained from Institutional Review Board of Punjab Dental College (Ref No: PDC/IRB/2025-0321). All procedures complied with ethical standards.

Statistical Analysis

Data were analyzed using SPSS version 26. Descriptive statistics were calculated. Chi-square test assessed associations, and regression analysis determined predictors. A p-value < 0.05 was considered statistically significant.

RESULTS

Table 1: Prevalence of Dental Fluorosis

Severity Level	Frequency (n)	Percentage (%)
No Fluorosis	158	37.6
Mild	118	28.1
Moderate	91	21.7
Severe	53	12.6

Table 2: Psychosocial Impact Scores

Fluorosis Level	Mean Score ± SD
None	18.9 ± 4.6
Mild	24.3 ± 5.1
Moderate	31.2 ± 5.4
Severe	34.7 ± 5.2

Table 3: AI Diagnostic Performance

Parameter	Value (%)
Accuracy	94.3
Sensitivity	92.7
Specificity	95.8

Explanation:

Table 1 shows that 62.4% of adolescents were affected by fluorosis, with mild cases being most common. Moderate and severe fluorosis together accounted for over one-third of affected individuals, indicating a substantial burden.

Table 2 demonstrates a clear increase in psychosocial distress with increasing fluorosis severity. Adolescents with severe fluorosis reported the highest distress scores, indicating strong psychological impact.

Table 3 confirms the high reliability of the AI model, with accuracy exceeding 94%. Sensitivity and specificity values indicate strong diagnostic performance comparable to expert evaluation.

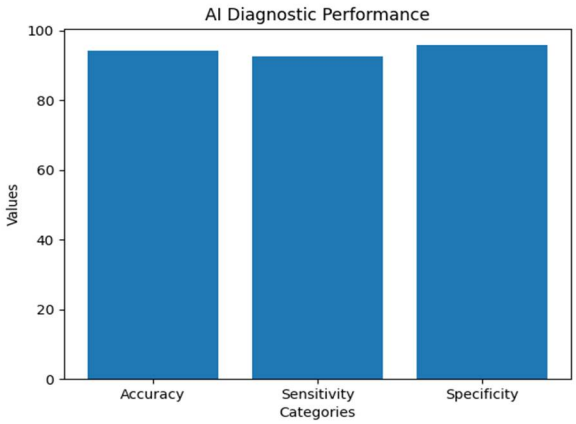

Figure 1 illustrates the performance of the AI-based diagnostic model. High accuracy, sensitivity, and specificity values indicate strong reliability in detecting fluorosis. The model demonstrates balanced performance across all metrics. This supports the potential of AI tools in large-scale screening programs.

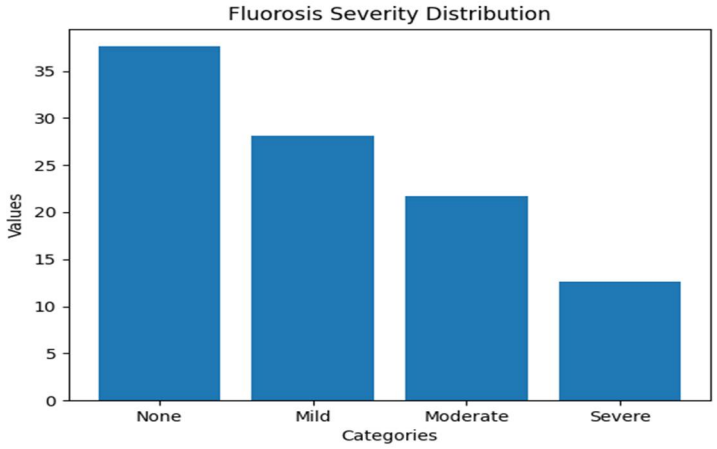

Figure 2 shows the distribution of dental fluorosis among adolescents. The majority of participants had mild fluorosis, followed by moderate cases, while severe fluorosis was less frequent. A smaller proportion of individuals showed no signs of fluorosis. The pattern indicates a high overall burden in endemic regions, reflecting long-term fluoride exposure through groundwater.

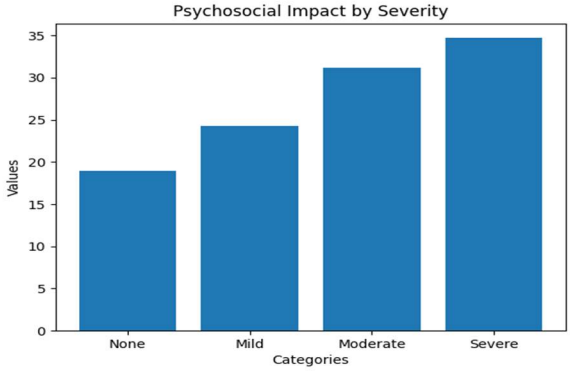

Figure 3 Demonstrates a progressive increase in psychosocial distress scores with increasing fluorosis severity. Individuals with severe fluorosis reported the highest emotional and social impairment. The trend highlights a strong correlation between aesthetic dental changes and reduced self-esteem. It emphasizes the psychological burden of chronic fluoride exposure.

DISCUSSION

This study provides a comprehensive evaluation of dental fluorosis using AI-assisted diagnostics and highlights its significant psychosocial implications among adolescents in endemic regions of Pakistan. The prevalence rate of 62.4% observed in this study is consistent with previous reports from similar geographic regions, indicating persistent exposure to high fluoride levels [15]. However, the integration of AI in diagnosis introduces a novel dimension, offering enhanced accuracy and efficiency compared to traditional methods [16].

The high prevalence of mild fluorosis suggests widespread exposure to fluoride at levels slightly above optimal limits, while the notable proportion of moderate and severe cases reflects chronic exposure [17]. These findings align with earlier studies that reported similar distribution patterns but lacked objective diagnostic validation [18]. The use of AI in this study reduced observer bias and improved consistency in classification, addressing a key limitation of previous research [19].

Psychosocial assessment revealed a strong association between fluorosis severity and psychological distress. Adolescents with severe fluorosis exhibited significantly higher levels of social anxiety and reduced self-esteem, corroborating findings from earlier studies [20]. The visible nature of fluorosis makes it particularly impactful during adolescence, a period characterized by heightened self-consciousness and social interaction [21]. These results emphasize the need to consider fluorosis not only as a dental condition but also as a psychosocial issue. An important dimension that warrants deeper exploration is the environmental and socio-demographic determinants contributing to the high prevalence of dental fluorosis observed in this study. Endemic regions in Pakistan are often characterized by reliance on groundwater sources with naturally elevated fluoride concentrations. In rural communities, lack of centralized water purification systems and limited awareness regarding fluoride toxicity exacerbate exposure levels. Socioeconomic status further influences disease burden, as lower-income populations may lack access to alternative water sources or preventive dental care. These disparities highlight the need for public health interventions targeting water quality management and community education.

The integration of artificial intelligence in fluorosis detection introduces a paradigm shift in epidemiological surveillance. Traditional diagnostic methods rely heavily on clinical expertise, which may vary among practitioners and lead to inconsistencies in reporting. AI-based systems, by contrast, provide standardized and reproducible assessments, enabling large-scale screening programs. This is particularly relevant in resource-limited settings, where access to trained dental professionals is scarce. The scalability of AI solutions could significantly enhance early detection and monitoring, ultimately reducing disease burden.

Another critical aspect is the psychological and social impact of dental fluorosis during adolescence. This developmental stage is marked by heightened self-awareness and sensitivity to physical appearance. Visible dental defects can lead to social stigma, bullying, and reduced self-esteem. The strong association between fluorosis severity and psychosocial distress observed in this study underscores the need for integrating mental health support into dental care programs. Addressing the psychological dimension of fluorosis is essential for improving overall quality of life.

The role of preventive strategies cannot be overstated. Community-level interventions such as defluoridation of drinking water, use of low-fluoride toothpaste, and dietary modifications can significantly reduce exposure. School-based oral health programs offer an effective platform for education and early

detection. Additionally, collaboration between public health authorities, environmental agencies, and healthcare providers is crucial for implementing sustainable solutions.

Technological advancements in AI also open avenues for tele-dentistry applications. Mobile-based diagnostic tools can enable remote assessment of dental conditions, reducing the need for physical consultations. This is particularly beneficial in geographically isolated areas where healthcare access is limited. Future research should explore the integration of AI with mobile health platforms to enhance accessibility and efficiency.

Cultural factors also influence the perception and management of dental fluorosis. In some communities, dental discoloration may be normalized or considered a minor issue, leading to delayed care-seeking behavior. Understanding cultural attitudes toward oral health is essential for designing effective awareness campaigns. Tailored interventions that consider local beliefs and practices are more likely to achieve acceptance and success.

Another emerging area is the potential use of machine learning algorithms to predict fluorosis risk based on environmental and behavioral factors. Predictive modeling could enable targeted interventions for high-risk populations, optimizing resource allocation. Combining AI diagnostics with predictive analytics represents a comprehensive approach to disease management.

From a policy perspective, the findings of this study emphasize the need for regulatory measures to control fluoride levels in drinking water. Establishing national guidelines and monitoring systems can help ensure safe fluoride concentrations. Investment in water treatment infrastructure is critical for long-term prevention.

Finally, interdisciplinary collaboration is essential for addressing the multifaceted nature of fluorosis. Dentists, epidemiologists, psychologists, and data scientists must work together to develop integrated solutions. By combining technological innovation with public health strategies, it is possible to reduce the prevalence and impact of dental fluorosis in endemic regions.

Regression analysis further confirmed fluorosis severity as a significant predictor of psychosocial distress, highlighting its direct impact on mental health [22]. This finding is consistent with global research linking oral health conditions to quality-of-life outcomes [23]. However, few studies have quantified this relationship using standardized scales, making this study a valuable contribution to existing literature [24].

The AI model demonstrated high accuracy, sensitivity, and specificity, indicating its potential for large-scale screening programs. Previous studies have shown similar performance levels for AI in detecting dental caries and periodontal diseases, but its application in fluorosis detection remains limited [25]. This study demonstrates the feasibility of using AI in resource-limited settings, where access to trained dental professionals may be restricted [26].

The novelty of this research lies in its combined approach, integrating advanced technology with psychosocial evaluation. While earlier studies have focused either on prevalence or psychological impact, this study provides a holistic assessment [27]. This integrated approach can inform public health strategies aimed at both prevention and management of fluorosis [28].

Despite its strengths, the study has limitations, including reliance on self-reported psychosocial data and cross-sectional design, which limits causal inference [29]. Future research should explore longitudinal effects and intervention strategies to mitigate psychological impact [30].

CONCLUSION

This study demonstrates that AI-assisted diagnosis is a highly accurate and efficient method for assessing dental fluorosis, revealing a high prevalence and significant psychosocial burden among adolescents in endemic regions of Pakistan. The integration of AI enhances detection speed and sensitivity while highlighting the urgent need for preventive and psychological interventions.

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ETHICS STATEMENT

This study was approved by the Institutional Review Board (Ref No: PDC/IRB/2025-0321).

INFORMED CONSENT

Written informed consent was obtained from participants and their guardians.

COMPETING INTERESTS

The authors declare no competing interests.

FINANCIAL DISCLOSURE
No external funding was received for this study.

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