AI-DRIVEN PREDICTIVE MODELING FOR DIGITAL SMILE DESIGN AND ESTHETIC OUTCOMES.

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ABSTRACT
Digital smile design has become an important part of esthetic dentistry, but conventional planning still depends heavily on clinician judgment. Artificial intelligence may improve the objectivity and predictability of smile esthetic assessment. Thus our aim was to develop and validate an AI model predicting digital smile design esthetic outcome among 50 patients requiring esthetic smile analysis and digital smile design. Standardized extraoral and intraoral photographs, along with digital records or scans, were collected using a calibrated protocol. AI-based predictive modeling was applied to analyze facial and dental parameters, generate digital smile designs, and predict esthetic outcomes. We had found that, AI model showed strong predictive performance with high training accuracy, validation accuracy, sensitivity, specificity, and overall agreement with expert design. There was no statistically significant difference between AI prediction and clinician assessment for major esthetic parameters such as smile arc, gingival display, midline alignment, tooth proportion, and overall esthetic score. Patient satisfaction was also high, with most participants reporting aesthetic improvement, improved confidence, and willingness to accept the AI-generated design. Thus, we have come to conclude that, AI-driven predictive modeling is a reliable adjunct for digital smile design and may improve esthetic treatment planning, clinical consistency, and patient satisfaction.

Keywords: Artificial Intelligence**,** Digital Smile Design**,** Esthetic Outcome, Predictive modeling, Patient satisfaction.
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INTRODUCTION

Digital smile design (DSD) has emerged as an important clinical and communication tool in esthetic dentistry.[1] It uses digital photographs, video records, facial reference lines, and software-based analysis to simulate esthetic treatment outcomes before clinical intervention.[1] This approach allows clinicians to evaluate facial proportions, dental relationships, and soft tissue display more systematically than traditional manual planning.[2] DSD also improves communication between clinician and patient because it makes the final outcome easier to visualize and understand, thereby helping patients participate more actively in treatment decisions. In this way, DSD supports both clinical precision and patient-centered care.[2,3]

Artificial intelligence (AI) has introduced a new direction in digital dentistry by enabling computers to analyze images, identify patterns, and make predictions with increasing accuracy.[4] In esthetic dentistry, AI can potentially assist in landmark detection, smile assessment, treatment simulation, and prediction of treatment outcomes.[1] Recent reviews have shown that AI integration in DSD may improve precision, reduce planning time, and enhance interdisciplinary communication.[2,4] AI-based systems can also help reduce subjectivity by providing standardized analysis of facial and dental features, which is particularly valuable in esthetic disciplines where individual judgment can vary. Several recent studies have begun to explore the clinical potential of AI in smile design.[3,5] A prospective clinical trial on AI-powered smile simulation found that some smile parameters could be predicted reliably, while others were less consistent, highlighting both the promise and the current limitations of AI-based estimation.[2] Comparative studies have also shown that AI-generated digital smile designs can be acceptable to clinicians and patients, although performance may vary depending on case symmetry and the method of design generation. These findings suggest that AI may already be useful as a supportive tool in esthetic planning, but stronger validation is still needed before it can be used routinely.[3,5] Despite the rapid development of DSD and AI tools, the literature still has important gaps therefore, there was a need for structured clinical studies that assess the predictive accuracy and practical utility of AI-assisted smile design.

AIM

To develop and validate an AI model predicting digital smile design esthetic outcomes.

MATERIALS AND METHOD

This prospective observational study included 50 patients in total who all were seeking esthetic smile analysis and digital smile design. Patients were selected from the outpatient clinic based on eligibility criteria, and informed consent was obtained before enrollment. Standardized extraoral frontal facial photographs, smiling photographs, intraoral photographs, and digital records or scans was collected using a calibrated imaging protocol with consistent patient positioning, lighting, and camera settings to ensure uniform data quality. These images and records was then be used for AI-based predictive modeling to assess key facial and dental parameters such as smile line, tooth proportions, midline position, incisal display, gingival exposure, and symmetry. The AI system generate digital smile design predictions, which was compared with clinician-generated assessments and patient satisfaction scores to evaluate esthetic accuracy and clinical relevance. The collected data was then analyzed using appropriate statistical methods to measure agreement, predictive performance, and overall outcome reliability**.**

INCLUSION CRITERIA

1. 18 years and above
2. Those seeking esthetic dental treatment or smile design.
3. Those complete clinical records and standardized facial/intraoral photographs.
4. Those with sufficient smile visibility for digital analysis.

EXCLUSION CRITERIA

1. Those with craniofacial anomalies or syndromic conditions.
2. Those with severe facial asymmetry.
3. Those with active periodontal disease or untreated oral pathology.
4. Those with poor-quality or incomplete photographs/records.

STATISTICAL ANALYSIS

The collected data was entered into Microsoft Excel and analyzed using appropriate statistical software. Descriptive statistics was used to summarize demographic variables and clinical parameters, with continuous data presented as mean and standard deviation and categorical data as frequency and percentage. The predictive performance of the AI model was assessed by comparing AI-generated smile outcomes with clinician assessments and patient satisfaction scores using correlation analysis, intraclass correlation coefficient, and agreement tests such as Cohen's kappa where applicable. For group comparisons are required, independent t test or chi-square test was applied for normally distributed continuous and categorical variables, respectively, while nonparametric tests was used for non-normal data. A p value of less than 0.05 was considered statistically significant.

RESULT

VARIABLE	CATEGORY	FREQUENCY (n=50)	PERCENTAGE (%)
Age	18-25 years	14	28%
	26-35 years	18	36%
	36-45 years	11	22%
	>45 years	7	14%
Gender	Male	21	42%
	Female	29	58%
Type of Esthetic Concern	Tooth shape/ size	15	30%

	Midline Discrepancy	11	22%
	Gingival Display	12	24%
	Smile Asymmetry	12	24%

TABLE 1: DEMOGRAPHIC PROFILE

Table 1 showed that the largest proportion of participants belonged to the 26–35 years age group, followed by 18–25 years, suggesting that esthetic smile concerns were more common among younger adults. Females constituted a greater share of the study population than males, indicating a higher esthetic awareness or treatment-seeking tendency among women. Among the esthetic concerns, tooth shape/size was the most frequent, while gingival display and smile asymmetry were also common, showing that the participants mainly presented with visible smile-related issues. Overall, this distribution suggests that the study included a clinically relevant group suitable for evaluating AI-driven digital smile design and esthetic outcome prediction.

PARAMETER	MEAN±SD
Smile width (mm)	47.6±3.8
Maxillary Incisor Display (mm)	8.4±1.6
Gingival Display (mm)	2.1±0.9
Midline Deviation (mm)	1.8±0.7
Smile Arc Score	2.4±0.6
Buccal Corridor Ratio	0.72±0.08

TABLE 2 : BASELINE SMILE PARAMETER BEFORE AI MODELING

Table 2 showed that the study participants had measurable variations in smile esthetics before AI modeling was applied. The mean smile width of 47.6 mm suggests that most patients had an average visible smile span, while the maxillary incisor display of 8.4 mm indicates adequate tooth exposure during smiling. The gingival display mean of 2.1 mm reflects mild gingival visibility, which is an important esthetic factor in smile analysis. Midline deviation, with a mean of 1.8 mm, suggests the presence of minor dental alignment discrepancies that may influence overall smile harmony. The smile arc score of 2.4 and buccal corridor ratio of 0.72 indicate moderate esthetic balance, but not an ideal smile pattern in all patients. Overall, these baseline findings suggest that the sample had clinically relevant esthetic variations, making it suitable for evaluating the ability of the AI model to predict and improve digital smile design outcomes.

PERFORMANCE MEASURE	VALUE
Training Accuracy (%)	92.0
Validation Accuracy (%)	88.0
Sensitivity (%)	86.0
Specificity (%)	90.0
Area under Curve (AUC)	0.91
Mean Absolute Error	0.84
Overall Agreement with expert design (%)	86.0

TABLE 3 : AI MODEL PREDICTIVE PERFORMANCE

Table 3 showed strong predictive performance in both training and validation, indicating that it learned the smile design patterns well and also generalized effectively to new cases. The training accuracy of 92.0% and validation accuracy of 88.0% suggest only a small decline in performance, which is a good sign of model stability and limited overfitting. The sensitivity of 86.0% shows that the model correctly identified most positive esthetic outcomes, while the specificity of 90.0% indicates a high ability to recognize less favorable outcomes accurately. The AUC value of 0.91 reflects excellent discriminative power, meaning the model was highly effective in distinguishing between different esthetic result categories. The mean absolute error of 0.84 suggests that prediction errors were low and clinically acceptable. Overall agreement with expert design was 86.0%, showing that the AI-generated smile designs were closely aligned with clinician judgment. Overall, these results indicate that the AI model is a reliable and accurate supportive tool for digital smile design and esthetic outcome prediction.

OUTCOME PARAMETER	AI PREDICTION	CLINICAL ASSESSMENT	P VALUE
Smile Arc Score	2.8±0.5	2.7±0.4	0.28
Gingival Display Score	1.9±0.6	2.0±0.5	0.34
Midline Alignment Score	2.6±0.4	2.5±0.5	0.41
Tooth Proportion Score	2.9±0.3	2.8±0.4	0.19
Overall Esthetic Score	8.7±0.9	8.5±1.0	0.22

TABLE 4 : COMPARISON OF AI PREDICTION & CLINICIAN ASSESSMENT

Table 4 showed very similar mean scores for all outcome parameters, including smile arc, gingival display, midline alignment, tooth proportion, and overall esthetic score. The p values for all variables were greater than 0.05, which indicates that there was no statistically significant difference between the AI-generated scores and the clinician-assessed scores. This suggests that the AI model performed in close agreement with expert evaluation and was able to predict esthetic smile outcomes with good clinical

consistency. Overall, these findings support the reliability of AI as an effective adjunct in digital smile design and esthetic treatment planning.

VARIABLE	MEAN±SD
Overall Satisfaction Score	8.6±1.1
Aesthetic Improvement Perceived	44(88%)
Willingness To Accept AI-Generated Design	42(84%)
Improved Confidence After Preview	41(82%)
High Satisfaction With Tooth Display	43(86%)
High Satisfaction With Facial Harmony	40(80%)

TABLE 5 : PATIENT SATISFACTION AFTER AI BASED SMILE DESIGN

Table 5 showed that the AI-based smile design was well accepted by most participants. The overall satisfaction score of 8.6 ± 1.1 indicates a high level of approval, suggesting that patients were generally pleased with the final esthetic preview and planning process. A large majority perceived aesthetic improvement, and most were willing to accept the AI-generated design, which reflects good trust and acceptability of the model. The findings also show that many patients felt more confident after seeing the preview, highlighting the psychological benefit of digital smile simulation in treatment planning. High satisfaction with tooth display and facial harmony further suggests that the AI-generated design was successful in addressing the most important esthetic concerns. Overall, these results indicate that AI-assisted digital smile design is not only clinically useful but also positively received from the patient perspective.

DISCUSSION

Our study's results suggest that AI-driven digital smile design is a feasible and clinically promising adjunct for esthetic planning. The model performed well overall, with strong predictive accuracy, good validation performance, and high agreement with clinician assessment, which indicates that it learned clinically meaningful patterns rather than simply fitting the training data. This is consistent with recent reviews showing that AI can improve precision, automate landmark detection, and support more efficient smile simulation in digital dentistry.[6,5] In our dataset, the lack of significant differences between AI prediction and clinical assessment for smile arc, gingival display, midline alignment, tooth proportion, and overall esthetic score further supports that AI can approximate expert decision-making in a structured manner.[1]

At the same time, our findings also fit the broader literature showing that AI is promising but not yet fully superior to clinician judgment in every aspect of smile aesthetics. Studies comparing AI-generated and conventional designs have found acceptable accuracy, but also noted that some esthetic details are still better refined by human expertise, especially when facial context and subtle artistic judgment are involved.[5,3] The high patient satisfaction in our study is also important, because digital smile design is ultimately successful only when patients accept and understand the proposed result; this aligns with evidence that digital visualization improves patient engagement and confidence.[1] Overall, our results support AI as a useful decision-support tool rather than a replacement for clinicians, and they justify a hybrid workflow in which AI improves efficiency and consistency while the clinician ensures personalization and final esthetic refinement.

CONCLUSION

This study concludes that AI-driven predictive modeling is a promising and effective approach for digital smile design and esthetic outcome prediction. The model demonstrated good predictive performance, strong agreement with clinician assessment, and high patient satisfaction, suggesting that it can support more objective, efficient, and patient-centered esthetic treatment planning. Although AI showed reliable results across major smile parameters, it should be used as an adjunct to clinical judgment rather than a replacement, since final esthetic refinement still depends on clinician expertise and individual patient preferences. Overall, the findings support the clinical value of AI in improving precision, communication, and predictability in digital smile design, and they highlight its potential role in modern esthetic dentistry.

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