



MULTIMODAL ARTIFICIAL INTELLIGENCE FOR PEDIATRIC DENTAL ANXIETY ASSESSMENT: FROM BEHAVIORAL AND PHYSIOLOGICAL SIGNALS TO REAL-TIME CLINICAL DECISION SUPPORT—A NARRATIVE REVIEW

Dentistry

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ABSTRACT

Background: Dental anxiety is a common problem in pediatric dentistry and may adversely influence children's cooperation, treatment acceptance and future dental attendance. Conventional assessment relies predominantly on self-report instruments and behavioral observation. Although these methods are clinically useful, they are generally intermittent and may be influenced by the child's age, communication ability and observer interpretation. Artificial intelligence (AI), computer vision and physiological sensing provide opportunities for automated and continuous assessment. **Objective:** To review the emerging application of artificial intelligence for pediatric dental anxiety assessment, with particular emphasis on multimodal integration of behavioral, facial and physiological signals and the potential development of real-time clinical decision-support systems. **Methods:** A focused literature review was undertaken using PubMed/MEDLINE and supplementary searches of major biomedical and scientific databases and publisher platforms. Literature addressing pediatric dental anxiety, artificial intelligence, machine learning, computer vision, facial-expression analysis, physiological monitoring and AI-assisted behavioral interventions was examined. Foundational pediatric dental anxiety instruments and recent AI-healthcare reporting recommendations were also considered. **Results:** The literature demonstrates increasing application of AI in pediatric dentistry. Recent work includes AI-assisted dental anxiety scales, machine-learning prediction of anxiety and cooperative behavior, AI-personalized behavioral interventions and digital approaches to anxiety management. However, the existing literature remains heterogeneous. Most studies use either conventional anxiety measures, individual physiological variables or AI as an intervention rather than developing an integrated real-time multimodal anxiety-monitoring system. Physiological signals offer continuous measurement but are nonspecific, whereas facial and behavioral features provide complementary information but are influenced by individual variability and environmental conditions. **Conclusion:** Multimodal AI integrating physiological and behavioral information represents a promising direction for pediatric dental anxiety assessment. Future systems should prioritize clinically independent reference standards, external validation, interpretable models, privacy-preserving edge processing and prospective multicenter evaluation before clinical deployment.

KEYWORDS

artificial intelligence; machine learning; pediatric dentistry; dental anxiety; computer vision; physiological monitoring; multimodal AI; children; clinical decision support.

1. INTRODUCTION

Dental anxiety and fear are important behavioral challenges in pediatric dental practice. Anxiety may manifest as avoidance, crying, withdrawal, verbal resistance or physical movement and can interfere with communication and treatment delivery. In addition to its immediate effect on cooperation, negative dental experiences during childhood may contribute to future avoidance of dental care.

Accurate assessment is therefore an important component of pediatric dental behavior management.

Several instruments have been developed to assess dental anxiety in children. The Facial Image Scale (FIS), Venham Picture Test (VPT), Modified Child Dental Anxiety Scale (MCDAS) and Children's Fear Survey Schedule–Dental Subscale (CFSS-DS) are among the commonly used measures. The FIS was developed as a rapid pictorial instrument for assessing children's emotional response to dental treatment, while the VPT provides a pictorial measure suitable for children who may have difficulty expressing anxiety verbally.

Although these tools have demonstrated clinical usefulness, their administration is generally restricted to particular points during the dental visit. Consequently, they may not capture the dynamic nature of anxiety during different stages of treatment.

Behavioral assessment represents another major component of pediatric dentistry. The clinician may observe crying, avoidance, resistance, facial expression and body movement. However, interpretation of behavioral responses may differ between observers.

Physiological measurements offer a complementary source of information. Heart rate, heart-rate variability, electrodermal activity and other autonomic variables may change during anxiety-provoking situations. Nevertheless, physiological activation is not specific to anxiety and may also result from pain, movement, excitement or other factors.

Artificial intelligence creates an opportunity to integrate these heterogeneous data sources.

Rather than relying on a single questionnaire or physiological measu-

rement, a multimodal system could combine facial/behavioral characteristics and physiological signals and generate an estimate of anxiety continuously during dental treatment.

This concept is particularly relevant to pediatric dentistry because anxiety is dynamic and may change substantially during examination, local anesthesia, tooth preparation and completion of treatment.

2. Artificial Intelligence in Pediatric Dentistry

AI is increasingly being investigated across multiple areas of pediatric dentistry, including caries detection, dental-age estimation, tooth identification, oral-health assessment, treatment planning and behavioral applications.

Recent systematic and umbrella reviews demonstrate that AI research in pediatric dentistry has expanded considerably. A 2026 systematic review and meta-analysis examined AI applications across pediatric dentistry, while a 2026 umbrella review synthesized existing systematic reviews and highlighted the rapid development of this field.

This growth establishes the technological basis for more specialized applications, including assessment of psychological and behavioral states.

However, AI should not be considered synonymous with deep learning. Machine-learning approaches may range from conventional regression and decision-tree methods to complex neural-network architectures.

For pediatric dental anxiety, the choice of algorithm should be driven by the clinical question, dataset size, interpretability and validation requirements rather than technological complexity alone.

3. Conventional Assessment of Pediatric Dental Anxiety

3.1 Facial Image Scale

The Facial Image Scale provides five facial representations corresponding to increasing emotional distress. It is rapid and particularly useful when verbal questionnaires are difficult to administer.

The original validation work demonstrated significant association

between FIS and the Venham Picture Test.

3.2 Venham Picture Test

The Venham Picture Test presents children with illustrated emotional situations and has been widely used as an observational/self-report approach in pediatric dental research.

3.3 Modified Child Dental Anxiety Scale

- The MCDAS incorporates multiple dental situations and allows broader characterization of dental anxiety.
- A facial version has also been developed to improve accessibility for younger children.

3.4 Behavioral Assessment

- Behavioral rating systems complement self-report measures by documenting observable distress and cooperation.
- The principal advantage of these approaches is clinical familiarity.
- Their principal limitation is that they provide discrete assessments rather than continuous monitoring.

4. Physiological Monitoring

Anxiety activates the autonomic nervous system.

This provides a physiological basis for monitoring variables such as:

- heart rate
- pulse rate
- heart-rate variability
- electrodermal activity
- skin temperature
- respiratory rate

Heart rate is particularly attractive because pulse oximeters and photo plethysmographic sensors are inexpensive and widely available.

However, heart rate alone cannot establish that a child is anxious.

For example, increased heart rate may represent anxiety, pain, movement, excitement or physical activity.

Therefore, physiological variables are better considered complementary features rather than independent diagnostic standards.

5. Computer Vision and Facial Features

Facial behavior may provide additional information regarding emotional state.

A camera-based system can potentially extract:

- Facial landmarks
- Eye-region movement
- mouth movement
- Head orientation
- Facial action characteristics
- Temporal changes in expression
- AI can then identify patterns associated with anxiety.
- However, facial-expression analysis is influenced by:
- Camera angle
- Illumination
- Facial occlusion
- Movement
- Individual facial characteristics
- Cultural and developmental differences
- Consequently, facial analysis should ideally be combined with other information.

6. AI-assisted Dental Anxiety Assessment

One of the most relevant recent developments is the Artificial Intelligence Child Dental Anxiety Scale (AI-CDAS).

A validation study involving 100 children aged 3–9 years evaluated an AI-assisted anxiety assessment using facial responses and compared the results with an established colored facial affective scale. The study demonstrated the feasibility of using AI-assisted facial responses for pediatric dental anxiety assessment.

This is an important development because it demonstrates that AI can be incorporated into a pediatric dental anxiety measurement instrument.

However, an AI-assisted pictorial/facial scale remains different from a continuous multimodal monitoring system.

The next logical step is therefore to investigate whether multiple independent signals can be integrated into a single clinically validated model.

7. Machine Learning for Anxiety and Cooperative Behavior

Recent evidence also indicates that machine learning can be used to predict pediatric dental anxiety and cooperative behavior.

A 2026 cross-sectional predictive modeling study included 952 children aged 6–11 years and evaluated machine-learning models for predicting dental anxiety and cooperative behavior. The study also examined predictors contributing to model performance.

This is important because it moves AI research beyond simple classification toward prediction.

However, prediction based primarily on demographic, clinical and behavioral variables differs from real-time physiological and visual signal fusion.

A multimodal real-time model could potentially capture moment-to-moment changes that baseline predictive models cannot.

8. AI as an Intervention

AI has also been investigated as a means of reducing pediatric dental anxiety.

A 2026 randomized controlled trial involving 80 children aged 6–12 years compared AI-personalized video self-modelling with conventional audiovisual modelling. Dental anxiety was assessed using CFSS-DS and MCDASf, with pulse and heart-rate monitoring also incorporated.

This follows earlier evidence that video modelling can reduce dental anxiety in children undergoing procedures such as fissure sealant placement.

The distinction between AI for assessment and AI for intervention is important.

- AI-based intervention asks: Can AI help reduce anxiety?
- AI-based assessment asks: Can AI accurately detect anxiety?

The latter requires independent clinical reference standards and diagnostic-performance validation.

9. Multimodal AI

A multimodal system could combine:

Camera → Facial/behavioral features
+
Pulse/PPG sensor → Physiological features
+
Clinical information → Contextual features
↓
Feature synchronization
↓
Multimodal fusion
↓
Machine-learning model
↓
Anxiety probability
↓
Clinician interface

This architecture may overcome some limitations of single-modality systems.

10. Early, Intermediate and late Fusion

- Multimodal data can be integrated using different strategies.
- Early fusion: Features from multiple modalities are combined before model development.
- Late fusion: Each modality is processed independently and the resulting predictions are combined.
- Hybrid fusion: Intermediate representations from individual modalities are integrated.
- For pediatric dental anxiety, comparing these approaches may help determine whether multimodal integration genuinely improves performance.

11. Current Research Gaps

The current evidence suggests several gaps:

1. Multimodal integration
2. Real-time assessment
3. Independent validation
4. Standardization
5. Explainability
6. Privacy

12. Edge AI and Privacy

Pediatric facial data require careful privacy protection.

A conventional system might transmit:

Camera → Internet → Cloud → AI

An alternative is edge AI:

Camera → Local processor → Feature extraction → Raw video discarded → AI prediction

Only numerical features or anonymized outputs could then be stored or transmitted.

This architecture is particularly relevant to electrical and electronics engineering because it permits integration of low-power processors, sensors, wireless communication, embedded machine learning and secure data storage.

13. Clinical Validation Requirements

A future multimodal system should be evaluated against an independent reference standard.

The AI should not use heart rate as an input and then use heart rate as the validation standard.

A stronger design would use AI inputs comprising facial/behavioral features, physiological features and contextual variables, versus an independent reference consisting of validated pediatric anxiety scales, standardized behavioral assessment and predefined clinical criteria.

Performance should be reported using sensitivity, specificity, positive predictive value, negative predictive value, F1 score, ROC-AUC, calibration and confidence intervals.

14. Future Directions

Future research should investigate:

1. Synchronized physiological and visual signals;
2. Larger multicenter pediatric datasets;
3. Independent external validation;
4. Age-specific models;
5. Explainable ai;
6. Edge-based processing;
7. Privacy-preserving architectures;
8. Longitudinal anxiety monitoring;
9. Integration with electronic dental records;
10. Clinical impact studies.

15. CONCLUSION

- Artificial intelligence is emerging as an important technology in pediatric dentistry, with applications extending beyond diagnosis into behavioral science and anxiety management.
- Recent studies demonstrate the feasibility of AI-assisted dental anxiety assessment and AI-personalized interventions.
- However, current research does not yet establish a universally vali-dated real-time multimodal anxiety-monitoring system.
- Integration of physiological signals, facial/behavioral features and machine learning may represent the next stage of development.
- Future systems should be independently validated, clinically interpre-table and designed with pediatric privacy and safety in mind.
- A successful multimodal AI platform could ultimately provide pediatric dentists with continuous, objective and individualized information regarding a child's anxiety during dental treatment.

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