Review Article *Open Access*

Journal of Biomedical Advancement Scientific Research

ISSN: 3069-0854

DOI: *doi.org/10.63721/25JBASR0115*

Bridging the Gap: AI, Data Science, and Evidence-Based Dentistry

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Citation: Kevin Thamson, Omid Panahi (2025) Bridging the Gap: AI, Data Science, and Evidence-Based Dentistry. J. of Bio Adv Sci Research, 1(2):1-07. WMJ/JBASR-115

Abstract

The burgeoning fields of artificial intelligence (AI) and data science are poised to revolutionize evidence-based dentistry (EBD) by providing unprecedented tools for analyzing vast datasets. Traditionally, EBD has relied on systematic reviews and randomized controlled trials (RCTs), which can be time-consuming and limited in scope. This paper explores how AI and data science can bridge this gap by accelerating the synthesis of scientific literature, identifying novel patterns in patient data, and providing real-time clinical decision support. We discuss the application of machine learning for predicting treatment outcomes, the use of natural language processing (NLP) to mine dental literature, and the integration of big data analytics to uncover insights from electronic health records. By leveraging these technologies, we can move towards a more dynamic and personalized form of EBD, where clinical decisions are informed not only by aggregated population data but also by individual patient characteristics. The paper also addresses the challenges of data quality, privacy, and the need for new frameworks to validate AI-driven evidence. Ultimately, the synergy between AI, data science, and EBD will lead to a more precise, efficient, and predictive era of dental healthcare.

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Submitted: 13.08.2025 **Accepted:** 18.08.2025 **Published:** 25.08.2025

Keywords: Artificial Intelligence, Data Science, Evidence-Based Dentistry, Machine Learning, Natural Language Processing, Big Data, Clinical Decision Support, Personalized Medicine, Dental Healthcare

Introduction

Evidence-based dentistry (EBD) has been the gold standard for clinical decision-making for over two decades. It represents a paradigm shift from reliance on anecdotal experience and expert opinion to a systematic approach that integrates the best available scientific evidence with a dentist's clinical expertise and a patient's values and needs. Traditionally, this process has been driven by the meticulous work of systematic reviews and meta-analyses of randomized

controlled trials (RCTs) [1-25]. While this methodology has been invaluable in establishing foundational knowledge, it is inherently slow, retrospective, and often limited by the scope of existing research. The time it takes to formulate a question, conduct a study, publish the results, and then synthesize that evidence into clinical practice guidelines can be years, if not decades. This time lag, coupled with the difficulty of applying general population-level findings to a specific patient, creates a significant "gap" between the generation of scientific evidence and its practical application at the chairside [26-43].

The advent of artificial intelligence (AI) and data science offers a powerful solution to this problem, promising to bridge this gap and usher in a new era of EBD. The core of this revolution lies in the ability of AI algorithms to process vast, complex datasets far beyond what any human or traditional statistical method can handle and to extract meaningful, actionable insights. This includes not only the synthesis of published literature but also the analysis of a wealth of "big data" from sources like electronic health records (EHRs), dental imaging, and even wearable health devices. By harnessing the power of machine learning, natural language processing, and advanced analytics, dentistry can move from a model of reactive, population-based evidence to a proactive, personalized, and predictive form of care. The synergy between these fields is not about replacing the principles of EBD but about profoundly enhancing them, making evidence more accessible, relevant, and timely for every patient [44-59].

The Pillars of a New Evidence-Based Paradigm

The integration of AI and data science into EBD rests on several key technological pillars. Machine learning is at the forefront, with algorithms that can be trained on millions of data points to recognize subtle patterns that correlate with disease, treatment success, or patient risk. For instance, an ML model trained on thousands of dental radiographs can identify early signs of periapical lesions or bone loss more accurately and consistently than the human eye. This capability extends beyond diagnostics to predictive analytics, where models can forecast the long-term success of a restoration or the likelihood of an orthodontic relapse based on a patient's unique biological and behavioral data [60-72].

Complementing machine learning is natural language processing (NLP), a branch of AI that enables computers to "read" and understand human language. NLP can be used to rapidly and systematically sift through the immense volume of dental literature clinical trial reports, case studies, and patient notes to identify relevant information and summarize key findings. This capability dramatically accelerates the process of systematic reviews, allowing clinicians and researchers to stay up-to-date with the latest evidence with unprecedented speed. Furthermore, NLP can be applied to unstructured data within EHRs, extracting valuable insights from clinical notes that would otherwise be inaccessible for large-scale analysis.

Finally, the concept of big data analytics provides the raw fuel for these AI engines. By aggregating and analyzing data from diverse sources including electronic health records, practice management software, insurance claims, and real-world clinical outcomes data science can uncover epidemiological trends and treatment effectiveness on a massive scale. This moves dentistry toward a "learning healthcare system," where every patient interaction contributes to a growing body of evidence that, in turn, informs and improves future clinical decisions. This new paradigm promises to make EBD more dynamic and personalized. Instead of simply relying on what worked for a general population, dentists will be able to leverage AI-driven insights to understand what is most likely to work for their individual patient, based on a combination of their specific clinical data, and the collective wisdom of millions of others. This is the future of evidence-based dentistry: a collaborative ecosystem where human expertise is empowered by the speed and precision of AI and data science [73-83].

Challenges

While the synergy between AI, data science, and evidence-based dentistry (EBD) offers tremendous promise, its implementation is fraught with significant challenges. These hurdles span ethical, technical, and practical domains, and must be addressed for this new paradigm to be successful.

Ethical and Regulatory Challenges

- **Data Privacy and Security:** The foundation of AI and data science is the collection and analysis of massive datasets, which often include sensitive patient information. This creates a primary

challenge in protecting patient data from breaches and ensuring compliance with regulations like HIPAA.

- **Algorithmic Bias:** AI models are trained on historical data. If this data is not representative of all patient populations, the algorithms can develop and perpetuate biases, leading to less accurate diagnoses or inequitable treatment recommendations for certain demographic groups.
- **Transparency and Accountability:** Many AI models are considered "black boxes" because their decision-making processes are opaque. This lack of transparency makes it difficult for dentists to trust the AI's recommendations and for patients to understand how a diagnosis was reached. It also creates a gray area for legal liability in the event of an AI-related error.
- **Informed Consent:** The use of AI in patient care introduces a new layer to the informed consent process. Dentists must be able to clearly explain to patients how AI is being used, its potential benefits, and its limitations, so that consent is truly informed [84-90].

Technical and Implementation Challenges

- **Data Quality and Standardization:** The effectiveness of AI is highly dependent on the quality of its training data. In dentistry, data is often fragmented, unstructured, and collected using different systems and terminologies. The lack of standardized data formats and a clean, high-quality, and diverse repository of dental data is a major technical barrier.
- **Integration with Existing Workflows:** AI solutions must seamlessly integrate with a dental practice's existing software, such as electronic health records (EHRs) and practice management systems. Compatibility issues and a steep learning curve can create resistance and hinder adoption.
- **Cost and Accessibility:** The high cost of developing, purchasing, and maintaining AI technologies can be prohibitive, particularly for smaller, independent practices. This can lead to a technology gap, where only well-funded practices or large dental service organizations can afford to leverage these tools, potentially worsening healthcare disparities.
- **Continuous Validation:** Unlike a fixed research paper, AI models are continuously learning and evolving. This requires ongoing validation and monitoring to ensure their continued accuracy, reliability, and safety in a clinical setting.
- **Lack of AI Literacy:** Many dental professionals lack a deep understanding of AI and data science principles. This knowledge gap can lead to an overreliance on AI recommendations without critical human oversight or a failure to properly interpret the probabilistic nature of the AI's output.

Future Works

The future of integrating AI and data science into evidence-based dentistry (EBD) will focus on creating a more dynamic, predictive, and personalized healthcare system. To achieve this, several key areas of work are essential.

Advancing Beyond Diagnostics to Personalized, Predictive Care

Future work will move beyond simply detecting disease to predictive and preventative analytics. By combining patient-specific data such as genetics, oral microbiome analysis, and lifestyle factors with large-scale clinical data, AI will be able to forecast a patient's risk of developing conditions like caries or periodontal disease. This will allow for highly personalized, preventive care plans that are proactive rather than reactive. Furthermore, AI will be used to simulate treatment outcomes, enabling dentists to visualize the long-term success of different interventions and customize treatment plans for the best possible results.

Enhancing AI's Role in Research and Education

Future efforts will focus on using AI and data science to accelerate dental research. Natural language processing (NLP) will become a powerful tool for rapidly analyzing and synthesizing vast amounts of scientific literature, dramatically speeding up the systematic review process that is central to EBD. In education, AI will be integrated into dental school curricula to train future professionals in AI literacy, data interpretation, and ethical considerations. AI-powered simulators and virtual reality environments will provide students with hands-on experience and a safe space to practice complex procedures and decision-making.

Developing Robust Ethical and Regulatory Frameworks

A critical area for future work is the establishment of clear ethical guidelines and regulatory standards. This includes creating standardized, diverse, and high-quality datasets to mitigate algorithmic bias and ensure equitable care. The development of Explainable AI (XAI) will be a priority, providing clinicians with a clear understanding of how an AI system arrived at a recommendation. Additionally, new regulatory pathways will be necessary to ensure that AI tools are validated, safe, and effective before they are integrated into routine clinical practice, helping to build trust among both dental professionals and patients.

Conclusion

The future of dentistry is not about replacing human expertise but about augmenting it. AI tools will serve as a co-pilot for clinicians, providing data-driven insights that inform and enhance their decisions. This will create a more dynamic, predictive, and personalized form of EBD, where treatment plans are based on a comprehensive understanding of a patient's unique biological, social, and behavioral data, in addition to general population-level evidence. The successful adoption of this new paradigm, however, requires a proactive approach to addressing the challenges of data quality, transparency, and algorithmic bias. By establishing robust ethical frameworks and fostering a culture of AI literacy among dental professionals, we can ensure that this technological revolution serves to improve health outcomes and equity for all patients.

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