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Artificial Intelligence in Pediatric Dentistry: Complementing Human Intelligence for Enhanced Care

[1]Dr. Dhanashree Sakhare, Ex-Associate Professor, Department of Orthodontics, M M College of Dental Sciences and Research, Mullana; Director, Lavanika Academy, Melbourne, Australia

[2]Dr. Shreya Dasgupta, Consultant Pediatric and Preventive Dentist, Department of Pediatric Dentistry, Pune 411057, India

[3]Dr. Satyawan G Damle, Ex-Professor, Department of Pediatric Dentistry, M M College of Dental Sciences and Research, Mullana, and Ex-Vice Chancellor, MM University, Mullana, Ambala 133207, India

Corresponding Author: Dr. Shreya Dasgupta, Consultant Pediatric and Preventive Dentist, Department of Pediatric Dentistry, Pune 411057, India

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Abstract

Artificial Intelligence (AI) is transforming healthcare, including pediatric dentistry, by enhancing diagnostic accuracy, treatment planning, and patient management. From AI-powered imaging interpretation to emotion recognition tools for anxiety reduction, its applications are expanding rapidly. In pediatric dentistry, AI supports behavioral management, individualized care, and operational efficiency. However, AI lacks empathy, adaptability, and nuanced decision-making, making it a complement rather than a replacement for human clinicians. This review explores AI's history, classification, and integration into pediatric dental practice, highlighting advantages, limitations, and ethical concerns. The synergy between AI's computational power and human intelligence offers the potential for compassionate, efficient, and innovative pediatric dental care.

Keywords: Artificial intelligence, Behavior management, Diagnostic imaging, Ethics, Human intelligence, Pediatric dentistry, Virtual reality

Introduction

Artificial Intelligence (AI) has evolved from early computational theories to a transformative force in modern healthcare. In dentistry, its ability to analyze large datasets, recognize complex patterns, and provide decision support has led to its adoption in diagnostics, treatment planning, and patient engagement. Pediatric dentistry benefits uniquely from AI through tools like emotion recognition and virtual reality for behavior management.

History of Artificial Intelligence

The roots of artificial intelligence (AI) can be traced back to antiquity, where legends and philosophical narratives envisioned artificial entities with consciousness or intelligence. The evolution of logic and formal reasoning laid a foundational framework that led to the development of the programmable digital computer in the 1940s. These early machines, grounded in abstract mathematical principles, sparked scientific curiosity around the idea of constructing an electronic brain. This rich historical background connects us to the past, helping us appreciate the evolution of AI.[1]

The formal inception of AI as a field occurred during a seminal workshop at Dartmouth College in 1956. The participants of this gathering—who would later become pioneers in AI research—envisioned the creation of machines with human-level intelligence within a few decades. Enthusiasm for this vision led to substantial financial backing from the U.S. government, aimed at accelerating progress in the field.[2]

By the mid-1970s, it became clear that the complexity of achieving general artificial intelligence had been significantly underestimated. Critical assessments and skepticism resulted in the curtailment of funding for non-targeted AI research. However, interest in AI was reignited in the early 1980s following Japan. Fifth Generation Computer Project and the commercial success of expert systems, which led to a surge in industrial applications and investments.[2,3]

Despite the rapid expansion, the AI industry experienced another downturn in the 1990s, often referred to as the AI winter, characterized by reduced media interest, skepticism from investors and stagnating progress. However, the field of AI did not give up. Foundational research continued under alternative labels and slowly gained momentum, inspiring us with the resilience and perseverance of the field. This perseverance is a testament to the industry commitment to progress and innovation.

The 2000s marked a turning point as machine learning algorithms found increasing success across academic and industrial domains. Improvements in computational power, the availability of large datasets and the development of robust statistical methods drove this progress. A significant leap occurred with the advent of deep learning, which surpassed earlier approaches in performance across a variety of complex tasks.

In 2017, the introduction of transformer architectures revolutionized natural language processing, paving the way for powerful generative AI models. By the 2020s, large language models (LLMs), such as ChatGPT, had become widely accessible, exhibiting remarkable capabilities in language understanding, creativity, and contextual reasoning.[2]

Human Superior Perceptual-Motor Intelligence

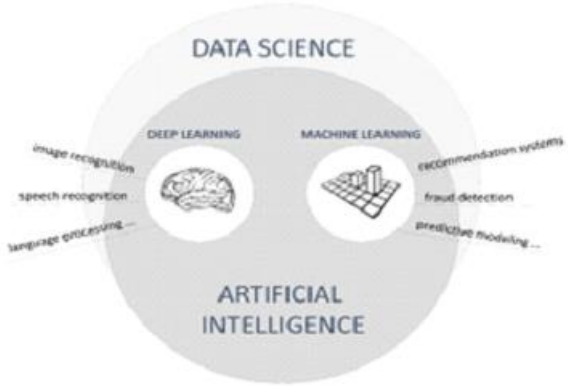
Moravec's paradox suggests that biological neural networks are intelligent in ways different from artificial neural networks. Intelligence is not limited to the problems or goals that we, as humans equipped with biological intelligence, find difficult. Intelligence, defined as the ability to realize complex goals or solve complex problems, is much more than that. According to Moravec (1988), high-level reasoning requires very little computation, but low-level perceptual-motor skills require enormous computational resources. Suppose we express the complexity of a problem in terms of the number of elementary calculations needed to solve it. In that case, our biological perceptual-motor intelligence is significantly superior to our cognitive intelligence. Our organic perceptual-motor intelligence is particularly adept at associating higher-order invariants within the ambient information. These are computationally more

complex and contain more information than the simple, individual elements. So, the difficulty of a task does not necessarily indicate its inherent complexity. As Moravec (1988) puts "We are all prodigious Olympians in perceptual and motor areas, so good that we make the difficult look easy. Abstract thought, though, is a relatively recent development, perhaps less than 100,000 years old. We have not yet mastered it. It is not all that intrinsically difficult; it just seems so when we do it."[4]

Classification of Artificial Intelligence

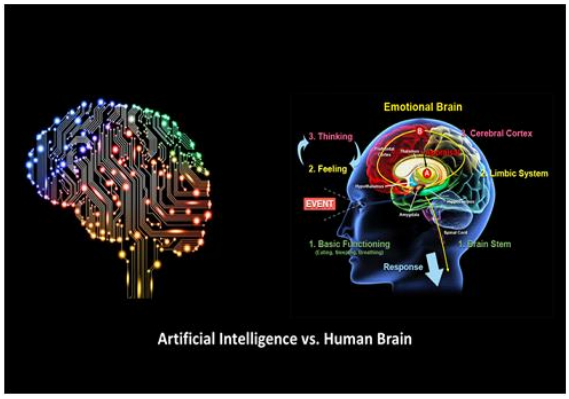
To better understand the concept of artificial intelligence, it is essential to clarify the distinctions between artificial intelligence, deep learning, machine learning, and data science. Artificial intelligence, deep learning, machine learning, and data science are related but distinct fields.

Artificial intelligence is the broadest field, encompassing machine learning and deep learning as subsets.[5] Data science leverages techniques from multiple fields to derive insights and knowledge from data. Artificial intelligence is a broad field that encompasses a range of techniques and methods aimed at creating intelligent machines capable of performing tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and natural language processing. Artificial intelligence can be divided into several branches, including expert systems, robotics, and natural language processing, among others. Deep learning is a subfield of artificial intelligence that utilizes neural networks inspired by the human brain structure to learn from large datasets. Deep learning algorithms can automatically identify and extract features from raw data, such as images, sounds, and text and use them to make predictions or informed decisions. Examples of deep learning applications include image recognition, speech recognition, and natural language processing. Machine learning is a subfield of artificial intelligence that focuses on developing algorithms and statistical models that allow computers to learn from data without being explicitly programmed. Machine learning techniques can be supervised (the algorithm learns from labelled data), unsupervised (the algorithm learns from unlabeled data), or semi-supervised (the algorithm learns from a combination of labelled and unlabeled data). Applications of machine learning include recommendation systems, fraud detection, and predictive modelling. Data science is an interdisciplinary field that combines statistical and computational techniques with domain- specific knowledge to gain insights and knowledge from data. Data science encompasses a range of activities, including data acquisition, cleaning and pre-processing, exploratory data analysis, statistical modelling, and machine learning. Data science is applied in various fields, including healthcare, finance, social media, and e-commerce.[5,6]



AI vs Human Intelligence: The Difference between AI and Human Intelligence

Let us examine the differences between AI and human intelligence through various parameters—functionality, learning ability, scope, flexibility, accessibility, and operational speed—to understand their strengths and limitations better.



- **Scope**

The scope of AI is constantly expanding, with every possible industry incorporating it into their operations, from finance and healthcare to education. Its scope is well-defined, especially at the start, with supervised learning processes. However, its abilities depend on human decision-making and data programming, limiting AI's operation to its designated scope.

Human intelligence, by contrast, is virtually endless. It can continually grow and evolve, with the ability to understand and interact with the world, form bonds, work collaboratively, and arrive at infinite combinations of decisions. It is not restricted by predefined parameters, allowing space for innovation.

- **Flexibility**

AI's flexibility is constrained by the scope of its algorithms and the data it has been trained on. While it can adapt within these parameters, it struggles to apply knowledge to unfamiliar situations. Most AI systems are task-specific, and their adaptability is defined by the extent of their programmed function.

Human intelligence is highly flexible, enabling individuals to absorb new information, learn, and make decisions far beyond initial goals. Decisions are shaped by life experiences, and humans can modify their approach to achieve success, thriving in diverse and dynamic environments.

- **Accessibility**

AI is becoming more accessible due to the widespread availability of technology. However, full utilization often requires niche technical expertise, limiting access to those capable of providing the correct inputs.

Human intelligence is inherently accessible at both the individual and organizational levels. While education, experiences, and opportunities can enhance it, socio-economic factors can influence its development.

- **Pace of Operations**

A significant advantage of AI is its speed in processing large volumes of structured or unstructured data, identifying patterns, and generating analyses in minutes. This rapid processing makes AI invaluable for time-sensitive tasks like financial trading, real-time analytics, and patient record management.

Human intelligence operates at a slower pace due to the additional steps of complex thought, deliberation, and collaboration. While slower, this process provides depth and nuance, especially important in areas requiring ethical judgment, creativity, and social responsibility.[7]

Utilization of Artificial Intelligence in Pediatric Dentistry

By providing individualized and sympathetic support, artificial intelligence (AI) may be beneficial in reducing children's needle phobia and fear of dental extractions through immersive technologies. Similar to virtual reality, AI can take kids to relaxing and entertaining virtual worlds while they are being extracted, taking their focus off of frightening situations. Dental practitioners can monitor a child's anxiety levels and respond with comfort or pauses thanks to AI's real-time emotion recognition capabilities. Additionally, by providing a kid-friendly explanation of the extraction process, AI-powered instructional tools can help alleviate anxiety and confusion. AI helps make extractions less frightening by

customizing the dental experience to each child's particular needs and feelings, creating a more positive and reassuring atmosphere for young patients.

In youngsters receiving dental treatment, the use of an analgesic pump with a single-chip microcontroller has also shown improved results. A timed mechanism is incorporated into the microcomputer-controlled intermittent electronic analgesia pump, allowing for the manual administration of single doses in addition to electronically controlled intermittent infusion. As a result, youngsters are less afraid of injection pain. The integration of AI in pediatric dentistry has created new opportunities for enhanced patient care, individualized treatment planning, and improved diagnostic capabilities. AI technology is being increasingly used in pediatric dentistry behavior management, providing creative ways to make encounters more pleasant. Children's fear and anxiety during dental operations may be reduced by AI-powered virtual reality (VR) experiences.

Additionally, AI algorithms can analyze facial expressions and voice tone to recognize and interpret children's emotions, thereby aiding in understanding their reactions and tailoring communication strategies accordingly. AI chatbots and virtual assistants can provide interactive education, answer questions and explaining dental procedures, thereby empowering children with knowledge and reducing their apprehension about dental procedures.

Although gamification has gained substantial traction in personal computers, its application to smartphone apps is a relatively recent area of exploration. Substantiated by evidence, a significant correlation emerges between gamification and the instigation of behavioral modifications within the healthcare domain. Comprehensive review studies underscore that gamification has a constructive impact on health-oriented interventions and the adoption of positive behaviors.

Therefore, while AI is intelligent in its computational capabilities, it remains a complement—not a replacement—for human intelligence in dentistry. The synergy of AI’s precision with the warmth and wisdom of dental professionals is the future of compassionate, efficient care.

AI is reshaping dentistry in ways that go far beyond diagnostics. Here are some of the most exciting and impactful developments:

1. Enhanced Imaging and Diagnostics

AI algorithms can analyze radiographs, CBCT scans, and intraoral images with remarkable precision—detecting caries, bone loss, periapical lesions, and even early signs of oral cancer that might be missed by the human eye2.

2. Predictive Analytics

By analyzing patient history, lifestyle, and genetic data, AI can predict the likelihood of future dental issues—like periodontal disease progression or orthodontic relapse—enabling proactive care.

3. Practice Management Automation

AI streamlines administrative tasks such as appointment scheduling, billing, and inventory management. Virtual assistants and chatbots can handle patient queries, send reminders, and even follow up on treatment plans.

4. Pediatric Behavior Management

In pediatric dentistry, AI-powered emotion recognition tools and immersive VR environments help reduce anxiety during procedures. These systems can adapt in real time to a child’s emotional state, making visits less stressful.

5. Treatment Planning and Simulation

AI assists in planning complex procedures like implant placement or orthodontic treatments. It can simulate

outcomes, helping both dentists and patients visualize results before treatment begins.

6. Forensic Odontology

AI is being used in forensic dentistry to identify individuals based on dental records, especially in mass disaster scenarios or criminal investigations.

7. Risk Assessment and Triage

AI tools can prioritize patients based on urgency, flagging high-risk cases for immediate attention—especially useful in tele dentistry and rural outreach programs.[8,9]

Drawbacks of using AI in pediatric dentistry

1. Lack of Personalized Interaction: AI systems require assistance in understanding the unique needs and emotions of pediatric patients. Children require a more personalized and empathetic approach, which AI might not be able to provide effectively. Building trust and rapport is crucial in pediatric dentistry, and AI might need to address these emotional aspects fully.
2. Limited Adaptability to Child's Behavior: Pediatric patients can exhibit a range of behaviors, from anxiety to curiosity. AI systems might be unable to adapt and respond appropriately to sudden changes in a child's behavior during a dental procedure, which a human dentist would be better equipped to manage.
3. Loss of Human Touch and Comfort: The comforting presence of a human dentist and staff plays a significant role in alleviating children's fears and anxieties during dental procedures. A greater reliance on AI could lead to the loss of the human touch, which is essential for establishing a positive dental experience for young patients.
4. Unpredictable Reactions to AI Tools: Children might react unpredictably to AI-powered tools and robots in a dental setting. Some children might find them intimidating, leading to heightened anxiety and distress, negatively impacting the dental experience.
5. Misinterpretation of Nonverbal Cues: Pediatric patients often communicate non-verbally, and experienced dentists rely on these cues to understand a child's comfort level. AI may require assistance to accurately interpret these nonverbal cues, which could lead to misunderstandings and suboptimal treatment.
6. Ethical and Safety Concerns: Implementing AI in pediatric dentistry raises ethical questions about data privacy, consent, and the potential for AI systems to harm children if not programmed and supervised correctly, as well as the risk of unintended consequences. Ensuring the safety of both the technology and the patients becomes a crucial concern.
7. Dependency on Technology: Overreliance on AI for behavioral management might hinder the development of essential communication and coping skills in children. These skills are crucial for their overall emotional and psychological development and should not be replaced entirely by technology.
8. Complexity of Procedures: Pediatric dental procedures can be intricate and vary widely based on individual patient needs. AI, while proficient in some tasks, may require assistance with the complexity of specific procedures, resulting in subpar outcomes or necessitating human intervention.
9. Parent-Child Relationship: The presence of parents or guardians during dental procedures is a familiar aspect of pediatric dentistry. AI might inadvertently disrupt the parent-child dynamic during treatments, as parents might feel less engaged or reassured by an AI presence than a human dentist.

10. Limited Learning from Experience: AI systems learn from data, but the behavioral management of pediatric patients is a nuanced skill that involves adapting to individual children over time. AI might lack the ability to learn from experiences in the same way that human dentists do. To effectively integrate AI in pediatric dentistry, a balanced approach that combines AI's capabilities with human expertise and empathy will likely yield the best results, ensuring young dental patients' overall well-being and comfort.[10]

Risks of AI in healthcare jobs

1. Data Privacy and Security Concerns

A National Library of Medicine survey revealed that 80 per cent of respondents expressed concerns about AI's impact on privacy.1 Healthcare professionals' limited familiarity with AI may also contribute to this apprehension. Security and privacy concerns also top the list regarding the deployment of AI. Moreover, it is not hard to see why. Healthcare institutions now manage vast amounts of sensitive data. It includes diagnostic images, genomic information, and medical records. Because training and validating AI algorithms require access to this data, concerns exist over unauthorized access, data breaches, and potential misuse. Moreover, integrating diverse data sources for AI applications poses challenges. Differences in data formats, quality, and completeness can compromise the accuracy and dependability of AI algorithms. This presents significant challenges to their application in clinical contexts.

2. Algorithm Bias and Fairness

Since AI systems are trained on past data, they may be biased and exhibit inequalities in healthcare provision. Biased algorithms can worsen inequality in healthcare by unfairly affecting certain patient groups. This undermines fairness and equality in healthcare services.

3. Clinical Integration and Adoption Challenges

Fifty-five per cent of medical professionals believe AI is not yet ready for medical use. This could be because they are still figuring out how to use it effectively in their fields. It is crucial to overcome adoption obstacles and gain physician buy-in for successful AI integration in clinical practice. Healthcare workers may be hesitant about AI due to concerns about job security, loss of autonomy, or compromised clinical judgment. This is why resistance to change and lack of experience with AI can hinder its full potential in improving patient outcomes.

Additionally, seamless integration with electronic health records (EHRs) and other health systems is vital for incorporating AI insights into clinical decision-making. Challenges such as usability issues, interoperability problems, and fragmented data architectures pose significant barriers.

4. Ethical and Regulatory Considerations

Ethics play a crucial role in shaping the guidelines surrounding the use of AI in healthcare. Besides tech worries, AI algorithms raise moral questions about patient rights, consent, and transparency. This is because any AI system works like a black box - you cannot see how it makes decisions. This lack of transparency could be a problem. It might not consider important details about a patient's health or situation. This raises concerns about transparency and fairness in healthcare decisions. Additionally, lawmakers, regulators, and industry stakeholders struggle to keep pace with the rapidly evolving rules governing AI in healthcare. Balancing innovation with patient safety, privacy, and rights remains a big challenge.

5. Generating Dangerous Predictions

One of the biggest concerns with AI in healthcare is its potential to make inaccurate or harmful predictions. AI

algorithms, particularly those that learn through machine learning, are heavily influenced by the quality of the data on which they are trained. Biases, errors, or missing information in this data can lead to the AI making incorrect decisions. These errors can have life-or-death consequences, especially in critical care settings where quick and accurate decisions are paramount. An AI-powered diagnostic tool that misidentifies patients as stable when they need immediate intervention could cause significant delays in life-saving treatment.

6. Causing Patient Harm

AI in healthcare holds immense promise. However, the biggest concern is the risk of harming patients. While AI can improve patient outcomes and diagnostic accuracy, it also brings new risks and unforeseen consequences that could harm patients. Imagine a hospital using an AI system to calculate medication dosages. This technology can be invaluable. It can personalize treatment based on each patient's unique needs. However, an AI trained on outdated data or regulatory information could recommend the wrong dosage, leading to serious side effects, complications, or even life-threatening situations.[11,12]

AI and Human Intelligence in Pediatric Dentistry: A Complementary Approach

AI algorithms can augment the capabilities of pediatric dentists, while human intelligence remains the core of patient care. AI can assist in diagnostic tasks and treatment planning, freeing dentists to focus on the more nuanced aspects of patient interaction and ethical decision-making. In pediatric dentistry, while AI algorithms offer efficiency and accuracy in diagnosis, they are not meant to replace human intelligence. AI can assist dentists in analyzing images and data, potentially leading to earlier detection of issues and more personalized treatment plans. However, human judgment, experience, and empathy are crucial for managing anxious children, tailoring treatment to individual needs, and ensuring ethical practice.

Conclusion

AI in pediatric dentistry offers unprecedented opportunities for improving diagnostics, behavioral management, and treatment planning. However, its optimal role is as a supportive tool, augmenting human expertise rather than replacing it. The future of pediatric dentistry lies in integrating AI's computational strengths with the empathy, adaptability, and nuanced care provided by skilled clinicians.

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