

Artificial intelligence's role in dentistry and dental bleaching

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ABSTRACT: This article has two aims: (1) To review the role of artificial intelligence (AI) in dentistry and teeth whitening. This is completed via discussion of technical descriptions, accuracy of AI, patients' trust in AI, teledentistry, benefits and risks of AI, and teeth whitening color and interpretation; and (2) To introduce a new project developed by the School of Dentistry, University of Washington (UW), one which enables access to datasets of images acquired through clinical treatment with patients, to those individuals and organizations interested in research and development of AI systems in teeth whitening. Access to the data repository is publicly available as a global online service, free of charge. A detailed synopsis of the 70-year history of AI is provided for comprehensive technical, social and clinical context of technologies and innovations previously and currently available commercially, and for those reported in dental and health care scientific literature. The UW project is relevant during this time where unprecedented levels of interest exist in esthetic dentistry, the technological progress and social impacts of artificial intelligence, and readily available datasets of actual patient outcomes. (*Am J Dent* 2025;38 Sp Is A:9A-15A).

CLINICAL SIGNIFICANCE: A detailed synopsis of the 70-year history of artificial intelligence is provided for comprehensive technical, social and clinical context of technologies and innovations previously and currently available commercially, and for those reported in dental and health care scientific literature.

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Introduction

History of artificial intelligence at a glance

The birth of artificial intelligence is widely considered to have been at the Dartmouth Summer Research Project on Artificial Intelligence in 1956.¹ This was convened and reported by John McCarthy (Dartmouth), Marvin Minsky (Harvard), Nathaniel Rochester (IBM Corporation) and Claude Shannon (Bell Telephone Laboratories). A select group of scientists worked through novel concepts which founded information systems and technologies that characterized the early evolution of AI, some of which endure into contemporary society, such as computers, natural language processing, and neural networks.

Prior to Dartmouth, notable scientists whose work would later be credited as important for this pioneering era include Turing,^{2,3} and Pitts & McCulloch.⁴ Soon after, published work on statistical, classification and regression models led to the emergence of some enduring mathematical and logistic systems, so-called, "neo-Bayesian" methods^{5,6} and K-Nearest Neighbours.⁷

Reduction in USA federal government investment in AI, following the 1966 ALPAC Report,⁸ effectively ended a decade-long surge in wide scale funded interests and in 1974 the Lighthill Report⁹ led to a similar decline in the UK's funded interests. The first reported, "AI Winter"^{10,11} thereafter commenced. Following this hiatus, the 1980s brought Recurrent Neural Networks,¹² Back Propagation Neural Networks¹³ and Reinforcement Learning.¹⁴ AI thereafter experienced its second Winter, following the collapse of the Lisp Machine market in 1987.¹⁵

The past 30 years have been an era of immutable expansion in research, development, commercial and regulatory interest in AI technologies. Support Vector Machines,¹⁶ Random Forests,^{17,18} and other Ensemble Methods (such as

Stacking,¹⁹ Bagging²⁰ and Boosting²¹), supervised machine learning (ML) algorithms, emerged with interest through the 1990s. More recently, the resurgence of interest in neural network concepts paved the way for our current era of AI-driven technologies. These include Deep Learning²² which utilizes Supervised, Semi-supervised and Unsupervised Learning in its training, and Generative Adversarial Networks,²³ using only Unsupervised Learning. These have led to interest in predictive modelling of continuous and categorical data (including imaging data) of unprecedented levels.

Natural Language Processing models were always the most controversial and considered the final frontier of development, until the arrival of the Transformer,²⁴ the first reported, "Large Language Model" (LLM). This frontier has been crossed with LLMs, perhaps most notably OpenAI's Chat-GPT²⁵ in 2022. It appears our future professional and personal lives will feature technologies and innovations refined from those which emerged from this past 30 years, perhaps without another AI Winter anytime soon.

Governance policies of privately-owned organizations and of sovereign and international communities are critical in the development of AI to include social, ethical and moral considerations. One of the more intriguing and potentially most influential developments is Explainable AI, for example SHAP Values,²⁶ an innovation which equips consumers and investors to view the so-called, "black box", of AI-based systems, as a "white box".

Social policies of OECD²⁷ (2019), GPAI²⁸ (2020) and UNESCO²⁹ (2021) established essential standards across the international community in ethical and responsible AI. The intended effects of these include their influence of governance standards within geopolitical borders, where appropriate, enabling individual populaces the necessary input in decisions of the impact of AI to their dependent communities.

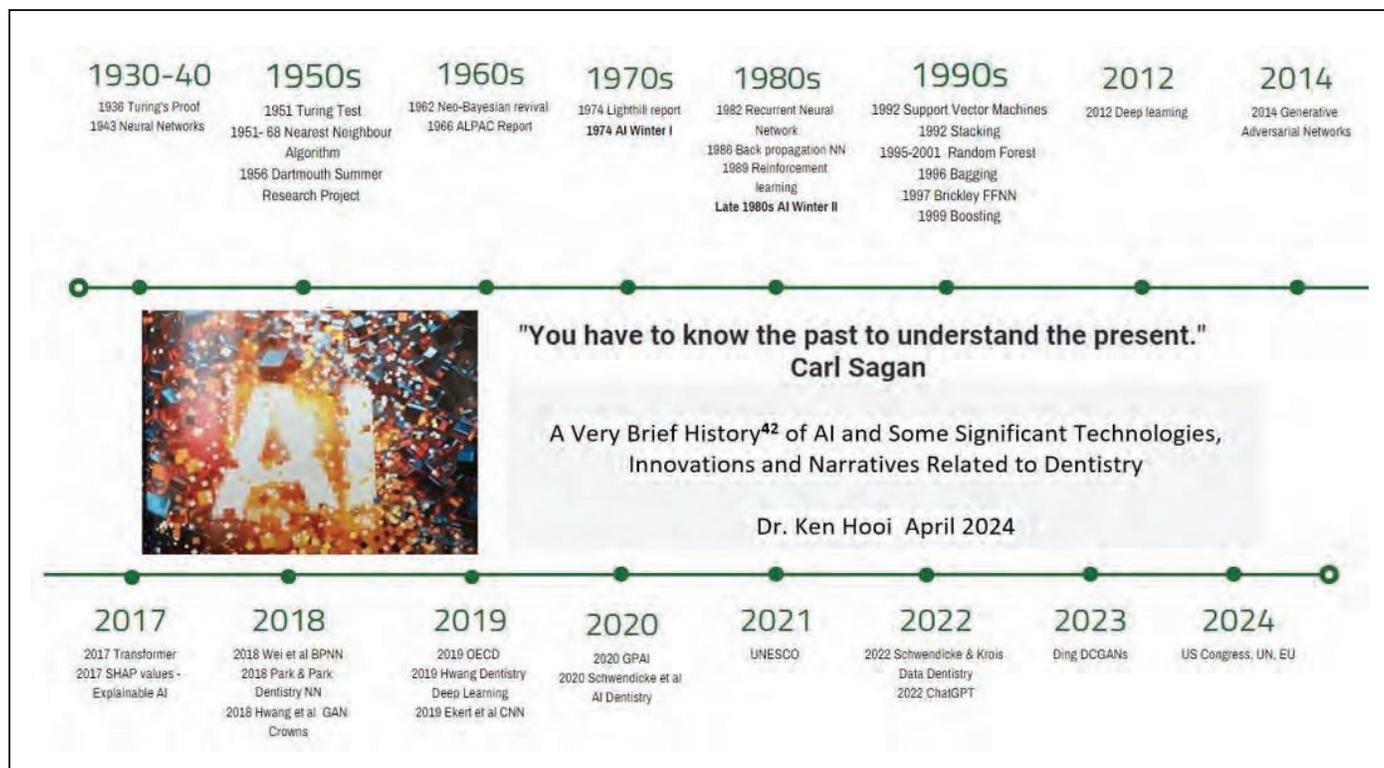


Fig. 1. Brief history of AI. The color graphic is captured from the Apr Issue of Scientific American.

AI developers in free market economies need to promote, market and argue the benefits of their business' technologies and innovations, while consumers need agency in the dialogue of humanitarian effects of life and livelihood, such as risks to health, education and labor markets.

This first half of 2024 already brought the US Congress Generative AI Copyright Disclosure Act,³⁰ UN Resolution on AI,³¹ and The European Union Artificial Intelligence Act.³² It is anticipated that global sovereign states will reference these as seminal AI mandates for development and governance of this current era.

A glance at artificial intelligence systems in clinical dentistry

AI-based applications in clinical dentistry of these past 30 years have featured mainly decision support systems utilizing image data. These have evolved with those technologies available, including third molar surgery treatment planning decisions with panoramic radiographs using a Feed-Forward Neural Network,³³ prosthodontic color matching using a Back Propagation NN,³⁴ single tooth-borne crown design with GAN³⁵ and Deep Convolutional GAN,³⁶ and radiological apical pathology detection using Convolved NN.³⁷

The quality of reporting data by Ekert et al³⁷ is uniquely comprehensive, transparent and replicable for other AI research and development units in the dental Clinical Decision Support Systems (CDSS) domain. It is anticipated that this publication, and similar ones reporting high standards of predictive model features and outcomes including ROC-AUC and the complete suite of accuracy measures, will become - if not already - the benchmark of data scientific reporting in dentistry CDSS.

Dentistry's clinical, technological and research spheres have seen excellent reflective, progressive and visionary narra-

tive reviews³⁸⁻⁴² which continue to bear sustainable relevance, even in this era of exponential change.

A summary of this introduction is provided in Fig. 1.

Artificial intelligence's role in dentistry and teeth whitening - Technical descriptions

McCarthy⁴³ opted for this term, "artificial intelligence", to elucidate the capacity of machines to engage in activities deemed "intelligent" in nature.

In the contemporary world, artificial intelligence encompasses machines or technologies capable of emulating human cognitive skills, such as problem-solving. To gain insight into AI, it is crucial to familiarize oneself with several vital aspects. Artificial intelligence represents the capacity of machines to manifest a unique form of intelligence. The objective was to create machines capable of learning from data to address problems effectively. Machine learning (ML), an integral part of AI, relies on algorithms to predict outcomes based on datasets. The primary goal of machine learning is to empower machines to learn autonomously from data, enabling them to resolve issues without human intervention. Machine learning enables systems to learn automatically from experience rather than relying solely on programmed data.⁴⁴ Neural Networks are machine learning systems which consist of algorithms that process signals through artificial neurons, designed to emulate the functioning of the human brain.

Deep learning, a further subset of machine learning, employs a network with multiple computational layers in a deep neural network to analyze input data. It aims to construct a neural network that autonomously identifies patterns, thereby enhancing feature detection.⁴⁵ Through the differential interpretation of these layers, insights are generated.⁴⁶ For instance, an AI-based system can analyze a radiograph, dis-

cerning variations in radiopacities to suggest, for example, the presence of caries in a specific tooth. Such AI systems can aid clinicians in screening, diagnosis, and decision-making.

Artificial Intelligence (AI) has predominantly found application in dentistry in the past decades, by enhancing the accuracy and efficiency of diagnostic processes. These CDSS may one day become paramount for achieving optimal results in treatments and delivering superior-quality patient care.

Accuracy of AI in dentistry

Through literature review, the AI models under evaluation demonstrated caries diagnosis accuracies from 76% to 88.3%, sensitivities between 73% and 90%, and specificities varying from 61.5% to 93%. The accuracy of caries prediction in these studies ranged from 83.6% to 97.1%. Additionally, the studies revealed diagnostic accuracies for vertical tooth fractures ranging from 88.3% to 95.7%. Furthermore, an article employing AI models for locating the finishing line reported accuracies within the 90.6% to 97.4% range.⁴⁷ Dentists leverage their comprehensive knowledge to diagnose and determine the most suitable treatment course. Additionally, they must predict prognosis, demanding accurate clinical decision-making skills. Yet, in specific scenarios, the limited timeframe and complexity of cases may pose challenges for dentists in making optimal clinical decisions. AI applications serve as valuable guides, empowering dentists to make informed decisions and enhance their overall performance.

Dental patients' trust in AI

Patients exhibited a high level of trust in traditional and AI-assisted communication regarding a dentist's decision; generally, they had confidence in their dentists.⁴⁸ Younger, more educated patients or students benefitted more from AI-based communication. Elderly patients are usually more likely to be skeptical of technology in health care and are often fearful of being dependent on technology in health and caregiving.^{49,50} While AI-based diagnoses did not impact patients' trust, there was a favorable attitude towards AI in dentistry. AI-supported diagnostics can aid in conveying radiographic findings, as the investigated AI-based tool enhanced patients' ability to identify caries lesions on dental radiographs. Consequently, dentists should consider incorporating AI-based tools to improve communication between patients and providers. In the future, AI-based instruments are expected to become increasingly significant in clinical dentistry.

Chat Generative Pre-Trained Transformer (ChatGPT) is a natural language processing AI-powered computer program extensively trained on vast datasets to generate human-like responses to user prompts, enhancing these bots' computational linguistics, communication proficiency, and responsiveness. Utilizing machine learning and deep learning through text-based interfaces, ChatGPT leverages advanced AI methods to generate responses resembling natural language in a large language model.^{51,52} This versatile tool can offer various services in education, healthcare, and patient interactions. Patients can ask healthcare questions and receive personalized responses, which can help them understand their concerns with extensive knowledge and information from

Tell me more about dental bleaching.

Dental Bleaching: What You Need to Know

What Is Dental Bleaching?
 Dental bleaching is a cosmetic procedure designed to lighten the color of your teeth by removing stains and discoloration. It involves the use of bleaching agents, typically hydrogen peroxide or carbamide peroxide, to break down stains and whiten enamel.

Types of Dental Bleaching:

1. **In-Office Bleaching** – Performed by a dentist, this method uses a high-concentration bleaching gel and sometimes a special light or laser to accelerate the process. It delivers quick and noticeable results in a single session.
2. **At-Home Bleaching** – Dentists can provide custom-made trays and a lower-concentration bleaching gel for at-home use. Results take longer but are effective.
3. **Over-the-Counter Whitening Products** – Whitening toothpaste, strips, gels, and rinses are available, though they are less potent and may take weeks to show results.

Benefits of Dental Bleaching:

- Enhances appearance by removing stains from coffee, tea, wine, smoking, and aging.
- Boosts self-confidence with a brighter smile.
- Non-invasive and generally safe when done correctly.

Potential Side Effects:

- Tooth sensitivity, which usually subsides after treatment.
- Gum irritation if the bleaching agent comes into contact with soft tissue.
- Uneven whitening if dental restorations (crowns, veneers, or fillings) do not respond to bleaching.

Who Should Avoid It?

- Pregnant or breastfeeding women.
- Individuals with severe tooth sensitivity or gum disease.
- People with dental restorations in visible areas, as they won't bleach.

Would you like recommendations for specific products or professional treatment options?

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Fig. 2. ChatGPT question generated answers on dental bleaching.

cross-disciplinary databases. From the answers obtained, the information conforms to the current literature and are judged to be of good quality (Fig. 2).

Teledentistry

The term "Teledentistry" originates from the combination of "tele", meaning distance, and "dentistry", the medical field concerned with diagnosing and treating issues related to teeth and surrounding tissues. Therefore, Teledentistry can be described as the remote practice of dental care and education, involving the diagnosis, treatment, or teaching of dentistry from a distance through various telecommunication platforms such as phones, computers, email, radio broadcasting, television, etc. Coined by Cook⁵³ in 1997, the term specifically refers to the use of video-conferencing technologies for diagnosing and providing treatment advice over a distance.

In the upcoming years, Teledentistry is poised to become more intelligent with the integration of AI. Artificial intelligence in dentistry is defined as the science dedicated to creating intelligent machines and systems that emulate human intelligence through predefined algorithms. These systems can potentially assist dental clinicians, academicians, and researchers in their respective activities.

AI benefits and risks

Two main categories of AI are utilized in general healthcare delivery: physical and virtual. Biological applications involve advanced robots or automated robotic arms. On the other hand, virtual components consist of software-based algorithms designed to aid in clinical decision-making.⁵⁴ From a dental standpoint, AI applications can be categorized into diagnosis, decision-making, treatment planning, and predicting treatment outcomes. Among these, diagnostic applications stand out as the most popular. AI has proven capable of delivering more accurate and efficient diagnoses, therefore alleviating the dentist's workload. The dental profession is witnessing a shift towards increased reliance on computer programs for decision-making.⁵⁵ These dental-oriented computer programs are advancing intelligence, accuracy, and reliability. Research on AI in dentistry is expanding across all its fields. However, it comes with its disadvantages and limitations. AI can place the patient's privacy at risk because it needs to collect and store the patient's data and medical history to perform its required task.⁵² Regarding privacy risks, AI contains personal information from all over the internet.⁵⁶ AI cannot substitute for human interaction in matters of emotions. Therefore, utilizing AI in counseling and therapy is deemed ineffective.^{16,56} While AI may never replace a pediatric dentist, it can be a supportive and complementary tool in various dental specialties.⁵⁷ Despite its advantages, AI has certain drawbacks. One such limitation is its potential to generate responses that seem accurate but are, in fact, incorrect, a phenomenon commonly referred to as the hallucination effect, prevalent in various natural language processing models.⁵⁹ Moreover, AI tends to stick to instructions rather than engaging in genuine interaction. For instance, in situations with inadequate user input, AI might make assumptions about the desired response without seeking further clarification.⁵⁸ ChatGPT proves valuable for individuals seeking basic information on a wide range of subjects, but these limitations should be acknowledged.

Teeth whitening color interpretation

Traditionally, clinicians have relied on visual inspection, using the naked eye to predict the efficacy of tooth bleaching by matching the initial tooth color with a shade guide. Clinicians commonly observe that yellowish teeth respond well to bleaching, while the treatment's effectiveness is often lower for grayish teeth. However, the subjective nature of this visual assessment with a shade guide poses challenges in accurately gauging tooth color, potentially compromising the predictability of the treatment.⁵⁹ Moreover, the bleaching response may vary based on patient characteristics or tooth properties, even if they initially appear to be the same color. Consequently, the utility of this traditional method in predicting tooth bleaching efficacy is limited.

As new platforms have been developed to meet HIPPA requirements for de-identification, utilizing AI to create a global dental bleaching data repository for predicting teeth whitening results can be a beneficial diagnostic tool.⁶⁰ If pre-operative and post-operative images and treatment details could be gathered through all dentists worldwide, AI can

efficiently process vast amounts of diverse data, including different bleaching methods, patient profiles, and treatment outcomes.⁶¹ AI can recognize patterns and correlations within the data that may not be immediately apparent to human observers, leading to the implementation of machine learning algorithms for pattern recognition and outcome prediction.⁶² AI systems can continuously learn and adapt to emerging trends, new products, and evolving treatment techniques, ensuring the predictions stay up-to-date.⁶³ For patient education, AI-generated predictions can educate patients about expected outcomes, helping manage expectations and improve overall patient satisfaction. The global dental bleaching data repository can serve as a valuable resource for ongoing research in teeth bleaching, contributing to innovation and advancements.

University of Washington Online-Global Data Repository (OGDR) for teeth bleaching

The primary focus of AI applications in teeth bleaching is on making accurate predictions using machine learning models, collective knowledge bases and the reasoning process of clinical decisions. Personalized and predictable bleaching prescription is the goal. The production and use of knowledge is a collective enterprise, and communication between its participants is the challenge. The internet and cloud-based software has greatly reduced the physical barriers to communication and coordination, making an Online-Global Data Repository possible. Similar databases have been established, such as the "Dental Registry and DNA Repository" at the School of Dentistry, University of Pittsburgh.⁶⁴

The University of Washington (UW) in Seattle is fortunate enough to be near companies like Microsoft, Amazon, Boeing, and Google. Our Computer Science & Engineering (CSE) programs are very strong and among them, the UW CSE AI Laboratory is ranked in the top five departments in AI by U.S. News & World Report. The UW CSE programs are active in all major areas of AI, including machine learning, natural language processing, planning, reasoning, robotics, and vision. The University of Washington Department of Restorative Dentistry intends to collaborate with UW CSE AI on this project. We are proposing to develop an Online-Global Data Repository for Teeth Bleaching. This can potentially lead to an exponential increase in the number of questions answerable by a collective knowledge base.

The proposed methodology is such that global researchers can access the before and after bleaching pictures of consenting patients. The repository is available through Cao Group (www.caogroup.com) in collaboration with the University of Washington, Department of Restorative Dentistry. The repository will give global researchers unprecedented access to dental bleaching data that can be used to advance research. Dental schools and individual clinicians across the globe will be invited to contribute to the repository. Researchers and clinicians who contribute to the repository will have the privilege of accessing the data bank and can use data to conduct retrospective cohort studies and observational studies. Approved researchers will have access to partially de-identified clinical data about each patient, including:



Fig. 3. An example image to be uploaded to the Repository that meets the criteria.

Demographics

- Age
- Gender
- Race/ethnicity (optional)
- Diagnosis (optional)
- Periodontal charts (optional)
- If pre-whitening dental prophylaxis was done
- Procedures (strips, OTC, supervised, take-home)
- Duration
- Concentrations of bleaching agent
- Presence/absence of sensitivity

Requirements for photography

Any image you upload to the Repository needs to meet the following criteria:

- The file format should be JPEG and /or PNG
- The file resolution should be a minimum of 3.4 MP (2400 × 1600)
- Each file size must not exceed 2 MB.
- Files should not be modified from their original size.
- Only the treatment area (anterior teeth) needs to be included.
- If the image contains a person or people, everyone in the photo must sign a model release.
- You should not artificially enlarge, distort or stretch the file to increase its size or resolution.

One of the key elements in a successful Online-Global Data Repository (OGDR) is a high-fidelity image database. Therefore, the above specifications for images without modification and distortion are paramount (Fig. 3). The bleaching project is not as high profile nor medically important as curing cancers and Alzheimer's disease so it will be a safe initial platform for international collaboration.

ChatGPT and other AI-based tools in dental education

AI is fundamentally shifting the classroom and clinical teaching. AI-powered tools rapidly analyze data and identify patterns via either discriminative classification, where decision boundaries differentiate data classes of interest, or clustering techniques, utilizing probability distribution of similar data, the latter being the basis for generative AI. The educators and students must evaluate how AI is used in classrooms and clinics and how to prepare for transformations with technology.⁶⁵

One question to be asked is what are the prerequisite criteria the students should possess before they are accepted into dental training? Are the basic sciences such as physics,

chemistry and biology still as important? Should computer science knowledge and mathematics play a more important role? Should we offer computer science training as electives in future dental school curriculum to inspire students to rethink dental technologies?

Using AI to enrich dental bleaching teaching

Aside from the teledentistry concept described above, the list below contains just a few of the ways dental educators might use AI to enhance dental bleaching teaching. A thoughtful approach to using AI can help instructors boost student engagement with concepts and can assist in the development of course materials and assessments. It's important to remember that AI is merely an assistive technology, and one always refines AI-generated output.

Below are some examples of how instructors might use AI to facilitate dental bleaching learning by using our proposed OGDR collective data bank. Many of these examples familiarize students with AI-based tools, but also prompt critical examination of their value, accuracy, strengths, and shortcomings.

Think-study group-AI-share

Students think (as individuals) about a dental bleaching question/problem, e.g. tetracycline-stained teeth, presented by a patient, then pair up with a study group to discuss. The group then plugs the question/problem into an AI tool (e.g., ChatGPT, GPT4, Bing Chat) and discusses or analyzes the output (Fig. 2)

Evaluating AI output

Develop a treatment outcome rubric with students that describes the components of an effective protocol. How long will the treatment take? How much will be the cost? What are the eventual shades to be achieved? Will there be any teeth sensitivities? Students prompt an AI tool to generate different versions of the protocols on a given patient and then use the rubric to evaluate the quality of the AI-generated versions (Fig. 4).

Improving upon/adapting AI-generated output

Students must improve upon the AI-generated output. When students turn in their treatment protocol, they must include both the AI-generated text and their improved version.

Explaining the steps in an AI-generated solution

Working from the AI-generated solution, the study group then works to explain or analyze the steps that the AI tool used to arrive at the solution.

Visualizing concepts with AI

Students select a treatment concept covered in lecture or course readings, e.g., office bleaching, at-home bleaching, and OTC strips etc. Students then prompt an AI image generator to create an image that represents each treatment protocol. Students will then analyze the strengths and shortcomings of treatment protocols generated by AI image generators.

Contribute to AI machine learning

Guided by the instructor, students submit comments and revisions on the AI-generated output to AI tool and contribute to machine learning.

How do I treat tetracycline staining?

Tetracycline staining is a form of intrinsic tooth discoloration caused by exposure to the antibiotic tetracycline during tooth development, typically in utero or during early childhood. Treating tetracycline staining can be challenging, but there are several options depending on the severity of the staining and your desired outcome. Here are some effective treatments:

1. Teeth Whitening (Bleaching)

- **Professional Whitening:** In-office bleaching treatments with high-concentration peroxide solutions can lighten mild to moderate tetracycline stains. Multiple sessions may be needed.
- **Take-Home Whitening Kits:** Custom-fitted trays with prescription-strength whitening gel can enhance the results over weeks or months.
- **Limitations:** Severe or deeply embedded stains may not respond well to bleaching alone.

2. Microabrasion

- A technique where the dentist removes a very thin layer of the enamel using a combination of mild acid and abrasive compounds.
- Effective for superficial discoloration but not for deep stains.

3. Veneers

- **Porcelain Veneers:** Thin, custom-made shells bonded to the front surface of the teeth to cover discoloration.
- **Composite Veneers:** A less expensive option made from tooth-colored resin but may not last as long as porcelain.
- Suitable for moderate to severe staining.

4. Dental Bonding

- Applying a tooth-colored resin directly to the stained teeth to improve appearance.
- Less expensive than veneers but not as durable or stain-resistant.

5. Crowns

- For cases where staining is severe, or teeth are also damaged, crowns (caps) may be placed over the affected teeth.
- Provides complete coverage and strength.

6. Combination Treatments

- In some cases, a combination of bleaching and veneers or bonding is used to achieve optimal results.

Considerations:

1. **Consult a Dentist:** A thorough evaluation is essential to determine the best treatment for your case.
2. **Custom Approach:** The treatment plan may vary depending on the depth of the stains, your oral health, and cosmetic goals.
3. **Maintenance:** Professional cleaning and home care are critical for maintaining results.

Would you like to explore any of these options further?



Fig. 4. ChatGPT question and generated answers on treating tetracycline staining. Such a treatment protocol can be used in the AI teaching tool to test the students' familiarity with AI tools and critical self-examination.

This article introduces an online global repository of patient data for teeth whitening, made available for research-

ers and developers in this therapeutic domain who use artificial intelligence systems for analytical systems and development of clinical protocols. A review of the history, and role in dentistry, of artificial intelligence is provided for context. In this time of exponential emergence of artificial intelligence influences in professional and social application, it is hoped this article serves as a simple offering to the dental community of foundational information and data resources.

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References

1. McCarthy J, Minsky ML, Rochester N, Shannon CE. *A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence* 1955. <http://www.formal.stanford.edu/jmc/history/dartmouth/dartmouth.html>.
2. Turing AM. On computable numbers, with an application to the Entscheidungsproblem. *Proc London Mathemat Soc* 1937;58(s2-s42):230-265.
3. Turing, AM. Computing machinery and intelligence. *Mind* 1950; 59:433-460.
4. McCulloch WS, Pitts W. A logical calculus of the ideas immanent in nervous activity. *Bull Mathemat Biophys* 1943;5:115-133.
5. Fix E, Hodges JL. Discriminatory analysis, nonparametric discrimination: Consistency properties. Technical Report 4, USAF School of Aviation Medicine, Randolph Field (1951).
6. Cover T, Hart P. Nearest neighbor pattern classification. *IEEE Transactions Inform Theory* 1967;13:21-27.
7. Fienberg SE. When did Bayesian inference become "Bayesian"? *Bayesian Analysis* 2006;1:1-40.
8. National Research Council (U.S.). Automatic Language Processing Advisory Committee. Language and machines: computers in translation and linguistics - A report by the Automatic Processing Advisory Committee. National Academy of Sciences, National Research Council Washington (1966).
9. Lighthill J. Artificial intelligence: A general survey. *Artificial Intelligence* 1974;5:317-322.
10. Schuchmann, S. Analyzing the prospect of an approaching AI Winter (2019). Thesis for Bachelor.
11. Floridi, L. AI and its new winter: From myths to realities. *Philosophy & Technology* 2020. <https://doi.org/10.1007/s13347-020-00396-6>
12. Hopfield JJ. Neural networks and physical systems with emergent collective computational abilities. *Proc Natl Acad Sci USA* 1982; 79:2554-2558.
13. Rumelhart D, Hinton GE, Williams RJ. Learning representations by back-propagating errors. *Nature* 1986;323:533-536.
14. Watkins CJCH. *Learning from delayed rewards*. PhD Thesis 1989. University of Cambridge, England.
15. <https://www.actuaries.digital/2018/09/05/history-of-ai-winters/>
16. Boser B, Guyon I, Vapnik V. A training algorithm for optimal margin classifiers. In: *Proceedings of the Fifth Annual Workshop on Computational Learning Theory*, Pittsburgh 1992.
17. Ho TK. Random decision forests. *Proceedings of 3rd International Conference on Document Analysis and Recognition*, Montreal, QC, Canada 1995;1:278-282.
18. Breiman L. Random Forests. *Machine Learning* 2001;45:5-32.
19. Wolpert D. Stacked generalization. *Neural Networks* 1992;5:241-259.
20. Breiman L. Bagging predictors. *Mach Learn* 1996;24:123-140.
21. Schapire R. A brief introduction to boosting. *Proceedings of the 16th international joint conference on artificial intelligence* 1999;2:1401-1406.
22. Krizhevsky A, Sutskever I, Hinton GE. ImageNet classification with deep convolutional neural networks. In: Pereira F, Burges CJC, Bottou L, Weinberger KQ. *Advances in neural information processing systems*, Curran Associates, Inc. 2012:1097-1105.
23. Goodfellow I, Pouget-Abadie J, Mirza M, Xu B, Warde-Farley D, Ozair S, Courville A, Bengio Y. Generative adversarial nets. In: *Advances in Neural Information Processing Systems* 2014:2672-2680.
24. Vaswani A, Shazeer N, Parmar N, Uszkoreit J, Jones L, Gomez AN, Kaiser L, Polosukhin I. Attention is all you need. In: *Advances in Neural*

- Information Processing Systems* 2017:5998-6008.
25. <https://openai.com/blog/chatgpt>
26. Lundberg SM, Lee SI. A unified approach to interpreting model predictions. *CoRR* 2017;abs/1705.07874.
27. <https://www.oecd.org/digital/artificial-intelligence/>
28. <https://gpai.ai/>
29. <https://www.unesco.org/en/artificial-intelligence/recommendation-ethics>
30. Schiff, A. *Generative AI Copyright Disclosure Act of 2024*. US Congress House of Representatives 118th Congress 2D Session. 8 January 2024.
31. *Seizing the opportunities of safe, secure and trustworthy artificial intelligence systems for sustainable development*. UN General Assembly Seventy-eighth Session Agenda item 13. 11 March 2024.
32. artificialintelligenceact.eu
33. Brickley M, Shepherd J. Performance of a neural network trained to make third-molar treatment-planning decisions. *Medical decision making. Soc Med Decision Making* 1996;16:153-160.
34. Wei J, Peng M, Li Q, Wang Y. Evaluation of a novel computer color matching system based on the improved back-propagation neural network model. *J Prosthodont* 2018;27:775-783.
35. Hwang JJ, Azernikov S, Efros AA, Yu SX. Learning beyond human expertise with generative models for dental restorations. *arXiv:1804.00064 (cs)* 2018.
36. Ding H, Cui Z, Maghami E, Chen Y, Matinlinna JP, Pow EHN, Fok ASL, Burrow MF, Wang W, Tsoi JKH. Morphology and mechanical performance of dental crown designed by 3D-DCGAN. *Dent Mater* 2023;39:320-332.
37. Ekert T, Krois J, Meinhold L, Elhennawy K, Emara R, Golla T, Schwendicke F. Deep learning for the radiographic detection of apical lesions. *J Endod* 2019;45:917-922.
38. Park WJ, Park JB. History and application of artificial neural networks in dentistry. *Eur J Dent* 2018;12:594-601.
39. Hwang JJ, Jung YH, Cho BH, Heo MS. An overview of deep learning in the field of dentistry. *Imaging Sci Dent* 2019;49:1-7.
40. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: Chances and challenges. *J Dent Res* 2020;99:769-774.
41. Schwendicke F, Krois J. Data dentistry: How data are changing clinical care and research. *J Dent Res* 2022;101:21-29.
42. Adapted from: *Data Science and Artificial Intelligence*. Institute of Data, University of Technology Sydney 2024;9(1):11-20.
43. Rajaraman V. 2014. John McCarthy Father of artificial intelligence. *Reason* 2014;198-207.
44. Maksut S, Timur S, Zhanar B, Aigul A, Marina Z, Nazym A, Yerzhan T, Ildar F. The recent progress and applications of digital technologies in healthcare: A review. *Int J Telemed Appl* 2020;2020:1-18.
45. Khanagar SB, Al-Ehaideb A, Maganur PC, Vishwanathaiah S, Patil S, Baeshen HA, Sarode SC, Bhandi S. Developments, application, and performance of artificial intelligence in dentistry - A systematic review. *J Dent Sci* 2021;16:508-522.
46. Dentistry 4.0: A Whole New Paradigm. Tagra Himanshu, Panchali Batra. https://discoveriesjournals.org/discoveries-reports/DRRep.2021_RA-Batra.pdf Discoveries Reports. 2021;4:e19.
47. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Özcan M, Att W, Krishnamurthy VR. Artificial intelligence applications in restorative dentistry: A systematic review. *J Prosthet Dent*. 2022;128:867-875.
48. Kosan E, Krois J, Wingenfeld K, Deuter CE, Gaudin R, Schwendicke F. Patients' perspectives on artificial intelligence in dentistry: A controlled study. *J Clin Med* 2022;11:2143.
49. Wälivaara B-M, Andersson S, Axelsson K. Views on technology among people in need of health care at home. *Int J Circumpolar Health* 2009;68:158-169.
50. Harrefors C, Axelsson K, Sävenstedt S. Using assistive technology services at differing levels of care: Healthy older couples' perceptions. *J Adv Nurs* 2010;66:1523-1532.
51. Gilson A, Safranek CW, Huang T, Socrates V, Chi L, Taylor RA, Chartash D. How Does ChatGPT Perform on the United States Medical Licensing Examination (USMLE)? The implications of large language models for medical education and knowledge assessment. *JMIR Med Educ* 2023;9:e45312. Erratum in: *JMIR Med Educ*. 2024 Feb 27;10:e57594. doi: 10.2196/57594. PMID: 36753318; PMCID: PMC9947764.
52. Eggmann F, Weiger R, Zitzmann NU, Blatz MB. Implications of large language models such as ChatGPT for dental medicine. *J Esthet Restor Dent* 2023;35:1098-1102.
53. Batra P, Tagra H, Katyal S. Artificial intelligence in teledentistry. *Discoveries (Craiova)* 2022;10:153.
54. Wang L, Wang D, Zhang Y, Ma L, Sun Y, Lv P. An automatic robotic system for three-dimensional tooth crown preparation using a picosecond laser. *Lasers Surg Med* 2014;46:573-581.
55. Schleyer TK, Thyvalikakath TP, Spallek H, Torres-Urquidy MH, Hernandez P, Yuhaniak J. Clinical computing in general dentistry. *J Am Med Inform Assoc* 2006;13:344-352.
56. Alkaissi H, McFarlane SI. Artificial hallucinations in ChatGPT: Implications in scientific writing. *Cureus* 2023;15:e35179.
57. Vishwanathaiah S, Fageeh HN, Khanagar SB, Maganur PC. Artificial intelligence its uses and application in pediatric dentistry: A review. *Biomedicine* 2023;11:788.
58. Shen Y, Heacock L, Elias J, Hentel KD, Reig B, Shih G, Moy L. ChatGPT and other large language models are double-edged swords. *Radiology* 2023;307:e230163.
59. Herrera LJ, Pulgar R, Santana J, Cardona JC, Guillén A, Rojas I, Pérez MdM. Prediction of color change after tooth bleaching using fuzzy logic for Vita Classical shades identification. *Appl Opt* 2010;49:422-429.
60. Freymann JB, Kirby JS, Perry JH, Clunie DA, Jaffe CC. Image data sharing for biomedical research - Meeting HIPAA requirements for de-identification. *J Digital Imaging* 2012;25:14-24.
61. Joiner A. The bleaching of teeth: A review of the literature. *J Dent* 2006;34:412-419.
62. Cruz AA, Lopes FM. Artificial intelligence (AI) and the challenges of the dentistry in the third millennium: Towards a new ethical and deontological framework. *J Orthod* 2017;22:17-23.
63. Schwendicke F, Krois J, Gomez J. Impact of artificial intelligence on oral health: Will the hype outpace scientific progress? *J Clin Med* 2019;8:526.
64. Dental Registry and DNA Repository. <https://www.dental.pitt.edu/research/drdr>. Accessed from the web 4_24-2024.
65. ChatGPT and other AI-based tools. <https://teaching.washington.edu/course-design/chatgpt/>. Accessed from the web 4_24-2024.