Analysis Artificial Intelligence

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Applications of Contemporary Artificial Intelligence in Dental Surgery

rtificial intelligence (AI) is a rapidly developing field that has the potential to transform the professions, including dentistry, and their activities. AI refers to the development of computer systems capable of performing tasks that normally require human intelligence, such as learning, decision-making, and problem-solving (1). In dentistry, AI may revolutionize the way care is provided; it could improve patient outcomes and streamline day-to-day administrative tasks. This article aims to explore how clinicians can responsibly incorporate AI tools into dental practice, as well as illuminate a few aspirational use cases for the technology, and several AI-related issues requiring the due diligence of the prudent dental surgeon.

Diagnosis and preoperative planning

Researchers have found AI to be a potential solution for the issue of discrepancies in diagnosis when multiple dentists are asked to perform a radiographic interpretation (2). A systematic review by Hegde et al. suggests that six factors play a role in creating diagnostic inconsistencies, four of which are dentist-related: clinical knowledge and experience, technical ability, location and duration of dental education, and cognitive load (3). Removing the "human factor" is hypothesized to greatly reduce the subjectivity involved in radiographic interpretation and diagnosis of subtle or borderline cases. An example of such application would be the development of various convolutional neural networks (CNNs) trained to detect interproximal caries using radiographic bitewing images (4-7). Aside from caries diagnosis, a novel CNN was recently developed by Warin et al. that has been validated to detect mandibular fractures in panoramic radiographs with greater accuracy than expert-level classification (staff oral and maxillofacial surgeons) (8). These AI technologies have the potential to improve the accuracy and speed of diagnosis for patients with craniofacial trauma, in addition to assisting surgeons in developing patient-specific treatment plans.

Aside from diagnosis, AI is also making its way into the treatment planning and operating rooms of hospital-based oral and maxillofacial surgery. Fibula free flap reconstruction surgery is a complex procedure that involves transferring a piece of bone along with associated vascular tissue, known as a "flap," from the fibula to the craniofacial skeleton to repair maxillary or mandibular defects. Preoperative planning is a critical step in this procedure, as it involves creating a detailed 3D surgical plan along with splints and cutting guides to ensure optimal functional and esthetic outcomes (9-11). Recently, a set of novel open-source mandibular and maxillary statistical shape models (SSMs) have been developed and validated by Wang et al. and Zhou et al. (12,13). These models have been trained on large datasets of craniofacial anatomy and are able to digitally reconstruct various large bony defects from patient CT scans in a reproducible, automated, and patient-specific manner (Figure 1).

Although the applications of AI in oral and maxillofacial surgery are promising, it is important to consider ethical, legal, and regulatory implications. The ultimate responsibility for the treatment of patients lies with the clinician, and the clinician must always be prepared to serve as the "catch-all" for any potential mistakes made by components of their health care team. This may now include mistakes made by AI tools and AI-assisted workflows that may be used in the delivery of care. Additionally, there also exists a potential risk of over reliance on AI-generated information, which could lead to a reduction in critical thinking and decision-making skills among dentists and other health care professionals. It is important for clinicians to maintain a balanced approach and to critically evaluate information generated by AI tools to ensure that the best interests of the patient are being served. Another concern is that the increased diagnostic sensitivity of AI may come at the expense of reduced specificity, resulting in a tendency to over-treat patients. Finally, clinicians must communicate clearly with patients about the role of AI in their care and to ensure that they fully understand the limitations and potential risks of using AI tools. By taking a proactive and transparent approach, clinicians can help to build trust and confidence in the appropriate use of AI in health care.



Figure 1. Virtual maxillary defect reconstruction is a clinical application of Zhou et al.'s craniofacial statistical shape model (SSM) (13). Displayed in white is a post-maxillectomy CT scan mesh with a large maxillary defect, followed by the virtual anatomical reconstruction in blue. Readers can interact with a live version of this SSM at 3dmodels.trevorthang.com/ssm/ or publish.uwo.ca/~kzhou54/.

Dental education

Although the prospect of integrating AI tools into clinical practice can be challenging due to liability concerns, many current AI technologies show promising benefits when employed in the classroom. Generative adversarial networks (GANs) are machine learning models trained to generate realistic output data, usually images. The training is accomplished via incremental evolution of the model over many repeated learning tasks where two sub-models – a generator and a discriminator – compete in a zero-sum game, where the former is rewarded for generating realistic output and the discriminator is rewarded for detecting non-representative output.

Images generated by such networks are different than those produced by a database or Google images search due to their completely original nature. The pedagogical application of GANs, such as the DALL-E 2 system developed by OpenAI or similar projects, may eventually allow for the on-demand generation of prototypical example images of various pathologies (Figure 2) (14). In theory, students and educators could ask for a typical intraoral presentation of lichen planus, and an AI tool trained on millions of clinical cases could produce a completely computer-generated image of the condition, free of patient confidentiality liability.

Unfortunately, at this time, DALL-E 2 does not possess such capability, as clinical matters (radiographs, histopathology, intraoral images, etc.) were not prioritized in the creation of its training dataset (Figure 3). However, Quiros et al. have recently developed a specialized open-source GAN for histopathology of colorectal and breast cancer (15). The images of hematoxylin and eosin-stained slides generated by this AI were rated for realism by two expert pathologists and showed no statistically significant differences when compared to that of real biopsy slides (15). Another benefit of AI-assisted learning comes from harnessing the sheer volume and variety of clinical cases that AI systems are capable of processing. For instance, over 110 high-resolution CT scans of human craniofacial anatomy were used to train the SSM developed by Zhou et al (13).



Figure 2. A pedagogical application of Dayma et al.'s generative adversarial network (GAN): text input of "squamous cell carcinoma" and the associated GAN output. The Al-generated images are convincing and, most importantly, do not have the confidentiality considerations associated with real patient photos. Images attributed to Al model Craiyon (formerly DALL-E mini) by Dayma et al. (20).



Figure 3. Text input of "panoramic dental X-ray of a patient with full dentition" and the associated GAN output. Unspecialized GANs such as DALL-E 2 are not yet suitable for producing realistic educational figures, as the system currently fails to demonstrate an understanding of radiographic anatomy. Image attributed to OpenAI (14).

In this study, unsupervised machine learning was used to generalize the anatomic variability of the training dataset to create an "average" model that could be distorted along a few dimensions to express 90 per cent of the original anatomical diversity (13). These "compressed" models, along with the appropriate software that would allow latent-space visualization, could be used by preclinical dental students to gain an exceptional understanding of natural dental or maxillofacial anatomical variation without the need to flip through hundreds of physical models or case studies. An example of such functionality is available at 3dmodels. trevorthang.com/ssm/ or publish.uwo.ca/~kzhou54/ (13). Together, these AI tools have the potential to provide students with on-demand learning and feedback when universities are faced with limited classroom/lab time, instructor availability, and clinical teaching resources.

Although AI tools in dental education are a promising solution to many issues, the authors caution against the over-reliance on emerging technologies in the classroom. The purpose of AI in education should be to help facilitate student learning or overcome physical limitations, not to replace the important scholarly skills of comprehension, analysis, and synthesis. Dental students should be developing a well-rounded set of skills, knowledge and, most importantly, critical thinking abilities. Hence, AI should be integrated into curricula as an adjunct to traditional tools, rather than as a substitute.

Patient education

Another potential application of AI in dentistry is in the rapid creation of educational materials for patients. Such information usually takes on the form of blogs or articles discussing certain clinical procedures or conditions, published on the websites of private practices. Although traditionally these resources would require a significant time investment to assemble, neural network-based language generation models exist that can automate the process. ChatGPT (developed by OpenAI) is one such example (16). These models are trained on large datasets of human-generated text from a variety of sources such as books and articles.

Explain the difference between reversible and irreversible pulpitis in simple terms to a dental patient with poor oral hygiene habits requiring root canal therapy for the 34.

Reversible pulpitis is a condition in which the pulp (the tissue inside the tooth that contains nerves and blood vessels) becomes inflamed but is still able to heal. This can be caused by things like tooth decay, a small cavity, or a cracked tooth. The pain associated with reversible pulpitis is usually relieved by removing the source of irritation and may not require a root canal.

On the other hand, irreversible pulpitis is a condition in which the pulp has become irreversibly damaged and cannot heal. This is often the result of neglecting dental care, such as not treating cavities or not brushing teeth regularly. The pain associated with irreversible pulpitis is usually constant and severe, and a root canal is usually necessary to remove the infected pulp and save the tooth.

It is important to take good care of your teeth and gums to prevent pulpitis and other dental issues. This includes brushing teeth twice a day, using fluoride toothpaste, and seeing a dentist regularly for check-ups and cleanings.

Figure 4. A clinical application of OpenAl's generative large language model, GPT-3. When asking the ChatGPT interface to "Explain the difference between reversible and irreversible pulpitis in simple terms to a dental patient with poor oral hygiene habits requiring root canal therapy for the 34" (top), the Al-generated output/response (bottom) is a remarkably competent foray into the difficult task of patient communication. Image attributed to OpenAl (16).

After proofreading by the clinician for accuracy, the AI output can be used to help assemble a knowledge database for patients, specific to the needs of the private practice. ChatGPT can produce fluent and accurate educational articles at a variety of tunable complexity levels (from elementary level to complex medical terminology) (Figure 4). The model is also able to translate and simplify English clinical jargon into a variety of different languages and may be useful as an aid for live interpretation (Figure 5).

Although the application of AI in patient education presents exciting possibilities, the prudent dentist is always aware of the increased liability that comes whenever tasks are off-loaded to a third party. There are many legal and ethical issues to keep in mind, such as the inability of ChatGPT to cite sources, risk of misinformation, patient privacy considerations, and possible over-reliance on AI-generated information. In particular, unsupervised use of ChatGPT by patients is an ethical dilemma. On the one hand, patients stand to gain improved accessibility to information that is tailored to their clinical situation and levels of understanding. However, it may be difficult for patients to verify the accuracy or reliability of the information, and the risk of miscommunication — no matter how unlikely — creates the duty for dentists to warn patients of the potential risks.

The accuracy of any AI-generated output is dependent on the quality and reliability of the training data. If training data contains errors or inaccuracies, the AI model may generate incorrect or misleading information. AI models are also trained on datasets that represent a mere "snapshot" of the ever-evolving knowledge that exists in the public domain. Due to the computational resources required to train these models, infrequent dataset updates are commonplace in many AI projects. Thus, it is quite probable that medical and dental AI tools produce outputs that fail to consider more current research or clinical advancements. It is important for dentists to carefully consider the potential risks and liabilities associated with using AI in patient education and to take steps to minimize these risks.

1	Explain cellulitis to a high school student in two sentences.
\$	Cellulitis is a bacterial skin infection that causes redness, swelling, and warmth in the affected area. It can spread quickly and can be serious if not treated with antibiotics.
	Translate that to French.
\$	Cellulite est une infection bactérienne de la peau qui cause de la rougeur, de l'enflure et de la chaleur dans la zone touchée. Il peut se propager rapidement et peut être grave s'il n'est pas traité avec des antibiotiques.
	Translate that to Spanish.
\$	La celulitis es una infección bacteriana de la piel que causa enrojecimiento, hinchazón y calor en la zona afectada. Puede propagarse rápidamente y puede ser grave si no se trata con antibióticos.
	Translate that to Mandarin.
\$	细菌性蜂窝组织炎是一种细菌皮肤感染,会导致受影响部位发红、肿胀和发热。它可以迅速 蔓延,如果不用抗生素治疗可能会严重。
Figure 5. An example of ChatGPT's interpretation capabilities. The model can translate between some of the most commonly spoken languages with	

a high degree of accuracy. Image attributed to OpenAI (16).

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Administrative tasks

AI tools such as ChatGPT could also be used to streamline office processes by generating appointment reminders and other automated messages for patients. For example, a dentist could input a patient's appointment information into ChatGPT and the model could generate a personalized reminder message that includes the date, time, and location of the appointment. This could allow dentists and office staff to divert resources away from tasks that distract from patient care, allowing them to focus on more important endeavours. From the authors' preliminary examination of ChatGPT's functionality on non-clinical administrative tasks at the Schulich School of Medicine & Dentistry, Western University, the AI tool is extremely adept at taking short bullet points of information as input and producing highly professional and comprehensive letters complete with appropriate social mannerisms and context-specific suggestions.

The introduction of AI to the field of dentistry may be particularly well-suited to start with assistance of administrative tasks, given the lower risks compared to clinical matters. However, it is still important to carefully consider the potential risks associated with using AI even for non-clinical tasks. Clinicians should implement robust quality control measures, as well as develop protocols for managing potential errors. This can include *post hoc* human screening, frequent audits of AI-assisted tasks, and mechanisms for staff or patients to flag/report errors.

A glimpse into our future

There is ongoing debate about the extent to which AI can approach the level of advanced judgement and sophistication required to make diagnoses and treatment plans in medicine or dentistry. On the one hand, proponents of evidence-based dentistry may argue that since many clinical decision-making processes are protocol-oriented and based on established guidelines, it is possible that AI models could eventually reach a level of complexity that allows them to understand and follow these protocols in making diagnoses and treatment recommendations (17). For example, AI models could be trained on large datasets of patient records and treatment outcomes to identify patterns and make predictions about the most appropriate course of action. (Figure 6 shows an example of capabilities that exist in current AI tools).

On the other hand, it is important to consider that dentistry is highly complex and requires a high level of skill,

concepts, such as the correct order of treatment plan phasing (acute, disease control, definitive,
maintenance, etc.) and the need for a crown due to increased risk of tooth fracture after endodontic
treatment. Image attributed to OpenAl (16).stions.expertise, and to a certain degree, subjective judgement
based on the outcomes of previous cases during the clini-
cian's lengthy training (18). Many diagnostic and treatment
decisions require a deep understanding of the patient's medi-
cal history, current condition(s), and treatment goals, as well
as the patient's desires and priorities in life. This information
is only possible to obtain through an excellent clinician-pa-
tient relationship, making it highly unlikely that AI mod-
els will be able to fully replicate the quality of medical and
emotional service that dentists provide. However, given the

Generate a detailed treatment plan for an ASA class 1, 25-year-old male patient presenting with gross caries of the 46 extending into the

Here is a detailed treatment plan for an ASA class 1, 25-year-old male patient presenting with gross caries of the 46 extending into the

history, a dental exam, and radiographic imaging (e.g. x-rays) to assess the extent of the decay and the overall condition of the patient's

teeth and gums. This step may also include a consultation with the patient to discuss their treatment options and to develop a treatmen

remove the infected or damaged tissue and to fill the root canal with a filling material. This procedure is typically performed under local

Crown placement: If the tooth is severely damaged or decayed, it may be necessary to place a crown (a cap that covers the entire

4. Follow-up care: This step involves regular check-ups and cleanings to ensure that the patient's oral health is maintained and to address

Figure 6. When provided with a brief hypothetical patient case presentation and asked to provide

a detailed treatment plan, ChatGPT demonstrates an apparent understanding of several foundational

pulp. Tooth is restorable and periodontal condition is stable. Provide estimated treatment costs.

plan that is tailored to their specific needs and preferences. Estimated cost: \$100-\$300.

anesthesia and may require multiple visits to complete. Estimated cost: \$500-\$1,500

combination of materials. Estimated cost: \$1,000-\$3,000

depend on the extent of the decay and the condition of the tooth. Potential treatment options may include

pulp, with a stable periodontal condition:

tient relationship, making it highly unlikely that AI models will be able to fully replicate the quality of medical and emotional service that dentists provide. However, given the current progression in AI research, it is more than likely that, in the near future, these tools will continue to demonstrate significant value and become widely adopted in health care to assist clinicians with specific tasks.

A word of caution

The Therac-25 was a Canadian radiation therapy medical linear accelerator involved in a series of accidents in the 1980s that resulted in serious injuries and deaths to cancer patients due to software flaws that caused the machine to deliver more than 100 times the intended dose of radiation (19). The principal cause of these catastrophic failures was perhaps the overconfidence of engineers in the Therac-25's software, which was developed during a time when computers were just starting to be used extensively in health care settings. Today, we are on the verge of another computational revolution, this time driven by AI tools. The Therac-25 accidents should serve as a cautionary tale about the importance of critical thinking, the need to implement fail-safe measures, and the dangers of placing blind trust in medical software without expert human review and oversight.

In addition to being cognizant about the dangers of over-reliance on AI tools, dentists should also make efforts to choose software that aligns with their moral and ethical principles. As legal and regulatory frameworks surrounding the use of AI struggle to catch up in the next several years, it will be more important than ever for dentists to be aware of and exercise caution around poorly engineered AI tools, which may harm rather than improve clinical objectivity by perpetuating or amplifying existing prejudices. Before adopting any AI tools, clinicians should seek out primary data that answers the following important questions:

- 1. Has the AI's training dataset been sampled appropriately to avoid algorithmic bias from over- or under-represented populations?
- 2. Do the researchers or institutions creating and validating the AI have existing prejudices or conflicts of interest?
- 3. What quality control has the training dataset gone through to eliminate false or prejudiced data?

Importantly, open-source projects tend to demonstrate a higher level of transparency and are held to a higher degree of social accountability by the public, compared to proprietary AIs.

Conclusion

AI has the potential to revolutionize the field of dentistry by improving clinical and non-clinical activities. There are already several promising applications of AI in preoperative planning, dental education, patient education, and administrative tasks. However, it is important to consider the ethical, legal, and regulatory implications of using AI in health care and to ensure that the best interests of the patient are always served. Open-source projects may be a good choice for clinicians looking to adopt AI tools due to their excellent standard of transparency. As the field of AI continues to develop and become widely adopted in health care, it will be important for dental surgeons to keep abreast of new technologies and critically appraise their potential contributions and harms to patients, the dental profession, and society.

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