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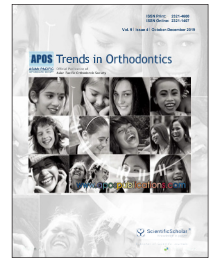

Experts Corner

Artificial intelligence in orthodontics

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ABSTRACT

This article aims to discuss how AI with its powerful pattern finding and prediction algorithms are helping orthodontics. Much remains to be done to help patients and clinicians make better treatment decisions. AI is an excellent tool to help orthodontists to choose the best way to move teeth with aligners to preset positions. On the other hand, AI today completely ignores the existence of oral diseases, does not fully integrate facial analysis in its algorithms, and is unable to consider the impact of functional problems in treatments. AI do increase sensitivity and specificity in imaging diagnosis in several conditions, from syndrome diagnosis to caries detection. AI with its set of tools for problem-solving is starting to assist orthodontists with extra powerful applied resources to provide better standards of care.

Keywords: Artificial intelligence, Orthodontics, Aligners, Diagnosis, Dentistry

INTRODUCTION

A 25-year-old young man has a great deal of discomfort regarding the appearance of his teeth and chin. He visits an orthodontist and is diagnosed with an Angle class III malocclusion, for which the only treatment is combined orthodontic-orthognathic surgery. However, he decides to take another opinion from a second orthodontist, who confirms the diagnosis as Class III, understanding, nonetheless, that the problem is of intermediate severity and suggests a treatment using aligners. Due to this discrepancy between both treatment plannings, the man decides to take another opinion. A third orthodontist says that he would not recommend surgery if the young man was his son, but asserts that the treatment is too complex to be performed using aligners and, hence, proposes a treatment using fixed appliances and lower premolars extractions. Faced with this impasse, the man takes yet another opinion. A fourth orthodontist agrees with the third orthodontist on the use of braces without requiring orthognathic surgery; however, he proposes to extract the third molars and use a skeletal anchorage system to distalize all the lower teeth.

More often than not, patients come across a multitude of opinions regarding their treatments. Therefore, they find themselves at a crossroads of anguish and difficulty while making a decision about which treatment to pursue. As a consequence, treatments are either postponed or simply not performed due to the uncertainty in pursuing a treatment. Furthermore, this uncertainty leads to a certain discredit of the opinions of the experts in general. To make matters worse, patients' anxieties, values, and fears are often not taken into account in an informed decision-making model.

On the clinician's side, where various treatment options can be applied to a problem, there is apparently a greater decision-making difficulty.[1] Besides, if any of these treatment options are novel (such as new surgical techniques, new drugs, or new appliances), clinicians are apparently more likely to choose a more obsolete form of treatment or even suggest that no treatment is needed.[1]

Thus far, no tools exist to lead patients and clinicians out of the decision-making uncertainty, in which they are trapped when they face a condition that has several possible correct treatment options – though some better than others. It is in this context that artificial intelligence (AI) can make a significant contribution.

AI is driving discoveries across all sciences. Its powerful pattern finding and prediction algorithms are helping researchers and clinicians in all fields[2] – from finding new ways to access sleep quality[3] to classify the presence and absence of root[4] and crown caries.[5]

Morgan Stanley estimates that the global market for AI in health care could surge from $1.3 billion in 2019 to $10 billion by 2024, growing at an annual compound rate of 40%.[6] However, the clinical applications of AI are still in the developing stage. It is as important to perform the treatments as to define which treatment is best for each person, taking into account, both the scientific evidence and the expertise of the clinicians, as well as the values of the patients.

However, currently, there are more tangible boundaries and more immediate and achievable goals in orthodontics. This article aims to review these points and discuss the future directions of advancement in our specialty.

WHAT AI IS

Broadly speaking, AI is the behavior of non-biological entities that perceive, learn, or react to complex environments.[2] AI is not a computational tool that necessarily mimics the workings of the human brain; rather, it is a set of tools for problem-solving, each with its own specific rules.

Research is being performed in the field of AI to achieve human-like generality.[7,8] However, most of the progress on AI has been on models that focus on a single problem, having a constrained set of rules-problems such as playing chess or identifying caries from X-ray scans.[4] For many of these problems, computers far surpass human results.

While an AI model can be classified as narrow or general on the basis of its problem-solving capabilities, from an algorithmic perspective, there are two main categories of AI: Symbolic AI and machine learning. Table 1 depicts how these categories are divided.

Symbolic AI is a collection of techniques that are based on structuring the algorithm in a human-readable symbolic manner. This category was the paradigm of AI research until the late 1980s and is widely known as GOFAI – good old-fashioned AI.[9]

Table 1: Types of AI.

Symbolic AI	Machine learning	
	Unsupervised learning	Supervised learning
Expert systems	Principal component analysis, hierarchical clustering, K-means	Multilayer perceptron, convolutional neural networks, random forests

AI: Artificial intelligence

The techniques in symbolic AI use rules, such as if-then statements, where if a certain criterion is met, then the corresponding action must be taken. These systems are limited to the current human understanding of the problem and the ability to organize this understanding in an algorithmic form. Symbolic AI is still used for solving problems, in which the possible outcomes are limited, computational power is scarce, or human explainability is essential. However, in health care, where problems tend to be complex, not always fully understood, and have with many explanatory variables, building a model based on a set of rules is extremely difficult, if not impossible.[8]

The other structural approach to AI is machine learning, which is the current paradigm. The fundamental difference between machine learning and symbolic AI is that, in machine learning, the models learn from examples rather than a set of rules established by a human. In this way, algorithms shift from rules on how to tackle a problem, to rules on how to learn from the data available.

The underlying mathematical knowledge required for most of the recent progress in machine learning has existed for more than 30 years now.[10] However, it was only due to the increasing amount of data and computational power for the past few years that some of the algorithms were made accessible for a wide range of fields.

Different types of machine learning algorithms process data in different ways. Some algorithms, known as unsupervised learning algorithms, require only a set of input data to group and identify patterns in the data. Principal component analysis, a common type of unsupervised learning algorithm, can be used, for example, to indicate the determining attributes to arch size, shape, and occlusal relations from a wide set of variables.[11]

To train supervised learning algorithms, one must have, beforehand, both the inputs and the correct outputs of what the model is trying to achieve – referred to as labels in AI jargon. For example, for a set of facial profile images of patients with Class 1, 2, and 3 malocclusions, an unsupervised algorithm may even be able to group the images on the basis of visual proximity between them; however, the algorithm will only be able to correctly classify the images if it learns how to associate certain image characteristics with the patients' class of malocclusion.

For training supervised learning algorithms, inputs are given to the model, it estimates outputs and calculates the difference between the estimates and the labels. This difference, which is the error of the model, is automatically used to correct internal parameters to minimize future error. By performing this process for thousands – or millions – of different inputs, the error decreases. When the model obtains acceptable error rates, the algorithm is ready to be used for new, unlabeled data.

We live in an era of great hardware development. For instance, a leaked paper authored by physicists from Google claims to have achieved "quantum supremacy."[12] This means the development of a new quantum computer that could do in a little over 3 min what would take a supercomputer 10,000 years to reproduce. Therefore, the main challenges in using machine learning include selecting the suitable algorithms, tuning them correctly, and, primarily, having sufficient data to train the models.

MACHINE LEARNING FOR TOOTH MOVEMENT PLANNING

The use of AI for assisting in orthodontic treatment planning has apparently been a reality for some time. More than one aligner company claims to use AI algorithms to optimize orthodontic planning, thereby saving the time of orthodontists in this process. Because these algorithms are industry secrets, the truth is that the point where AI algorithms end and marketing strategies begin is unknown.

AI is an excellent tool to help orthodontists to choose the best way to move, for instance, a tooth or group of teeth from point A to point B, once the orthodontist instructs the machine where the final position should be. This is useful because orthodontics performed in a totally traditional way – with brackets only – require high manual skill, and many professionals do not have or have not received proper training to develop it. AI assists these dentists, but there are several limitations of machine learning in contemporary aligner treatment.

AI today completely ignores the existence of oral diseases[13-17] and possible previous health treatments that may affect the prescription of orthodontic corrections, either with aligners or fixed appliances.[18] Patients with periodontitis seem to be more interested in correcting the alignment of their teeth,[19] as pathological tooth migration is a common consequence of periodontitis.[20] However, performing orthodontic movement with active disease is contraindicated. Thus, it is essential that an orthodontist prepares a proper anamnesis, examines the patient, makes a diagnosis, and only then prescribes the appropriate treatment before performing it. More often than not, orthodontics is performed after essential endodontic, periodontal, restorative, etc., treatments.

This fact makes it particularly risky to use AI technology for the so-called "do-it-yourself orthodontics." Companies in several countries have been selling aligners to patients without proper dental supervision. This has led to numerous reports of tooth mutilation and bone loss in the general population. However, a mismatch exists between the professional reports in conferences of these damages to the health of the population and the reports of these problems in scientific journals. In addition, there is some subliminal pressure and fear in the clinical and scientific community regarding the possibility of legally responding to the exposure of the damage caused by these alleged corrections. Companies' financial resources for a legal fight go beyond that of clinicians and – in some cases – even that of the largest orthodontic associations.

Another limitation of AI algorithms being implemented today is that they do not incorporate patients' facial analysis, their proportions,[21,22] and esthetics.[22] There is a direct interaction between orthodontic dental movements and facial esthetics. Only a qualified orthodontist can perform these analyses because tooth movement in any direction of the space is commonly connected with facial and smile esthetics.[23] In addition, facial analysis is the first step toward determining whether dentofacial deformities are present[24] and thereby the possibility of surgical orthodontic corrections.

AI used in contemporary planning does not consider the impact of functional problems and the stability of the tooth position – or lack thereof – when tooth movements are performed. For example, problems associated with important functional etiology, such as the open bite malocclusion, can be treated using aligners.[25] However, AI today cannot determine the etiology of the problem or predict specific retention strategies.

In machine learning models, the machine needs to be trained to identify the benchmark, such as excellent treatment results. A relevant point in AI algorithms for aligners is that companies use cases that have already been treated to feed their databases with successful references. Furthermore, most – if not all – aligner companies provide appliances for non-orthodontic specialists; it is common knowledge that non-specialists have difficulty in planning and executing treatments with excellence. Thus, the company samples are biased, as the reference treatments are – largely – of dubious quality. The natural conclusion is that the algorithms are biased by poor treatment results and need to improve considerably before they can significantly help orthodontists achieve excellent treatment results.

In addition, AI algorithms do not effectively incorporate many orthodontic tools, thereby limiting treatment tool and strategies, such as skeletal anchorage, dental extractions, and integrated restorative procedures. This is at least partially associated with the mechanical limitations of aligners to control certain tooth movements. When the fixed orthodontic appliance was developed, nearly 100 years ago, we had doctor-centered treatments and not patient-centered ones. In other words, more consideration was given to how easy and efficient the treatment would be mechanically for the doctor, rather than how comfortable and effective the treatment would be for patients. Moreover, brackets, wires, and other attachments were developed from the doctor's point of view.

However, orthodontic treatment and appliances need to be patient centered to improve the user experience.[26] This is one of the biggest challenges of contemporary orthodontics because if the conventional bracket device is not the ideal device for esthetic- and comfort-related limitations, the aligners will also not be ideal due to mechanical limitations. Hence, a considerable amount of effort is still required to achieve a device design that addresses all these parameters.

AI IN DIAGNOSIS

Imaging diagnoses have gradually incorporated AI to increase sensitivity (ability to adequately predict the existence of a disease or problem in a patient) and specificity (ability to exclude the disease or problem when an individual does not have it). AI has excellent application in imaging diagnostics due to the ease with which the machine deals with patterns.

There are more than 8000 identified genetic syndromes. However, despite all the advances in genetics, including next-generation sequencing-based tests, establishing the correct diagnosis is still a difficult task. Timely diagnosis of genetic syndromes tends to improve the outcomes. By the same token, craniofacial phenotypes are extremely informative for establishing the correct diagnosis of genetic congenital diseases because many syndromes have recognizable facial features. These changes in facial morphology are often of significant orthodontic interest. Several syndromes lead to dentofacial deformities and malocclusions that require orthodontic treatment.

In this field, AI has helped in a relevant way. One such advancement is a mobile phone application called Face2Gene (FDNA, Boston, USA). The application uses the contrast of a patient's image against thousands of images in its databases to determine the subtle patterns that different syndromes tend to have. The diagnostic hypothesis established by the App has already proved to be useful for Caucasian and Asian populations[27] and outperformed clinicians in diagnosing a number of syndromes.[28]

Another interesting recent application of AI is the prediction of extractions in orthodontic planning.[29] The teeth to be extracted (first and second premolars) and the variability of dentofacial alterations included in this study were limited, and this arbitrary constraint probably reflects the relatively small original database. However, this is a promising and exciting first step toward determining whether extractions are required in the treatment plan.

AI has already been used to diagnose and classify osteoarthritis in the temporomandibular joint,[30] and it may provide future data for establishing treatments for problems that are specific to the different severities of the condition.

CONCLUSIONS

AI is a set of tools for problem-solving that can assist orthodontists with extra powerful and applied tools to provide better standards of care. AI can assist orthodontists to choose the best way to move a tooth or group of teeth, but AI today completely ignores the existence of oral diseases, does not fully integrate facial analysis in its algorithms, and is unable to consider the impact of functional problems in treatments. At the same time, imaging diagnosis has been incorporating AI do increase sensitivity and specificity in numerous conditions, from syndrome diagnosis to caries detection.

Declaration of patient consent

This is a hypothetical case hence patient's consent not required.

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Conflicts of interest

There are no conflicts of interest.

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