A ADVANCED JOURNAL IN ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING TRENDS IN BIOLOGICAL SCIENCES
Open Journal

Review

Applications of AI to ZrO_2 in Biological Research

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Article information
Received: March 1st, 2023; **Revised:** May 10th, 2023; **Accepted:** June 15th, 2023; **Published:** July 3rd, 2023

Cite this article
Singh J,Singh S. Applications of AI to ZrO_2 in biological research. 2023; 2(2). doi: https://doi.org/10.70705/ppp.bioai.2023.v02.i02.pp40-46

ABSTRACT
In the ever-expanding field of artificial intelligence (AI), researchers are aiming to program computers to do hitherto human-only activities. Machine learning (ML) is a branch of artificial intelligence that uses algorithms to "learn" hidden information from data by analyzing its inherent statistical patterns and structures. Due to its increased biocompatibility, aesthetically pleasing appearance, great oxidation resistance, superior mechanical qualities, and absence of reported allergic reactions, ZrO2 has risen to popularity at the same time as the focus on cosmetic dentistry. Innovations in artificial intelligence and machine learning have opened up new possibilities for using ZrO2 in dental devices with a focus on biology. The capacity of artificial intelligence (AI) systems to evaluate data and find relationships between apparently unconnected occurrences has made them a hot topic in ZrO2-related medicinal applications and research. This is mainly because to their absorption into zirconia. Due of zirconia's adaptability in the scientific community, the use of AI in this field changes depending on the particular ways zirconia is employed. So, the artificial intelligence applications of ZrO2 in dental medicine are the main points of this piece.

Keywords
Biomedical engineering; Artificial intelligence; Machine learning; Zirconia.

INTRODUCTION

When it comes to clinical treatment, laboratory operations, student education, administration, and dentistry research, among many other procedures and activities, digital technology is heavily used in the dental industry [1]. Examples of the ways in which digitization has contributed to clinical care include digitally conducting CAD/CAM, shadow analysis, smile design, impressions, and virtual communication [1,2]. An idea for what is now known as "artificial intelligence" (AI) emerged in the 1950s.

Rapid advancements supported by computing power [3]. A branch of computer science known as artificial intelligence (AI) allows smart machines or software to do tasks that often require human intelligence. Robots that can learn from their errors, adjust to new situations, and carry out tasks that are similar to human ones have recently been developed thanks to advancements in artificial intelligence [4].

Artificial intelligence (AI) is permeating many areas of human society, including dentistry and medical, and is expanding rapidly within these industries (Figure 1). Implants must to be resistant to corrosion. Corrosion and wear are the primary causes of material degradation [5–18]. Since its introduction in the 1960s, zirconia—a kind of high-tech ceramic—has found several uses in the biological field [19]. Lots of people are interested in using zirconia in dentistry since it is biocompatible, aesthetically pleasing, mechanically robust, resistant to corrosion, and has no known adverse reactions [20-22]. Artificial intelligence (AI) methods have been well-received in biomedical and ZrO2-based research in recent decades due to its association with data processing and ability to give regression/correlation between complex phenomena. Given the potential therapeutic uses of these approaches, this is a significant development. Consequently, dentists need a thorough understanding of AI in ZrO2-based research in order to examine the applications of ZrO2. In this research, we review the state of the art and present challenges of artificial intelligence methods used to dental applications including ZrO2.

Use of AI in dentistry applications and industry

There has been a recent explosion in the use of machine learning (ML). Machine learning (ML) has the potential to self-train and advance by examining different data sets, then assembling prior knowledge and methods [23,24]. In the realm of dentistry, medicine, and other medical specializations, the emergence of AI-ML has brought both new opportunities and new challenges. In several dental subspecialties, including orthodontics, prosthodontics, maxillofacial surgery, and others, an accurate diagnosis is the cornerstone of a successful treatment approach [25]. Reason being, it is capable of specifying

machine learning facilitates the diagnosis, prediction, and evaluation of disease onset and treatment outcomes by establishing connections between operational records and patterns in massive data sets [26-28].

The growth of data computing and the analysis of massive clinical patient data sets have led to notable developments in AI application technology in the dental sector [2,19]. The researchers provided an exhaustive analysis of the most recent findings. In their comprehensive and current review, the researchers included all the latest information about AI dental diagnostics and diagnostic imaging. In order to keep up with the newest medical technology and use it therapeutically, it is essential for dental surgeons and dentists to understand artificial intelligence (AI), study it, and become experts in it. As an example, Hung et al. reviewed the literature extensively on AI's clinical uses in maxillofacial imaging and dentistry [29]. To repair a tooth with a vertical fracture, Kositbowornchai et al. [29] constructed an ANN. Jung et al. used a back-propagation approach to create neural network ML models that orthodontists may employ to aid in treatment plan determination. In order to diagnose extractions, these models were used [29]. As shown in Figure 2, Li et al. [30] obtained a new patient's medical records using a neural network prediction approach and described the 24 inputs, which comprised demographic data, cephalometric data, dental data, and soft tissue data. The data was sent to the other two networks after they determined that the extraction probability (0.955) was higher than 0.692, indicating that it was an extraction case. Probabilities of various extraction and anchoring patterns are among the outcomes generated by the other networks. After researching each of these therapeutic options and taking into account a host of other considerations, the doctor settled on a successful plan of action.

Several dental applications, such as monitoring oral health and diagnosing oral diseases, now make use of AI. Appointments and medical advice are two examples of AI-implemented apps that are more sophisticated and used in hospitals and dental clinics. Possible future uses for artificial intelligence in dentistry include oral surgery, cosmetic dentistry, analysis of radiographs, oral healthcare, etc. [31]. To detect gum inflammation, for instance, Li et al. [32] used AI algorithms on patient photos using pixel semantic segmentation. It was a deep neural network that helped get the job done. This approach, which makes use of mobile apps, may be suitable for dental self-examination, according to the results.

The use of AI and ML is also on the rise in many other fields, including education, research, oral health management, and illness treatment. Without a doubt, ML may provide a lot of relief and help to the dentist. Pretending that ML can match human performance is risky. The purpose of artificial intelligence and machine learning in dentistry is not to render dentists obsolete, but to assist them in providing more precise clinical diagnosis and treatment suggestions. The objective of using AI-ML in dentistry is to eventually replace dentists, yet this is still not the case. The exponential growth of computing power is bringing us a new age in artificial intelligence. New applications for ZrO2 in dental devices have emerged as a consequence of advancements in AI and ML, which have important implications for biomedicine. Depending on the direction of ZrO2 application, the topic of AI in ZrO2 science varies. Nowadays, AI-ML technologies are no longer seen as futuristic ideas but as tools for improving our daily lives. Discussions on its impact on politics, healthcare, the economy, and society were extensive and included researchers from a broad range of fields. The dental profession also includes things that fit under this group. Most people agree that artificial intelligence will be very important for the future of dentistry.

Preparation of artificial tooth AI technology

A complex process is followed during the preparation of ZrO2 restorations. The job that a dentist does daily includes preparing teeth for crowns and bridges. Even though the dentist has years of expertise, the job is nevertheless difficult. The most difficult part of the process is figuring out how to preserve as much of the natural tooth as possible while yet leaving enough room for restoration. Tooth preparation normally utilizes mechatronics engineering. The use of a robotic arm as a tool to aid dentists in the process of tooth preparation is an intriguing and astute suggestion. A dental drill was the first invention by Simon et al. [33] which was the first electromechanical system. During the process of tooth preparation, the robotic arm may assist the dentist in operating the instrument more accurately and smoothly. The mechatronic technology lessens the likelihood of iatrogenic oral injuries and may decrease the number of handshakes that are necessary due to weariness. Using this mechatronic system resulted in a 53 % increase in positional accuracy. The mechatronic system improved the accuracy by giving support and stability while the dentist was working with dental drills. The general agreement and goal of the global medical community are to go in the direction of precision medicine. As a result, the great precision, dexterity, and speed of the robot may eventually surpass the limitations of manual operation, therefore improving the effectiveness and precision of

clinical operation [34]. Yuan et al. [35] developed a robotic tooth preparation system to increase the quality, accuracy, and clinical effectiveness of the procedure. This was done to avoid the drawbacks of the constraints that conventional manual procedures provide. LaserBot is a micro-robotic system that was developed by Wang et al. [36] which was effective in tooth finishing by utilizing the laser beam. Li et al. [37] developed a robotic manipulator system with a smaller and softer bracer for dentistry applications. This system was fitted with a tendon sheath transmission mechanism. This particular robot's electric-motor actuators don't have to be in close proximity to the manipulator. This system provides tool interchangeability and can be completely modified to meet the requ- irements of any dental operation. As a result, it has the potential to be used in a variety of contexts, such as the treatment of crowns and the elimination of caries. Many other systems were developed to improve the precision of dentistry treatments as compared to conventional treatment [38,39].

AI in digital impression

AI is also helpful in obtaining colorimetry and 3D impressions of the teeth and tissues [40]. This further helps in designing the restorations through readable 3D data. The dental prosthesis was produced using a process known as computer-aided manufacturing. At the moment, more recent research makes use of tooth preparation robots with a respectable level of intelligence and precision. These robots have become the direction that the development of digital dental prostheses is heading. In the realm of dentistry, high-precision restorations may be crafted with the use of CAD/CAM-based technology (Figure 3). In addition, inlays, crowns, bridges, and inlays are designed and manufactured with the help of AI-based technologies [41].

Figure 3. Digital impression of teeth using iTero scan [42]
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These systems take the place of the conventional approach to the creation of restorations, which has the potential to minimize the amount of time spent on production and the number of mistakes that may occur. Dentists have greater standards than ever before for the ease with which their practices may be carried out. Patients are becoming more particular about the aesthetics of their dental care, and they are hoping that their visits to the dental clinic would take less time. The CAD/CAM technology that is used in contemporary dentistry has become an essential component in the production of zirconia restorations. Additionally, the digital intraoral impressions technology that

is used in dentistry is regarded as an effective impression procedure [43,44]. A study was conducted by Gao et al. [45] to examine the precision of digital scanning. They identified that digital impression scanning was far better than conventional intraoral and cast scanning. Oh et al. [46] also suggested that scanning an impression is the most effective method for developing a digital dental model.

AI in digital media

Digital technologies particularly digital Information and communication, are finding more and more use in the dentistry industry [41]. Computers play a vital role in dental practices [47,48]. A large-scale online survey was carried out by Parmar et al. [49] to investigate the perspectives of patients and dentists regarding the utilization of social media platforms (specifically Facebook) and their activities conducted online in the present day. They researched to investigate the prospects and possible hurdles associated with the adoption of social media techniques by dentists. They investigated the beliefs, ideas, and activities associated with using social media from the points of view of both patients and dentists. According to the findings, the level of contact and involvement of patients may be raised with a greater level of social media activity on the part of the dentist. They can contact their dentists more conveniently and efficiently via the use of social media platforms for their dental treatment. In the same vein, dentists may use digital media to connect with patients as well as CAD/CAM tools to fabricate restorations [49]. This made the clinical job of the dentist easier and more efficient. In the future, AI-ML will digitalize the numerous phases throughout the process of aesthetic treatment by assessing through digital smile design [50].

AI in dentistry labs

Additionally, AI-adapting dentistry labs can learn from the experiences of millions of patients in order to create more effective designs for prostheses inside design software used for restoration [51]. An AI system may be provided with a data set for picture training. Within this system, one network can concentrate on creating a newer image. However, at the same time, another network attempts to determine which photos are false and which are genuine. With the use of this technology, restorations may be crafted to look exactly like the patient's native anatomy. Library-based systems tend to create more intricate anatomical structures comparable to surrounding dentitions that wear down with usage. This is especially true for elderly individuals. The design that was produced by the GAN program successfully matches the patterns and detail that occur as a result of wearing dentures.

Use of AI in ZrO2 biomedical applications in dentistry

ZrO2 in dentistry

Researchers and dentists are currently focusing on producing an aesthetically pleasing restorative material that does not include any metals because of rising concerns about cytotoxicity and allergic reactions associated with certain metals [52,53]. In restorative dentistry, ZrO2 may be used in a variety of applications, including implants, abutments, posts, cores, crowns (both complete and partial), bridges, inlays and onlays, and veneers [54,55]. Zirconia has been shown in previous clinical investigations to have an abrasive impact on dentition, which results in excessive wearing in the structure of the tooth [56-58]. In 2018, Pjetursson et al. [59] conducted a comprehensive study to explore the survival rates of ZrO2 and metallic-ceramic crowns as well as the rates of technical, biological, and cosmetic complications associated with these crowns. Single crown implants made of zirconia showed a 97.6 % survival rate after 5 years (95 % confidence interval: 94.3-99.0), and it exhibited a similar frequency of biological difficulties while having fewer cosmetic issues.

In addition, by studying the evolution of modern dental ZrO2 ceramics, Zhang et al. aimed to make zirconia materials more transparent without compromising their strength [60]. ZrO2 might also be employed as an option for titanium implants even though it is a non-metallic biomaterial. Additionally, ZrO2 exhibits high fracture toughness and flexural strength as compared to many other ceramics materials [61,62]. According to the findings of Hashim and colleagues, the survival rates of 1- and 2-piece ZrO2 implants after one year of function were found as 0.92 (0.95 confidence interval: 87-95) [63].

It has been found that monolithic zirconia with no veneer possesses greater fracture resistance than traditional ZrO2, and it is anticipated that this will lead to a decrease in the frequency of porcelain fracture in the region of the posterior teeth [64]. Shen et al. performed a retrospective clinical analysis on the monolithic ZrO2 single crowns and tried to learn more about the performance of monolithic ZrO2 prostheses that are held in place by implants [65]. They took panoramic radiographs at various times throughout the therapy and the follow-up visit to research the marginal bone level (MBL). During the healing phase, patients whose implants were covered by monolithic ZrO2 saw MBL changes of 0.25 mm, whereas those whose implants were covered by conventional ceramics saw MBL changes of 0.43 mm. There are no statistically significant differences between the monolithic zirconia and metal-ceramic groups ($P > 0.5$), suggesting that both groups have similar rates of peri-implant bone resorption.

ZrO2 crown

Implant material namely monolithic ZrO2 crowns (MZCs) mounted on the back of patients' mouths was included in a recent retrospective study by Lerner et al. [66]. They checked the MZCs' chromatic integration, survival, and success rates. Their research created the customized ZrO2 abutment in CAD software, after which they obtained the initial visual imprint of the patient's mouth with the help of the CS 3600XR intraoral scanner. Notably, the scientist employed a fully digital procedure to create the zirconia crown, automating the process of creating margin lines with AI. Notably, the scientist employed a fully digital procedure to create the zirconia crown, automating the process of creating margin lines with AI. As a result, they were able to effectively produce MZCs that were subsequently cemented on bespoke hybrid abutments. According to the findings of the study, the success rate and survival rate of MZCs produced by an all-digital process were, respectively, 99.0 and 91.3 % after three years.

Prediction of the longevity of ZrO2 restorations

Dental restorations have a limited lifespan, and this lifespan is heavily influenced by the material that was used to create them [67]. Zhang et al. [60] presented an overview of the several generations of commercial dental zirconia and a synopsis of each generation's mechanical and compositional characteristics. The first-generation 3Y-TZPs had to bend strengths more than 1 GPa in flexure. The sintered Al2O3 content of these first-generation 3Y-TZPs was 0.25 weight percent. The next step is monolithic ZrO2, which was created to take into complete consideration the aesthetics and mechanical properties of zirconia. Developing a partially stabilized ZrO2 with higher Yttria contents, such as 4Y- PSZ (4 mol.%) or 5Y-PSZ (5 mol.%), which produces a more non-birefringent c-phase, achieves this goal. This decreases the opacity of the material. The development of transparent ZrO2 resulted in several benefits, including improved mechanical qualities, increased decreased wear, less tooth preparation, and increased strength on antagonistic surfaces [68,69]. Because of this, there are a wide variety of zirconia materials on the market, each with its distinct brand name and set of technical parameters, from which patients and dentists may pick. However, therapies for patients might change

depending on the characteristics of the restorative material that is used. They have a hard time deciding which material will serve them the best and endure the longest.

Fortunately, AI is playing an important part in resolving this issue. For instance, Aliaga et al. [67] gathered data from Dr. Vera's restorative therapy notes, graphs, and radiological data. They next used artificial intelligence (AI) to analyze the data gathered to find the best material and subsequently advance the creation of teeth restoration. In addition, AI might be utilized to estimate how long CAD/CAM crowns will last in the patient's mouth. Case-based reasoning (CBR), a method developed by Aliaga et al. [67], can model and predict how long dental restorations will survive. In a separate investigation that was carried out by Yamaguchi et al. [68], an AI-based convolution neural network (CNN) was utilized to develop the CAD/CAM crowns. Data was procured from 24 instances in total, of which half had debonding problems with their crowns. Additionally, they acquired 8,640 2D images of the 3D models created from virtual teeth. According to the findings, artificial intelligence technology, namely the CNN approach, demonstrates improved performance in forecasting the likelihood of debonding in CAD/CAM crowns.

Matching of ZrO2 colors

Patients place more importance on the cosmetic qualities of their restorations, in addition to the zirconia material's reputation for durability and capacity for functional recovery. Aesthetic dentistry places a significant emphasis on the processes of color matching and shade reproduction [69]. Recently, a variety of zirconia ceramics, each with its distinct optical characteristics, have been available for purchase in the marketplace. When trying to match the color of the restoration to the patient's natural teeth, it can be challenging for both the patient and the dentist to select the proper configuration, appropriate material, and precise shade. A back-propagation neural network, also known as a BPNN, has previously been put to use in the dental clinic for computer color matching [70]. However, BPNN has some drawbacks, including low accuracy and instability. To improve the accuracy of the matching, the initial weight and thresholds in the BPNN, Li et al. [70] used a genetic algorithm (GA). The findings of the experiment show that the suggested strategy plays a significant part in enhancing the consistency and accuracy of color matching when choosing repair materials. Additionally, AI was utilized to forecast the shade of the teeth that would result from the bleaching treatment. The clinical decision support system that was created by Thanathornwong et al. [71] used an AI-based regression model. Results demonstrated that this approach was capable of accurately predicting the color shift by making use of colorimetric variables.

ZrO2 abutment

ZrO2 abutments are advised alternatively to metal abutments since they produce superior outcomes in terms of aesthetics. After five years, fixed implant single crowns with zirconia abutments had a 99.3 % success rate in the posterior locations, which did not show a statistically significant difference when compared to titanium abutments, which had a success rate of 99.57 % ($P = 0.26$). The research was conducted by Vechiato-Filho et al. [72] and was based on a systematic evaluation and analysis. In most cases, the bespoke abutment begins with the use of computer- aided design (CAD), which is followed by milling and zirconia sintered production [73]. During the extraoral cementation procedure, there is tolerance between the ZrO2 abutment and the boding foundation. This can lead to cementing mistakes [74]. Even though they are extremely minor, these inaccuracies can lead to positioning issues for monolithic ZrO2 restorations when they are delivered to patients in the form of bespoke abutments and temporary restorations [75]. Fortunately, the

aforementioned challenges may be conquered with the help of AI, which has decreased the number of mistakes and the prosthetic therapy cost [76,77].

Biomedical applications of ZrO2

Additionally to its use in therapeutic applications, artificial intelligence has found widespread usage in zirconia-related research, being the subject of several studies [78]. Hydroxyapatite (HAP)/ ZrO2-ba- sed composites were also used in biomedical applications. HAP is a bioactive material used in metallic implants [12,13]. HAP coated by plasma spraying is used in many dental and orthopedic prosthe- ses [13]. Arif et al. [79] developed an ANN model to wear the performance of Al (element) hybrid composites that were reinforced with nano ZrO2 (0-9 %). The use of AI was successful in studying the impact of several control parameters on hybrid composite wear behavior. The advancement of robotics, automated systems, and AI-integrated devices will be greatly aided by the creation of artificial muscle shortly. Because of its substantial free surface area and fewer grain boundaries, zirconia shape-memory ceramics have the potential to dramatically improve shape-memory characteristics by an additional 8 %. Du et al. [80] created highly aligned shape-memory ZrO2-based yarns and springs using AI as a consequence. These materials have the potential to be employed as artificial muscles at very high temperatures. In addition, ZrO2 is an essential transition metal-oxide that plays a significant role in the development of high-performance computer systems. The authors The Behler-Parrinello Neural Network (BPNN) may be employed in the molecular dynamics simulation of the O2 vacancy diffusion since its accuracy is similar to simulations [81] based on density functional theory (DFT) [82].

Conclusion and future perspective

Finally, due to its excellent biocompatibility, beautiful appearance, strong corrosion resistance, and lack of allergenic effects, ZrO2 has garnered a lot of interest in the dental industry. Advancements in dental technology that make use of AI are speeding up the transition from one era to another. In recent years, advancements in AI and ML have led to novel applications of zirconia in dental devices for biomedical applications. Consequently, it will be beneficial in the future to have a good understanding of the ideas behind AI technology and its applications. We anticipate a day when artificial intelligence (AI) can be fully used across the board in dentistry.

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