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Review Article

ARTIFICIAL INTELLIGENCE: GETTING TECHNOLOGY IN DENTAL CLINICS- A REVIEW

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A B S T R A C T

Artificial intelligence (AI) includes a broad spectrum of evolving technologies that continue to influence daily life. AI technology has affected the health care field because of the need for accurate diagnosis and superior patient care. It has also made deep inroads into dentistry in the past few years. From the basic process of taking a patient's history to information processing and then to extract the details from the data for diagnosis, artificial intelligence has many applications in dental science. While in no case AI can replace the role of a dentist but it is important to be known with the scope to amalgamate this advancement of technology in future for betterment of dental practice. This article aims to review the role of AI in dentistry.

INTRODUCTION

The human brain is an inimitable structure composed of networks of interlinked neurons which transmit signals throughout the body. This unparallel nature of human brain has always made researchers and scientists inquisitive from time immemorial.[1]The field of science has witnessed various inventions with the advent of technology for creating a model that can simulate the functioning of the human brain. This constant search has given rise to what is known as Artificial Intelligence (AI), which is a highly evolved system capable of mimicking functioning of the human brain. Thus, AI is defined "as the simulation of human intelligence on a machine, so as to make the machine efficient to identify and use the right piece of "Knowledge" at a given step of solving a problem".[2]AI is also defined as "a field of science and engineering concerned with the computational understanding of what is commonly called intelligent behaviour and with the creation of artifacts that exhibit such behaviour".[3]As the expression, it itself suggests that AI enables machines to think and present the results of such thinking. These are most commonly the suggestions regarding the choice among the existing options or solutions in insufficiently clear or doubtful situations. Knowledge in the dental field is characterized by uncertainty, imprecision and vagueness.[4]The involvement of computer systems in clinical medicine and dentistry has of late become a necessity. This article aims to review the role of AI in dentistry.

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Applications of Artificial Intelligence in Various Fields of Dentistry

General Dentistry: The elegance of AI is that machines can be trained to evaluate large data sets and memorize from them to impart most favourable diagnoses. Artificial intelligence based virtual dental companions can perform different tasks in routine dental practice with less man power, fewer errors and with greater precision compared to humans.[29]

The dental practice now has been updated from use of dental chairs that were touch sensitive to voice controlled dental chairs that do not need any manual input from clinician. Based on the voice command the chair positions, water dispensing and light control can be efficiently handled. Furthermore, relatively sterile form of clinical examination can be practiced with reduced risk of cross contamination during treatments. Thus a detailed virtual database of the patient can be created which will go a long way in providing ideal treatment for the patient.[29]

Oral and Maxillofacial Surgery*:* The tremendous utilization of artificial intelligence in oral and maxillofacial surgery is alongside the evolution of robotic surgery where human body motion and human intelligence is simulated. AI software programs has assisted the surgeon in planning surgeries with reduced operation time there by preserving the vital structures around to the smallest detail prior to the actual surgery with higher intra operative accuracy. One more fruitful clinical application is image guided surgery that confess further accurate surgical resection possibly decreasing need for revision procedures.[29]

Table 1 Summary of Ai Application in Clinical Dentistry

	Study	Year	Detail	AI technology used	Accuracy
Orthodontics	Patcas.*et.al*[5]	2018	Impact of orthognathic treatment on facial attractiveness	CNN (Convoluted Neural Network)	66.4%
Oral medicine	Kim.*et.al*[6]	2009	Predictive modelling of dental pain	ANN (Artificial Neural Network)	80%
Oral surgery	Nieri.*et.al*[7]	2010	Factors affecting the clinical approach to impacted maxillary canine	BNA (Bayesian Network Algorithm)	
Oral radiology	Krois.*et.al*[8]	2019	Radiographic detection of periodontal bone loss	CNN	76%
Forensic odontology	Bewer.*et.al*[9]	2019	Sex determination of skeletal remaining	CNN	95%
Oral Medicine	de Dumast P.et[10]	2018	Shape analyser variation in TMJ osteoarthritis	NN (Neural Network)	93%
Oral radiology	Kise.*et.al*[11]	2019	Diagnosis of Sjogren's syndrome on CT images	DL (Deep Learning)	96%
Oral medicine	Krawczy.*et.al*[12]	2013	Diagnosis of primary headache	ML (Machine Learning)	72%
Oral medicine	Bas.*et.al*[13]	2012	Differentiation of TMJ internal derangement	ANN	93%
Endodontics	Saghiri.*et.al*[14]	2012	Locating minor apical foramen	ANN	93%
Endodontics	Kositbowornchai Suwadee.*et.al*[15]	2012	Vertical root fracture detection	ANN	95.7%
Orthodontics	Li Peilin.et al[16]	2019	Orthodontic treatment planning	ANN	94%
Endodontics	Johar M.*et.al*[17]	2017	Detection of vertical root fracture in premolar teeth	PNN (Probabilistic Neural Network)	70%
Periodontology	Lee J H.*et.al*[18]	2018	Diagnosis and prediction of periodontally compromised teeth	CNN	81%
Oral radiology	Kavitha .*et.al*[19]	2012	Diagnosis of osteoporosis from dental panoramic radiograph	SVM (Support Vector Machine)	90%
Oral radiology	Abdolali .*et.al*[20]	2016	Maxillofacial cysts in cone beam CT images	Iterative Residual Fitting (IRF) algorithm	85%
Oral radiology	Murata.*et.al*[21]	2018	Evaluation of maxillary sinusitis in OPG	CNN	87.5%
Oral radiology	Ariji.*et.al*[22]	2018	Contrast CT image assessment of cervical lymph node metastasis in oral cancer patients	CNN	78.2%
Oral medicine	Kim.*et.al*[23]	2019	survival prediction of oral cancer patients	CNN	81%
Oral radiology	Vinayahalingam.*et.al*[24]	2019	Detection of 3rd molar and mandibular nerve	CNN	83%
Forensic odontology	DeTobel.*et.al*[25]	2017	Staging of lower third molar development on OPG for age estimation	CNN	51%
Forensic odontology	Patil.*et.al*[26]	2020	Gender determination using mandibular morphometric parameter	ANN	69.9%
Orthodontics	NinoSandoval.*et.al*[27]	2017	Predicting mandibular morphology in skeletal class I,II,III	SVR	84%
Prosthodontics	Lerner.*et.al*[28]	2020	Artificial intelligence in fixed implant prosthodontics	CNN	91.3%

The impact of digital solutions on surgical-orthodontic protocols can be grouped in the following 4 domains: improved diagnostic precision using AI enhanced maxillofacial imagery; treatment planning using 3D models; CAD/CAM (Computer Aid Design, Computer Aid Manufacturing) manufacture of custom orthodontic and surgical appliances and equipment; improved therapeutic follow-up due to finer interval comparison of results using image superimposing (Fig 1).[30]

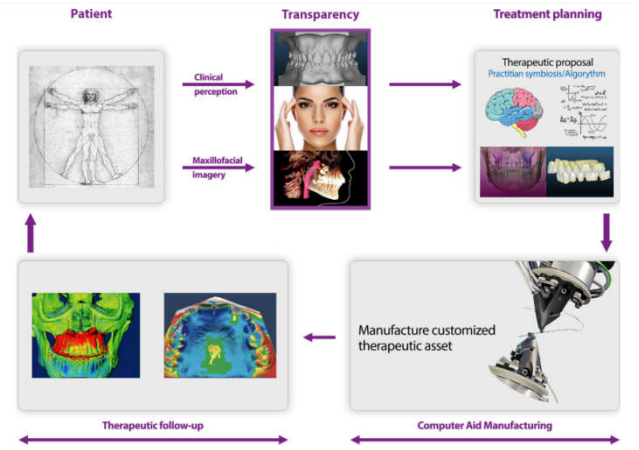

Fig 1 Digital workflow on surgical-orthodontic protocols

Bio printing is the another ingenious applications of AI, where organs and living tissues can be formulated in successive thin layers of cells which in the future may be used for regeneration of oral hard and soft tissues that are lost due to pathological or accidental reasons.[29]

Robotic surgery is often heralded as the new revolution, and it is one of the most discussed subjects in surgery today. Robot-assisted maxillofacial surgery has been growing steadily in popularity. Taking inspiration from its use in other surgical fields, robotics offers benefits including a 3D magnified view, precise movements, bimanual operation with articulated arms, and suppression of tremor, enhancing the surgeon's physical capabilities.

Therefore, procedures with robotic assistance can be performed with less blood loss, fewer complications, shorter hospital stays, and better cosmetic results than standard open surgical techniques.[31]

Oral medicine: Proper diagnosis of any disease is the basis for successful treatment. Artificial neural networks work well for this purpose especially in cases where the etiology of disease is multifactorial. Taking one example of recurrent apthous ulcer, a condition whose precise etiology is not known, and the diagnosis is made on its reoccurrence and by exclusion of other factors. Another one is internal derangement of temporomandibular joints where clinical and radiological diagnosis is considered as gold standard. Osteoarthritis, which is the most common degenerative disease affecting the temporomandibular joint (TMJ), is characterized by destruction of the articular cartilage and subchondral bone resorption. No method has been developed to quantify morphological changes in the early stages of the disease. deDumast *et.al* (2018) described a non-invasive technique, referred to as the shape variation analyzer, that uses neural networks to classify morphological variations of 3D models of the mandibular condyle into 7 different categories (G1, normal; G2, close to normal; and G3-6, various stages of degeneration). A rainbow color-coded map on 3D models defined the exact location of the morphological changes on the condylar surface. Categorization by neural networks will enhance the understanding of clinicians regarding the shape changes that occur in patients with TMJ osteoarthritis.[10]When in several studies the diagnosis given by a dental surgeon is compared with the one obtained by ANN (Artifical Neural Network), results inferred high specificity and sensitivity of ANN. Thus, revealing the importance of AI in diagnosis of even complicated oral diseases and reducing the chances of human errors. AI is then needed to gather and compute the data for prompt diagnosis and treatment of oral disease. ANN is also the gold standard to identify the patient at risk of development of oral precancers or oral cancers. Hence, AI

could be able to satisfy the ever-existing requirement of a method to diagnose oral cancers at their early stage.[32]

Dental and Maxillofacial Radiology: Radiologists are primarily known for their image interpretation skills. Advanced breakthroughs in image recognition using Artificial Intelligence Systems has shifted from science fable into reality in the radiology practice in the last two decades. In head and neck imaging modalities AI provides added advantage owing to its distinctive ability to learn and can be assimilated with other imaging modalities like CBCT, MRI to determine infinitesimal deviations from normality that could have gone unrecognized with human eye. Illustrations include definite location of landmarks on radiographs aids in location of minor apical foramen, detection of vertical root fractures, Cephalometric analysis, thereby strengthening the accuracy of working length determination, Logicon Caries Detector helps in detection and characterization of proximal caries. Economically all these could be translated in to a better patient care.[33]Clinical workflow these are the diagnostic tests inserted in existing clinical pathways. For example, when a patient requires a diagnostic imaging, radiologist is the one who decides the image selection and other protocols. Alternatively, AI applications can be applied using various scenarios to reduce the radiologist burden. Different scenarios used in clinical work flow are triage, replacement and add-on which are based on the conceptual frame work developed by Bossuyt.*et al*. Triage scenario adapted from is used as a screening tool to sort examinations based on the probability of disease being positive or negative according to AI. For example, AI will assess the not interpreted x-rays for highest probability of disease determined by an algorithm according to the content of images or other data available and determine which examination should be interpreted first.[33]

Oral oncology: Intelligent systems have been used for the early detection of head and neck cancers and cervical lymph node metastasis, which may affect the treatment choice and prognosis of head and neck cancer patients. CT and MRI are the imaging modalities most commonly used to identify cervical lymph node metastasis and sentinel lymph nodes. Recently, Ariji *et al* (2018) found that the use of a convolutional neural network enhanced the CT-based diagnosis of lymph node metastasis. The performance of a convolutional neural network image classification system resulted in an accuracy of 78.2%, a sensitivity of 75.4%, and a specificity of 81.0%, comparable to experienced radiologists.[22] Kim *et al* (2019) used a deep learning program to predict the survival of oral cancer patients and found that the diagnostic performance of the program was superior to that of the classical statistical model. Proper fit was found between the accuracy of the training and testing sets, which were 81% and 78.1%, respectively. Based on their analysis, they suggested that deep learning survival predictions might guide clinicians in choosing the best treatment option for oral cancer patients, thereby preventing unnecessary treatment interventions. These systems also enable the clinician to classify oral lesions as benign, potentially malignant, or malignant for early treatment interventions.[23]

Forensic Odontology: Age estimation is an important aspect of forensic odontology that has been used over decades for various reasons. However, the information regarding the use of Artificial Intelligence in dental age determination is sparse. Dental age estimation is based on the sequence of tooth formation and eruption time. Stages of Tooth formation can be observed radio graphically. Rameswari P J. *et.al* (2018)review the basic algorithms and methods used in dental x-ray processing are image enhancement, image segmentation, edge detection with feature extraction and neural networks based classification. Teeth segmentation (Fig 3) from dental x-rays is an essential step for automating diagnosis as well as forensic procedures like postmortem identification.[34]

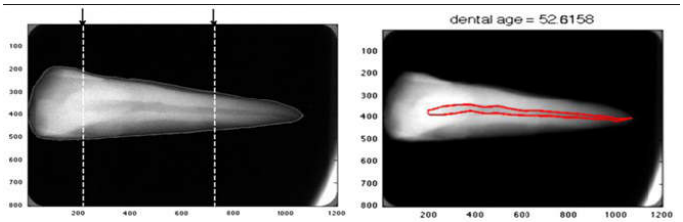

Fig 3 (a) Segmentation of teeth (b) Segmentation of the pulp area

Another important applications of AI in identification of victims by dental findings during a large-scale disaster. X-ray findings play an important role in identity verification. Comparison of pre- and post-mortem image data is often the decisive factor for identification, but saving image data to the database also has storage capacity issues, so X-ray findings are output to the oral examination standard code and stored in the database.[35]

DeTobel *et al* (2017) used automated technique based on CNNs for staging lower third molar development for estimating the age of a person after applying on panoramic radiographs (Fig 4). The system showed remarkable results, when compared to the trained examiners.[25]

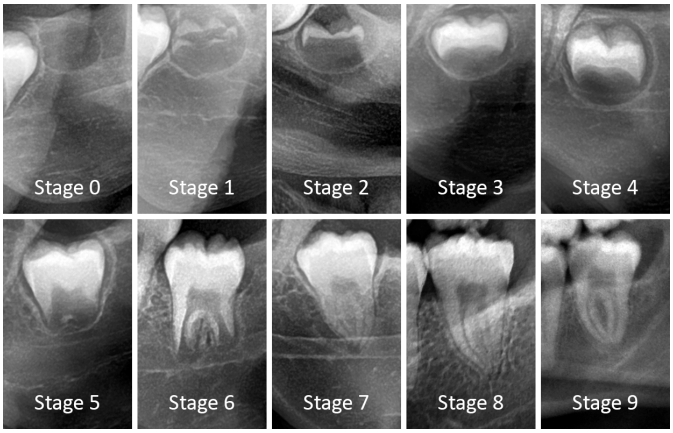

Fig 4 Representative examples of lower left third molars in each developmental stage. Third molars are depicted within their bounding box

Dental Education System: Recently Artificial Intelligence has been incorporated into tutoring intelligent education system and training in dentistry. These technologies have the capacity to create virtual reality that enables simulation of the practical procedures in three dimensions that enable simulation and allow assess to clinical and surgical techniques with sufficient detail and speed so as to evoke a sensorial experience similar to that of a real experience.[36]The practice sessions can be done unlimited times till the skill set is expertise by students over the subject prior to actual handling of real clinical cases reducing the risk of iatrogenic damage. This method of training proves to be more efficient, inexpensive and reliable.[29]Virtual reality simulation (VRS) technology can be used to simulate the facial profiles post treatment. This not only makes the dentist to efficiently design the esthetics, but

also acts as a encouragement tool for the patient. PHANToM Omni haptic device which allows six degrees of freedom for positional sensing and generates three degrees of freedom for force feedback. Such variables are needed to build AI algorithms for the upcoming generation of intelligent clinical skill training system that may allow more effective training experience with real-time feedback of skill performance.[37]

Prosthodontics: AI combined with designing softwares can help the dentist to design the best possible and aesthetic prostheses considering number of components like facial measurements, anthropological calculations, ethnicity and patient desire. AI plays an important role in identifying the type of bone, cortical thickness for making precise surgical guides for pacing implants. Another breakthrough in this field is the use of CAD/CAM technology which creates a 2D and 3D models has replaced the time consuming and laborious process of conventional casting thereby reducing human errors.[29]Lerner *et.al* (2019)studies 90 patients restored with 106 implant-supported MZCs were taken in the study. The follow-up was done from 6 months to 3 years. The quality of the fabrication of every single hybrid abutments showed a mean deviation of 44 µm (± 6.3) between the original CAD design of the zirconia abutment, and the mesh of the zirconia abutment recorded intraorally at the end of the provisionalization. At the delivery of the MZCs, the marginal adaptation, standard of interproximal and occlusal contacts, and aesthetic integration were excellent. The three-year collective survival and success of the MZCs were 99.0% and 91.3%, respectively (Fig 6).[28]

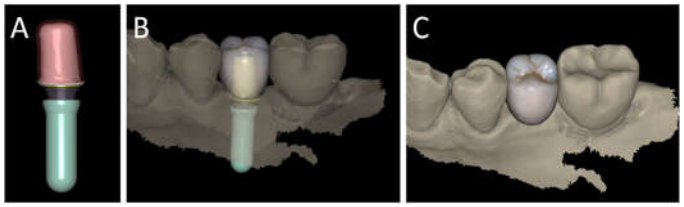

Fig 6 Computer-assisted-design (CAD) of the individual abutment and the provisional crown. (A) The individual abutment is modelled in CAD and saved in a dedicated folder of the software. (B) The individual abutment and the provisional crown. (C) Photorealistic rendering of the provisional crown

Orthodontics: Future of orthodontics is no longer handled by appliances but by AI. Recently by analysing the radiographs and photographs AI helps in orthodontic diagnosis, planning treatment and monitoring the progression of treatment. With the advent of intraoral scanners and cameras preparing a dental impression is being replaced by digital impressions and the above data is fed in to the system the set algorithms and AI software aids in predicting tooth movements and final outcome of the treatment. Latest technologies combined with customised aligner based orthodontics can improve case acceptance.[29]Faber J. *et.al* (2019) discussed how AI with its powerful pattern finding and prediction algorithms are aiding orthodontics. Much remains to be done to aid patients and clinicians make best treatment decisions. AI is a best tool to help orthodontists to choose the best way to move teeth with aligners to preset positions. On the side, AI today completely ignores the existence of oral diseases, does not fully include 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 many conditions, from syndrome diagnosis to caries detection. AI with its set of tools for problem-solving is starting to help orthodontists with extra powerful applied resources to provide better standards of care.[38]

Periodontics: Deep learning analysis using radiographs can assist in diagnosing and treatment planning of periodontal diseases by enabling the early detection of periodontal changes, boneless, and changes in bone density. Detection of peri-implantitis can also help in early intervention in implantology. Periodontal diseases are one of the commonest oral diseases affecting the mankind. It is a fact that this is one of the main reasons for the early loss of teeth. Many studies have been done to ascertain AI technology application to diagnose and predict periodontal diseases. Lee *et. al* (2018) found out the use of CAD system, based on a deep convolutional neural network (CNN) algorithm for diagnosing and predicting the teeth that are compromised with periodontal health. The result were quite acceptable with a mean predictive accuracy of 78.9%.[18]Yauney *et. al* (2018)[39] and Krois *et. al* (2019)[8]used an AI based system based on CNNs for correlating poor periodontal health with systemic health results and reported that, AI can be used for automated diagnoses and can also be useful for detecting other diseases.

Conservative dentistry and endodontics*:* The success of root canal treatment mainly based on accuracy of working length determination. The prognosis of the treatment can only be ensured when instrumentation ends at the apical constriction. Saghiri *et. al* (2012) used artificial neural network (ANN) system in determining the working length and showed exceptional accuracy of 96% which is higher than the accuracy compared to professional endodontists. These results were consistent to the study by Saghiri *et. al* (2012) where they used the ANN system for finding the minor apical foramen, with an accuracy of 93%.[40]

AI is also used to diagnose vertical fractures in root. A study employed by Johari *et. al* (2017), who used probabilistic neural network (PNN) for the diagnosis of vertical root fractures. This PNN system showed excellent performance with an accuracy of 96.6%. Similarly convolutional neural network in recognizing vertical root fracture, showing a highly encouraging precision was done by Fukuda *et al* (2019). These assessments shows that AI-based models are incredibly effective when it comes to the detection of vertical root fractures on CBCT images and panoramic radiograph.[17]

Advantages of AI

1. ***The Abundance of Data management in Dentistry:*** Wherever there are huge complex datasets, there is the chance to improve understanding of AI. Useful data is produced in many formats, e.g. natural text, tables, digital images/videos, and audio. AI can not only execute data analytics but can also carry out routine tasks and functions to aid dentists reduce overall workload, be more efficient, and build stronger patient relationships.
2. ***Measure the effectiveness of different treatment modalities:*** Using AI and large datasets that involves diagnostic results, treatments, and outcomes, it is now possible to empirically measure the effectiveness of various treatment modalities in light of very specific symptoms and anatomical conditions. This is especially main given the range of new dental technologies, techniques, and materials that are introduced every year.

3. ***Independent Dental Practices:*** Independent dentists can decide to include beneficial new technologies without the bureaucracy that is often found in big healthcare organizations (integrated hospital networks for example). Remaining competitive in today's dental market requires practice owners to be nimble and proactive about the technology of all kinds.
4. ***Accuracy in diagnosis:*** Though dentists do their best, there is still a nearly 20% misdiagnosis rate when studying x-rays in dentistry. AI technology can certainly be trained to study an x-ray and there have been some literatures to suggest that they can do it better and identify key conditions that we often misread. A world with AI diagnosis that is accurate and faster will save time, money, and lead to better dental health among patients.
5. ***Saves time:*** An AI computer can do some of these work and be able to free up more time to focus on more important things and improve job performance as well. One primary use of AI is virtual consultations. This saves patients time so when they visit the Doctor already knows what the next steps in their treatment will be.[41]

Disadvantages of AI

1. ***Distributional shift****:* A mismatch in data because of a change of environment or circumstance can lead to erroneous predictions. For example, over time, disease patterns can change, resulting a disparity between training and operational data.
2. ***Insensitivity to impact****:* AI doesn't yet have the capacity to take into account false negatives or false positives.
3. ***Black box decision-making****:* With AI, predictions are not open to inspection or interpretation. For example, anissue with training data could produce an inaccurate X-ray analysis that the AI system cannot factor in.
4. ***Unsafe failure mode****:* Unlike a human doctor, an AI system can diagnose patients without having confidence in its prediction, particularly when working with insufficient information.
5. ***Automation complacency:*** Clinicians may start to believe AI tools implicitly, assuming all predictions are correct and failing to cross-check or consider alternatives.
6. ***Reinforcement of outmoded practice:*** AI can't adapt when developments or changes in medical policy are implemented, as these systems are trained using historical data.
7. ***Self-fulfilling prediction****:* An AI machine trained to detect a particular illness may lean toward the outcome it is designed to detect.
8. ***Negative side effects****:* AI systems may recommend a treatment but fail to consider any potential unintended consequences.
9. ***Reward hacking****:* Proxies for intended goals serve as "rewards" for AI, and these clever machines are capable to find hacks or loopholes in order to receive unearned rewards, without actually fulfilling the intended goal.
10. ***Unsafe exploration****:* In order to learn new strategies or get the result it is searching for, an AI system may start to test boundaries in an unsafe way.
11. ***Unscalable oversight****:* Because AI systems are capable of carrying out unlimited jobs and activities, including multitasking, monitoring such a machine can be near impossible.[41]

CONCLUSION

AI has revolutionized dentistry in the last few years and dentists have always been at the forefront of implementing a technology. Hence, understanding the various concepts and the techniques involved will have a clear advantage in the future for dentist.

With the newest abilities enabled by deep learning techniques, AI will start to impact dentistry on a clinical level. The apocalyptic sci-fi fantasy that these machines and systems of AI will replace us as dentists is nowhere near reality. It is, however, sure that they'll soon make us better dentists by providing more data points for dentist's clinical decision making.

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