Antoine Lemoine

ODONTOLOGY & ARTIFICIAL INTELLIGENCE

UNIVERSIDADE FERNANDO PESSOA

Faculdade de Ciências de Saúde

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"Trabalho apresentado à Universidade Fernando Pessoa como parte dos requisitos para obtenção do grau de Mestre em Medicina Dentária".

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Sumário

Neste trabalho avaliam-se os três fatores que fizeram da inteligência artificial uma tecnologia essencial hoje em dia, nomeadamente para a odontologia: o desempenho do computador, *Big Data* e avanços algorítmicos. Estarevisão da literatura avaliou todos os artigos publicados na PubMed até Abril de 2019sobre inteligência artificial e odontologia. Ajudado com inteligência artificial, este artigo analisou 1511 artigos. Uma árvore de decisão (If/Then) foi executada para selecionar osartigos mais relevantes (217), e um algoritmo de *cluster k-means* para resumir e identificar oportunidades de inovação. O autor discute os artigos mais interessantes revistose compara o que foi feito em inovação durante o *International Dentistry Show*,2019 em Colónia. Concluiu, assim, de forma crítica que há uma lacuna entre tecnologia e aplicação clínica desta, sendo que a inteligência artificial fornecida pela indústria de hoje pode ser consideradaum atraso para o clínicode amanhã, indicando-se um possível rumo para a aplicação clínica da inteligência artificial.

Palavras-Chave: Odontologia, Inteligência Artificial, Machine Learning, inovação

Abstract

There are three factors that have made artificial intelligence (AI) an essential technology today: the computer performance, Big Data and algorithmic advances. This study reviews the literature on AI and odenotology based on articles retrieved from PubMed. With the help of AI, this article analyses a large number of articles (a total of 1511). A decision tree (If/Then) was run to select the 217 most relevant articles-. Ak-means cluster algorithm was then used to summarize and identify innovation opportunities. The author discusses the most interesting articles on AI research and compares them to the innovation presented during the International Dentistry Show 2019 in Cologne. Three technologies available now are evaluated and three suggested options are been developed. The author concludes that AI provided by the industry today is a hold-up for the praticioner of tomorrow. The author gives his opinion on how to use AI for the profit of patients.

Key words: Odontology, Artificial Intelligence, Machine Learning, Innovation

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AI - artificial intelligence

CAD/CAM - computer-aided design & computer-aided manufacturing.

IDS - international dentistry show

ISQ - Implant Stability Quotient

RFA - resonance frequency analysis

I Introduction

Artificial Intelligence (AI) is a technology present almost everywhere including in odontology There are several definitions of AI divided into four categories (Russell and Norvig, 2010). The most common definition of AI is acting humanly, described during the "Dartmouth summer" (1955) (McCarthy, Minsky and Shannon, 2006) as the ability of a machine to perform human cognitive functions, such as perceiving, reasoning, learning, speaking, problem solving, or exercising creativity.

Reseach made in University could lead to innovation, a process to change an idea into a valuable customer-oriented solution (Shaver, 2012). What is the state of Art between AI and odontology? Is-it possible to identify innovation from a large number of articles helped by AI? Is innovation different from research?

This study focuses on AI and its role in the field of odontology. First, it will explain the current state of Art in AI. It will be applied two algorithms to classify and make a semantic analyse of the most relevants articles. Then it will summarize the articles of interest and then discuss the innovation offers presented at the International Dentistry Show (IDS) 2019. Finally, the author will give his personal opinion on the war that is now beginning between industry and practitioners.

I.1 Methodology

To identify the relevant articles, we searched PubMed using the terms "odontology" with "artificial intelligence" or "AI" or "Deep-Learning" or "Machine-Learning". Using only Pubmed is also the limit of this studying. In April 2019, 1511 PubMed articles were retrieved. Two algorithms were used to select and analyze the articles.

A decision tree (Excel 2013, Microsoft™), a supervised machine learning, executed a sequence: If / Then. It is a supervised learning process, easy to interpret because each input is regulated by the human. All sources articles were classified into labels. We selected 13 labels: cariology, dental management, education, endodontic, forensic, imaging, oral medicine, orthodontic, paediatric dentistry, patient management, periodontic, prosthodontics, and surgery. The program selected 430 articles (appendix 1; figure1), including 217 from last decade (2011-2019), which were analysed. For example, all articles in the "American Periodontal Journal" or the "Periodontal Academy Board" went in the same label: Periodontic.

The second algorithm used was a k-means clustering (Phyton language on Linux™), which starts by placing centroids (K) at random locations in space. For each instance, a cluster is assigned to the nearest centroid, and each centroid is moved to the mean of the instances assigned to it. The algorithm continues until no instances change cluster membership. The result is a graph with different node sizes indicating the less strong recurrence of words, and nodes more or less distant according to their belonging to a lexical field (Appendix 1, figure 2), (Appendix 1, figure 3). A total number of 6115 keywords were extracted from PubMed with4283 differents keywords. The keyword "Human" was the most recurrent word with 471 instances, followed by "male" at 122 instances and "female" at 119 instances (Appendix 1, figure 4)..

II Development

II.1 The current state of AI

Since 2010, important improvements in computer memory allocation (Armbrust et al., 2009) and graphic card applications (Abbeel, Coates and Ng, 2010) have dramatically increased AI training leading to broadened AI applications.

As shown (Appendix1; figure5), AI success is due to the convergence of three factors (Russell and Norvig, 2010): Computation, Big Data, and AI algorithmic advancements.

“Computation”: It means the exponential increase in computing and storage power. According to Moore's empirical law, since 1975, processing power has doubled each year due to technological advances (Moore G., 1975). To illustrate this concept, a computer purchased for $1,000 in 2010 had the same capacity as the brain of a rat, while a computer bought at the same price in 2040 will have the same capacity as the human brain, and in 2060, the same as the brains of all humans.

“Big Data”: In the beginning of 2000, it was challenging to visualize large data sets or Big Data (Laney, 2001). Today, Big Data can be used to solve complex problems due to the variety of data collected, the volume of this data and how quick it is to access it. The volume of data comes from devices connected to the Internet, computers, smartphones, Internet of Things, and data warehouse.

“Algorithmic advancements”: An algorithm is a model of data. Each observed data point is considered to be an expression of a random variable generated by a probability distribution. To elaborate an algorithm, three types of learning are considered (McKinsey, 2018): supervised, unsupervised and reinforcement. During the 1980s and 1990s, because of low computer performances, “the good old AI” learned supervised, meaning that human set all inputs. The inputs were used to train the algorithm to predict a specified target using new unannotated inputs. The efficiency was low, but it was completely interpretable by humans. Now, algorithms imitate more and more the brain function with neurons and synapses, (Appendix 1, figure 6). They are based on statistics and combination. With unsupervised learning, input data are not annotated, and the algorithm trains itself to find similarities and patterns. Learning is reinforced by a reward system. Scientists are currently working on this issue, the more algorithms are efficient, the lessthey are interpretable.

The table below illustrates (McKinsey, 2018) some of the most useful algorithms and helps to identify the different types of learning.

AI's field	Algorithm	Type of learning
Machine Learning	Linear Regression, Logistic Regression, Quadratic Discriminant Analysis, Decision Tree, Naïve Bayes, Support Vector Machine, AdaBoost.	Supervised learning
Machine Learning	K-means clustering, Gaussian mixture model, Hierarchical clustering, Recommender system	Unsupervised
Deep Learning	Convolutional Neural Network, Recurrent Neural Network	Reinforcement

Table 1: Algorithmic advancements summarized from Mckinsey

II.2 Articles on AI in Odontology

As shown in (Appendix 2), AI can be used in different ways to identify patterns: visual recognition (shapes, colours, and textures), auditory recognition (waves, frequencies) or data mining.

Cariology: The visual identification capabilities of AI could identify caries by camera and laser (Gavinho et al., 2018), or improve the performance of intraoral cameras (Mangano et al., 2017). It could also classify teeth in the cone beam scanner (Miki et al., 2017), (Raith et al., 2017), panoramic radiography (Zhang et al., 2018), periapical film (Chen et al., 2019) or colour prediction with images (Li et al., 2015). The AI can be trained to examine different sounds during cutting, dentine or enamel (Zakeri, Arzanpour and Chehroudi, 2015). Meta-analyses of public health institutes or clinics can be more easily used with AI to consolidate heterogeneous data and determine, for example, the most sensitive variables in dental restoration (De Munck et al., 2012), or model the longevity of dental restorations (Aliaga et al., 2015). Observation of the data could also be used to assess the risk of decay related to the socio-economic and nutritional characteristics of inputs (Zanella-Calzada et al., 2018).

Endodontic: AI can be used to learn many images, colours or tooth shapes to locate minor apical foramens (Saghiri et al., 2012), todetect vertical root fractures (Kositbowornchai, Plermkamon and Tangkosol, 2013), and to measure the curvature of the canal and its 3D modification after instrumentation (Christodoulou et al., 2018).

Forensic: Using computer vision, AI can analyze panoramic radiograph to automatically identify people by comparing ante-mortem radiographs to autopsy radiographs (Heinrich et al., 2018) or using the analyzed 3rd lower molar (De Tobel et al., 2017). AI can also estimate age based on the development of permanent teeth compared to the conventional approach (Štepanovský et al., 2017).

Oral medicine: In terms of prediction, AI can concretely assist in the automatic detection of pathologies such as oral dysplasia and cancer (Song et al., 2018), occurrence of bisphosphonate-related osteonecrosis of the jaw (Kim et al., 2018) or more accurately predict the cancer risk for a habitual smoker (Sarkar et al., 2016) or the toxicity risk associated with drug use (Lysenko et al., 2018).

Orthodontic: AI can be useful for patient assessment at Big Data time (Allareddy et al., 2019; X. Wang et al., 2016; Gupta et al., 2016; Auconi et al., 2011), predicting and diagnosis extractions (Moghimi, Talebi and Parisay, 2012), or helping to make a judgment about patients' facial attractiveness (Patcas et al., 2019). AI is a tool to evaluate orthodontic materials for example mini implants (Wilmes, Panayotidis and Drescher, 2011), or materials from bimaxillary tooth positioners on canine malpositions (Lochmatter, Steineck and Brauchli, 2012).

Periodontic: AI tools seem to be very widely deployed in periology, with a wide variety of research areas: diagnosis and prediction of periodontally compromised teeth (J. Lee et al., 2018); predicting teeth surface loss using genetic algorithms-optimized artificialneural networks (Al Haidan, Abu-Hammad and Dar-Odeh, 2014); non invasive differential diagnosis of dental periapical lesions in cone-beam CT scans (Okada et al., 2015); correlation between health-care costs and salivary tests (Kakuta et al., 2013); identifying ethnicity-specific bacterial signatures in the oral microbiome (Mason et al., 2013); classification of oral malodor based on the microbiota (Nakano et al., 2014); microRNA expression profile of human periodontal ligament cells under theinfluence of Porphyromonas gingivalis LPS (Du et al., 2016); quantitative method to measure biofilm removal efficiency using SEM and image analysis (Vyas et al., 2016);; inter-personal diversity and temporal dynamics of dental, tongue, and salivarymicrobiota in the healthy oral cavity (Hall et al., 2016).

Prosthodontics: The prosthesis also benefits from the progress made by AI, particularly in terms of mechanical quality, by evaluating the precision of a robotic system for preparing laminated porcelain veneers (Otani et al., 2015) or the aesthetics of color evaluation (De Munck et al., 2012). The occlusion field also sees studies that use AI to improve the diagnosis of maxillary pain (Nam et al., undated), or oral-facial pain (Ceusters, Michelotti, et al., 2015; Durham et al., 2015), or to evaluate the influence of the lower jaw position on the running pattern (Maurer et al., 2015).

Surgery: Today, AI is deployed around two axes: implants and robotics. In implantology, AI aims to identify implant prognostic factors (Ha et al., 2018), to provide an integrated approach to oral implant surgery (Chiarelli and Sansoni, 2012), and to optimize dental implant (Li et al., 2018). Regarding robotization, dental implantation can be automated using image-guided robotics (Sun et al., 2011);telerobotics can assist the bone drilling system using bilateral control (Kasahara, 2012) or reference markerless CT data sets with conical beam sub-volume (Essig et al., 2012); and a dental arch generator can plan movement and synchronize the control of the dental robot (Jiang, 2012).

II.3 AI in Innovation

Innovation is a technological response to an evergrowing need for advancement in our society. Innovation is not intended for philanthropic use but instead should promote abstract concepts that would become goods and services sold to professionals which will eventually help our economic fabric. The latest version of the Oslo Manual (OECD, 2018) defines four categories of innovation. The first category is product innovation, which is defined as the introduction of a new or significantly improved good or service in terms of its characteristics or intended use. This definition includes significant improvements in technical specifications, components and materials, integrated software, usability or other functional characteristics. The second category is process innovation, which is the implementation of a new or significantly improved production or distribution method. This notion implies significant changes in techniques, hardware and/or software. The third category is organizational innovation, which is the implementation of a new organizational method in the firm's practices, workplace organization or external relations. The last category ismarketing innovation, which is the implementation of a new marketing method involving significant changes in the design or packaging, placement, promotion or pricing of a product.

The following sections highlight the most attractive innovations using AI in Odontology seen at IDS 2019.

In cariology, software is marketed to identify interproximal caries (Dentistry.ai™). Automatic tooth identification from radiology is now also possible. An intra oral camera from 3 shape ™ can scan in 3D and detect caries using AI. AI could eliminate artifacts, for example a praticien’s finger on a 3D scan or improve the localization on mouth (3 shape™) (Sirona™).

Orthodontics is the first area to have really benefited from AI, particularly in the perspective of learning orthodontics treatment (Invisalign™). Today the process is sufficiently controlled that some firms (Smile Direct Club ™) offer treatment plans designed by AI and supervised by an othodontist. Finally, some companies offer a measurable way to use the patient's smartphone to calculate the movement of teeth in the mouth (Dental monitoring ™).

Prosthodontic innovation promises to automate the processes of the dental laboratory and reduce the cost of production (biotech dental), thus competing with low-cost producing countries such as China, without compromising the quality of materials. This evolution is made possible by intra oral scanner and digital imagery. All known patient data is integrated in a virtual model based on AI, and missing data is extrapolated and continuously improved. This technology is used for ceramic-metallic prosthesis. High-precision automatic operations are ensured by 3D metal and ceramic printers. For the moment, human intervention remains on the aesthetic aspect of painting the teeth. To identify temporomandibular disorders, a numerical articulator has been launched in Germany(“Freecorder bluefox” by Orangedental ™).

In surgery, several surgical navigational devices use AI (Claronav™), in addition to infrared cameras, to anticipate patient head movements. There is also a technology developed on AI that detects the sounds of implants after placing them in the mouth (Osstell™). The program analyses the frequencies emitted by the implant after stimulation with a special probe.

III Discussion

III.1 Focus on three technologies available now

BiotechDental™ is an Europoan provider in implants, digital devices (camera intra oral called WOW) and also prostheses such as stellites, bars and complete resin. Their technology called Lucy use internet and AI to work properly and it is free to use. In return, patient's informations must be up-loaded (images, 3D scan, RX) to BiotechDental's servers and then, the company sent to the dentist a quote with a suggested treatment plan. To improve AI and match knowledge of the leader in the filed, Invisalign™, millions of data from dentists are needed. The great innovation of Biotech Dental is to educate AI with a simulator. Anatoscope ™ developed this simulator from the academic works of Francois Faure and Olivier Palombi and their students (Ali-Hamadi *et al.*, 2013), (Bauer *et al.*, 2017). This software is based on complex teeth contact scenarios and multi-material models. In 2018, Biotech Dental rose 200 millions euros to create, in France, a new automated prostetics factory. Their goal is to sell a quality stellite made in France and less expensive than one from China.

Osstell™ is a system to determine implant stability using the implant stability quotient (ISQ) (Meredith, Alleyne and Cawley, 1996). By means of a resonance frequency analysis (RFA) applied to the bone, it checks the stability. During this decade, the major evolution is to combine frequencies informations, AI and clinical data observations from all over the world to help dentists choose or benchmark the best implant protocol. For this technology, the dentist has to pay a reccurent fee. All customers' information is recorded: brand of implants, number of surgeries per day, success rates, etc. This information is valuable and becomes important incomes of many million euros per year.

The Trios 4 is the last intraoral scanner from 3 shape™ It combines a superior scanning technology with groundbreaking caries diagnostic aid technology for both surface and interproximal caries. AI has eliminated artefact and can identify possible interproximal caries undetectable to the eye. The design looks great is higt-tech, but this technology is very expensive and if the dentist does not pay the annual fees, they cannot the use the device anymore.

III.2 Propositions of technology for tomorrow

The author's opinion is to develop AI in areas where there is no expertise yet or where it is possible to do so on trivial, non-compromising aspects. He suggests using AI as in this article to summarize a large volume of data. His second recommendation is to imagine public health care improved by AI. Finally, AI can be used to understand multifactorial disorders and misunderstood diseases in order to find new solutions.

The initial idea developed in this article was to identify areas of innovation and summarize them with AI. After observing the grouping carried out by AI, it seems difficult to draw conclusions or interpretations. However, the first classification option with a tree decision algorithm considerably reduced the number of articles to be read. Using a k-means clustering algorithm could be dramatically improved if the PubMed database would standardize some critical information. The difficulties of analysis are explainable by the fact that authors of articles choose keywords without homogeneity, but these difficulties can be overcome. The purpose of these keywords is to improve the positioning of articles in search engines by improving their relevance, and not to be used as a way to summarize the article. The author suggests that a framework or methodology could be developed to support the choice of keywords that would allowthe scientific community to implement a powerful tool which could integrate AI to summarize research.

In public health, a technological solution envisaged by the author to develop his start-up in Montreal is to educate and monitor the right gestures and habits to reach optimal oral hygiene. The application is for everyone, children or adults. It is based on AI to detect the amount of plaque. The scenario is as follows: each time the teeth are brushed, a picture is taken using the application. Then, a music or video game animation repeats the techniques of how to brush properly using the principle of ASAP (Acknowledge, See, Active Practice). To finish, a last control picture is taken. The neural network that works in decentralized servers identifies whether brushing was effective and determines whether the number of weekly brushing is sufficient. The prevention program is free of charge. There is a more extensive post-intervention follow-up program for dentists to ensure that their patients comply with important hygiene rules on a daily basis. Hygiene is a crucial criterion for the success of an intervention. The practitioner will be alerted in case of therapeutic escape and can see on a photo the aspects to be improved with his patient. This more advanced part of the service will be on subscription.

The other aspect that is interesting to the author is the understanding of parafunctions such as bruxism or misunderstood mechanisms such as fibromyalgia being better understood with the help of AI. It would seem interesting to treat and numerically identify existing dental focal infections (cysts, devitalized teeth, abscesses, etc.) or the presence of muscle pain, lower-back pain, disc hernia, and tissue inflammation; mapping areas of muscle tension identifiable by trigger points or measuring brain waves to calibrate stress status. Measures can be taken by engineers to feed AI assisted by professional psychologists, dentists and physiotherapists. According to the author, AI is a powerful tool for breaking down barriers between professions, improving communication and enabling the medical professions to see their patients as a whole. It should be noted that there is a certain gap between research and innovation and that unfortunately the economic aspect has a negative impact and increases costs for patients.

III.3 Sides effects of AI

Today, AI is better than humans to identify patterns on images, sounds, etc. What is to be feared in this case is not the technology, but the use that humans will make of it. There is no danger in using AI as a tool to verify a diagnosis, but the easy drift is that the practitioner is subordinated to proving what the machine says. In the current state of data science research, AI algorithms are not interpretable, and it is not possible to interrogate AI to understand a reasoning. It is often described as black boxes.

The dental industry is unique in comparison to other sectors. This is one of the few areas where, despite the increase in competition, margins are improving. This phenomenon is not foreign to the adoption of increasingly expensive and digitalized technology by practitioners. Beyond the technology, the business model of companies is to increase efficiency (less time on the dental chair), and reduce annoyance by automating, in whole or in part, a manual or intellectual process. In return, the practitioner, in addition to purchasing the equipment, must share this expected gain by invoicing services or consumables.

Thus, the transition to AI is a corporate takeover of the practitioner who is becoming increasingly dependent on high service fees and the Internet to make the technology work properly. It is sad that a practitioner who stops paying the licence fees can no longer use his equipment.

In several countries, automated industrial solutions, for example in ortodonty, are emerging to offer direct solutions for the patient without the need to visit a specialist; the advantage is that, on average, it is 60% more affordable for the patient. To improve competitiveness, industry uses AI a lot because it is tireless and free; however, it remains mandatory for a professional to validate the work of the AI, even if this professionnal will never see the patient.

On the one hand, practitioners who wish to invest in technology are forced to increase the price of their consultations in part to support innovation. On the other hand, the industry attracted by profits industrializes profitable processes to provide direct solutions to patients and cut prices.

According to Paretho's law, 80% of the population in good health or slightly ill should not see their costs for treatment increase, but for the 20% who are in real demand the costs will explode.

IV Conclusion

AI success is due to the convergence of three factors: computation, Big Data, and AI algorithmic advancements. For the future, a lot of improvement is required to interpret the reasoning of the system, which is able to recognize things better than a human.

Two algorithms were used: the first one was a decision tree algorithm that considerably reduced the number of articles to be read, while the second was a k-means clustering algorithm that could be dramatically improved if the PubMed database standardizes some critical information.

The author's opinion is to develop AI in areas where there is no expertise yet or where it is possible to do so on trivial, non-compromising aspects. He suggests using AI as in this article to summarize a large volume of data. His second recommendation is to imagine public health care improved by AI. His last point is to understand multifactorial disorders and misunderstood diseases in order to find new solutions.

To conclude, AI is a free technology available on the Internet. The implementation may seem complicated, but it is not; this argument is made to discourage new actors. It is urgent to support the next promotions of dentists so that technology remains only a tool and not something hindering the quality or access to reasonable care for patients. We do not expect a clinician to do the work of a data scientist, but they must learn to communicate on the important aspects of innovation that will affect their work. Innovation is not improvisation; all actors of good will must organize themselves to work together at the risk of being forced to make choices that run counter to their values as health professionals.

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Zanella-Calzada, L. *et al.* (2018) 'Deep Artificial Neural Networks for the Diagnostic of Caries Using Socioeconomic and Nutritional Features as Determinants: Data from NHANES 2013–2014', *Bioengineering*. doi: 10.3390/bioengineering5020047.

Zhang, K. *et al.* (2018) 'An effective teeth recognition method using label tree with cascade network structure', *Computerized Medical Imaging and Graphics*. doi: 10.1016/j.compmedimag.2018.07.001.

Zhang, Y. De *et al.* (2011) 'Kinematics modeling and experimentation of the multi-manipulator tooth-arrangement robot for full denture manufacturing', *Journal of Medical Systems*. doi: 10.1007/s10916-009-9419-x.

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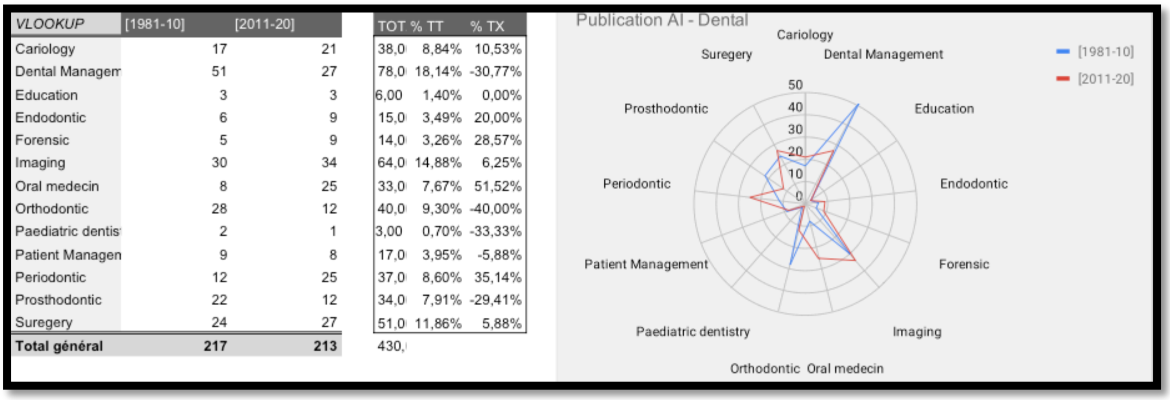
VI Appendix

VI.1 Figures



VLOOKUP	[1981-10]	[2011-20]
Cariology	17	21
Dental Managem	51	27
Education	3	3
Endodontic	6	9
Forensic	5	9
Imaging	30	34
Oral medecin	8	25
Orthodontic	28	12
Paediatric dentis	2	1
Patient Managen	9	8
Periodontic	12	25
Prosthodontic	22	12
Suregery	24	27
Total général	**217**	**213**

TOT	% TT	% TX
38,0	8,84%	10,53%
78,0	18,14%	-30,77%
6,00	1,40%	0,00%
15,0	3,49%	20,00%
14,0	3,26%	28,57%
64,0	14,88%	6,25%
33,0	7,67%	51,52%
40,0	9,30%	-40,00%
3,00	0,70%	-33,33%
17,0	3,95%	-5,88%
37,0	8,60%	35,14%
34,0	7,91%	-29,41%
51,0	11,86%	5,88%
430,		

Figure 1: Articles on odontology using AI : 1981-2010 and 2011-2019.

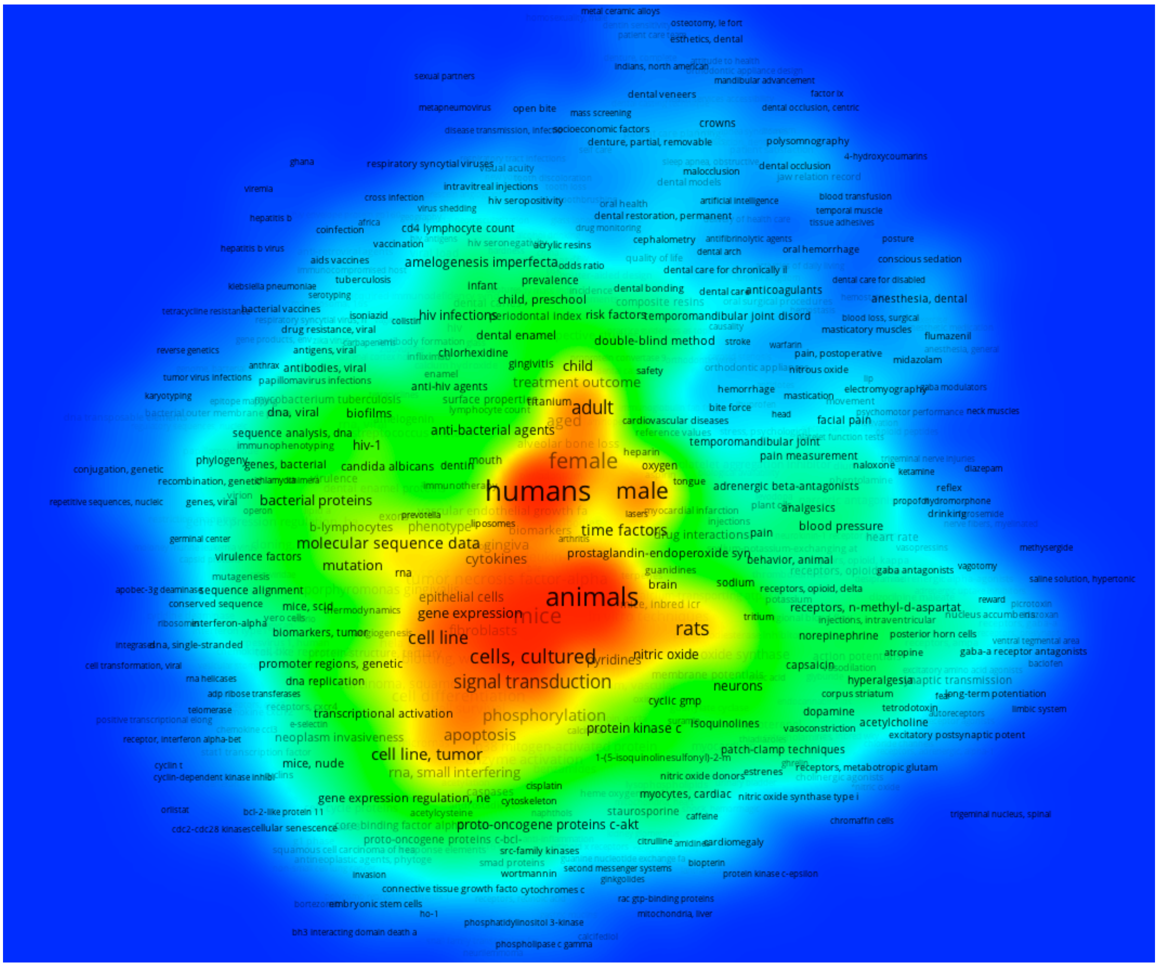


figure 2 : K-means analyse semantic

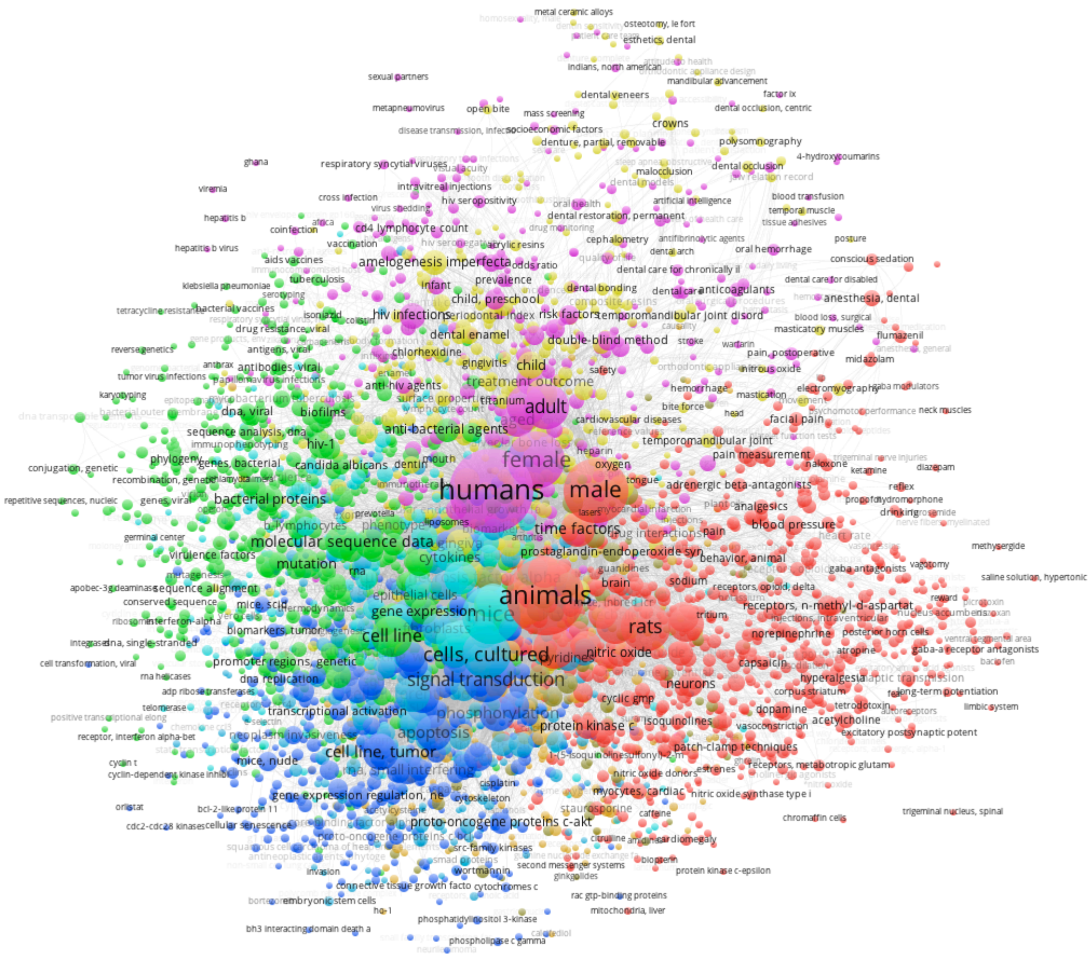


figure 3: K-means analyse semantic

#	n	Keyword	#	n	Keyword	#	n	Keyword
1	471	Humans	**10**	45	* Artificial Intelligence	**19**	33	Artificial Intelligence
2	122	Male	**11**	45	Sensitivity and specificity	**20**	33	Gen Ontology
3	119	Female	**12**	43	Software	**21**	30	Expert System
4	72	Adult	**13**	38	Neural Networks	**22**	30	Robotics
5	68	Algorithm	**14**	36	Young Adult	**23**	29	Algorithms
6	62	Middle Age	**15**	36	Adolescent			
7	60	Reproducibility results	**16**	34	* Expert System			
8	48	* Neural Networks	**17**	34	Child			
9	47	Aged	**18**	33	Equipment Design			

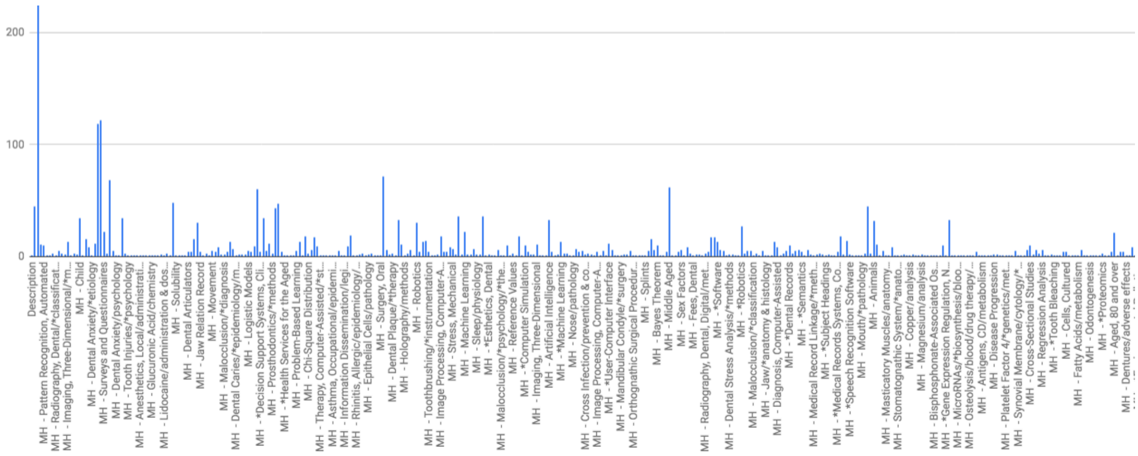


figure 4: Sum and graph of keywords

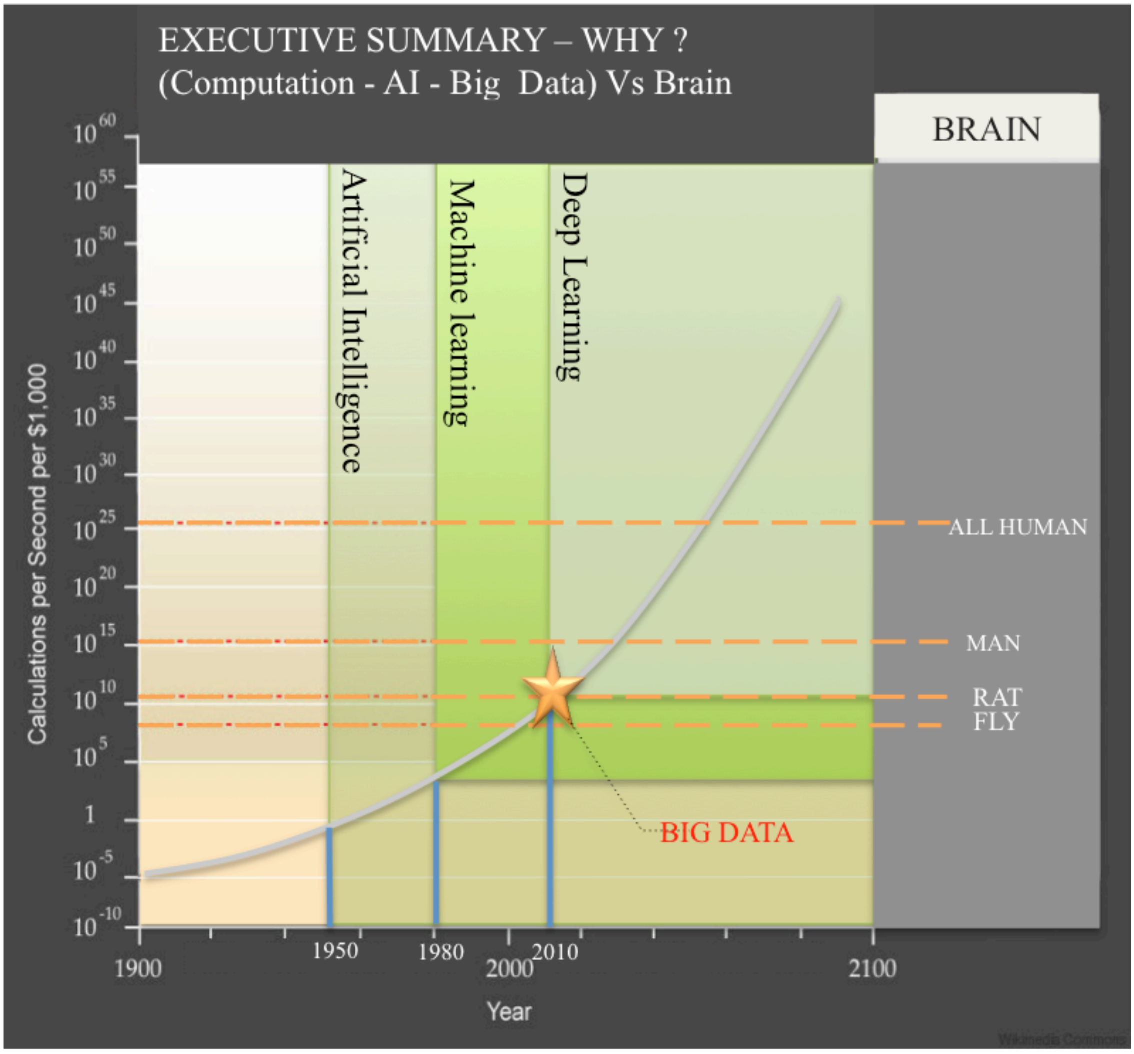


Figure 5: Computation, Big Data and Algorithms?

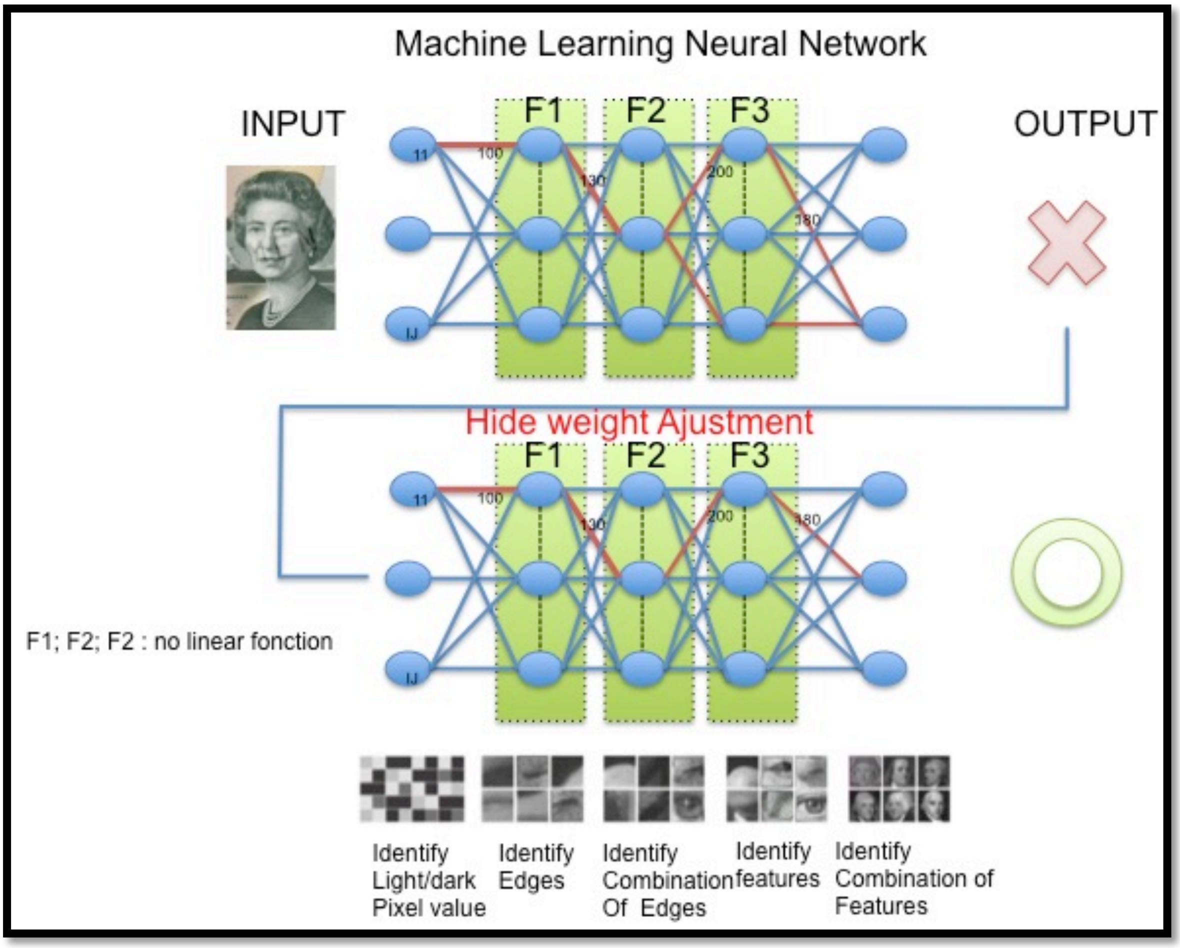


Figure 6: Machine Learning Neural Network

VI.2 Articles selected

Article	Author	Overview
		Cariology
(Mago *et al.*, 2011)	Mago	AI Assistance treatment of mobile tooth
(De Munck *et al.*, 2012)	De Munck	Meta-analytical review, DL based, consolidating heterogeneous data, 80% dataset for model-fitting, 20% validation proof. Variables “research group” and “adhesive brand” most sentive
(Zakeri, Arzanpour and Chehroudi, 2015)	Zakeri	Discrimination of tooth layers and dental restorative materials using cutting sounds.
(Aliaga *et al.*, 2015)	Aliaga	Modelling the longevity of dental restorations
(Gavinho *et al.*, 2018)	Gavinho	Detection of white spot lesions by segmenting laser speckle images using vision detection
(Zanella-Calzada *et al.*, 2018)	Zanella-Calzada	Diagnostic of Caries Using socio economic and nutritional Features as Inputs.
		Dental Management
(Banumathi, Raju and Abhaikumar, 2011)	Banumathi	Diagnosis of dental deformities in cephalometry images using support vector machine.
(Zhang *et al.*, 2011)	Zhang	Kinematics modeling and experimentation of the multi-manipulator tooth-arrangement robot for full denture manufacturing.
(Chambers, 2011)	Chambers	Developing a Self-Scoring Comprehensive Instrument to Measure Rest's Four-Component Model of Moral Behavior: The Moral Skills Inventory.
(Bekhuis *et al.*, 2011)	Bekhuis	Using natural language processing to enable in-depth analysis of clinical messages posted to an Internet mailing list: a feasibility study.
(Walji *et al.*, 2013)	Walji MF	Detection and characterization of usability problems in structured data entry interfaces in dentistry.
(Tanzawa *et al.*, 2013)	Tanzawa T	Medical emergency education using a robot patient in a dental setting.PG - e114-9
(Tancredi and Torgersson, 2013)	Tancredi W	An example of an application of the semiotic inspection method in the domain of computerized patient record system.
(Yilmaz, Erdur and Türksever, 2013)	Yilmaz O	SAMS--a systems architecture for developing intelligent health information systems.
(Gupta, 2011)	Gupta J	Nanotechnology applications in medicine and dentistry.PG - 81-8 -
(Takayama *et al.*, 2015)	Takayama T	Computer-Aided Prediction of Long-Term Prognosis of Patients with Ulcerative Colitis after Cytoapheresis Therapy.
(Hanagata, 2015)	Hanagata N	Global Gene Expression Analysis for the Assessment of Nanobiomaterials.PG - 78-89
(Melillo *et al.*, 2015)	Melillo P	Cloud-Based Smart Health Monitoring System for Automatic Cardiovascular and FallRisk Assessment in Hypertensive Patients.
(Araújo, Santana and de A. Santos Neto, 2016)	ml	AI makes preauthorisation decisions for healthcare in Brazil, based on historical Data, cost control,
(Ngan *et al.*, 2016)	Ngan TT	Decision Making Based on Fuzzy Aggregation Operators for Medical Diagnosis from Dental X-ray images.
(Yu Tsao Pan *et al.*, 2016)	Yu Tsao Pan P	MCQ-construction improves Quality of Essay Assessment among undergraduate dental students.
(Bindal *et al.*, 2017)	Bindal P	Neuro-fuzzy method for predicting the viability of stem cells treated atdifferent time-concentration conditions.
(I. Lee *et al.*, 2018)	Lee I	Estimating the Cost Savings of Preventive Dental Services Delivered toMedicaid-Enrolled Children in Six Southeastern States.
(Seligman, Tuljapurkar and Rehkopf, 2018)	Seligman B	Machine learning approaches to the social determinants of health in the healthand retirement study.
(Thanathornwong, 2018)	Thanathorn wong B	Bayesian-Based Decision Support System for Assessing the Needs for OrthodonticTreatment.
-	Yoon S	Applying Deep Learning to Understand Predictors of Tooth Mobility Among UrbanLatinos.
-	Yoon S	Machine Learning to Identify Behavioral Determinants of Oral Health in Inner City Older Hispanic Adults.
(J. H. Lee *et al.*, 2018)	Lee JH	Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm.

(Alarifi and AlZubi, 2018)	Alarifi A	Memetic Search Optimization Along with Genetic Scale Recurrent Neural Network forPredictive Rate of Implant Treatment.
(Komura and Ishikawa, 2018)	Komura D	Machine Learning Methods for Histopathological Image Analysis.PG - 34-42
(Lee, Park and Kim, 2017) (Park and Park, 2018)	Park WJ	History and application of artificial neural networks in dentistry.PG - 594-601
(Castaldo *et al.*, 2019)	Castaldo R	Ultra-short term HRV features as surrogates of short term HRV: a case study onmental stress detection in real life.
-	Patel J	Leveraging Electronic Dental Record Data to Classify Patients Based on TheirSmoking Intensity.
Education		
(Kolahi, Iranmanesh and Khazaei, 2017)	Kolahi J	Altmetric analysis of 2015 dental literature: a cross sectional survey.PG - 695-699
(Abe *et al.*, 2018)	Abe S	Educational effects using a robot patient simulation system for development of clinical attitude.
(Karimbux, 2018)	-	Imagination and intersection : an essay about the future.
Endodontic		
(Gandhi, Kathuria and Gandhi, 2011)	Gandhi A	Endodontic-periodontal management of two rooted maxillary lateral incisor associated with complex radicular lingual groove by using spiral computed
(Unver, Onay and Ungor, 2011)	Unver S	Intentional re-plantation of a vertically fractured tooth repaired with anadhesive resin.
(M. A. Saghiri *et al.*, 2012)	Saghiri MA	A new approach for locating the minor apical foramen using an artificial neuralnetwork.
(Bruellmann *et al.*, 2013)	Bruellmann DD	An optimized video system for augmented reality in endodontics: a feasibilitystudy.
(Kositbowornchai, Plermkamon and Tangkosol, 2013)	Kositbowornchai S	Performance of an artificial neural network for vertical root fracture detection:an ex vivo study.
(Mohammad Ali Saghiri *et al.*, 2012)	Saghiri MA	The reliability of artificial neural network in locating minor apical foramen: acadaver study.
(Gruber *et al.*, 2015)	Gruber R	Common target genes of palatal and gingival fibroblasts for EMD: the microarrayapproach.
(Yoshino *et al.*, 2017)	Yoshino H	Is It Safe to Use the Same Scissors After Accidental Tumor Incision DuringPartial Nephrectomy? Results of In Vitro and In Vivo Experiments.
(Jungnickel *et al.*, 2018)	Jungnickel L	Quality aspects of ex vivo root canal treatments done by undergraduate dentalstudents using four different endodontic treatment systems.
Forensic		
(Dinkar and Sambyal, 2012)	Dinkar AD	Person identification in Ethnic Indian Goans using ear biometrics and neuralnetworks.
-	Veleminska J	Dental age estimation and different predictive ability of various tooth types inthe Czech population: data mining methods.
(Ibáñez *et al.*, 2015)	Ibanez O	Study on the performance of different craniofacial superimposition approaches(I).
(Ibáñez *et al.*, 2015)	Damas S	Study on the performance of different craniofacial superimposition approaches(II): Best practices proposal.
(Oscar Ibáñez *et al.*, 2016)	Ibanez O	Study on the criteria for assessing skull-face correspondence in craniofacialsuperimposition.
(O. Ibáñez *et al.*, 2016)	Ibanez O	MEPROCS framework for Craniofacial Superimposition: Validation study.PG - 99-108
(Štepanovský *et al.*, 2017)	Stepanovsky M	Novel age estimation model based on development of permanent teeth compared withclassical approach and other modern data mining methods.
(De Tobel *et al.*, 2017)	De Tobel J	An automated technique to stage lower third molar development on panoramicradiographs for age estimation: a pilot study.
(Heinrich *et al.*, 2018)	Heinrich A	Forensic Odontology: Automatic Identification of Persons Comparing Antemortem andPostmortem Panoramic Radiographs Using Computer Vision.
Imaging		
(Spin-Neto *et al.*, 2013)	Spin-Neto R	Cone beam CT image artefacts related to head motion simulated by a robot skull:visual characteristics and impact on image quality.
(Frydenlund, Eramian and Daley, 2014)	Frydenlund A	Automated classification of four types of developmental odontogenic cysts.PG - 151-62
	Xing F	3D tongue motion from tagged and cine MR images.PG - 41-8
	Wang L	Automated segmentation of CBCT image using spiral CT atlases and convexoptimization.

(Rahman *et al.*, 2014)	Rahman HA	Classification of reflected signals from cavitated tooth surfaces using anartificial intelligence technique incorporating a fiber optic displacement
(Al Haidan, Abu-Hammad and Dar-Odeh, 2014)	Al Haidan A	Predicting tooth surface loss using genetic algorithms-optimized artificialneural networks.
(Okada *et al.*, 2015)	Okada K	Noninvasive differential diagnosis of dental periapical lesions in cone-beam CTscans.
(Gupta *et al.*, 2015)	Gupta A	A knowledge-based algorithm for automatic detection of cephalometric landmarks onCBCT images.
(H. Li *et al.*, 2015)	Li H	The prediction in computer color matching of dentistry based on GA+BP neuralnetwork.
(Gupta *et al.*, 2016)	Gupta A	Accuracy of 3D cephalometric measurements based on an automatic knowledge-basedlandmark detection algorithm.
(Kavitha *et al.*, 2016)	Kavitha MS	Automatic detection of osteoporosis based on hybrid genetic swarm fuzzyclassifier approaches.
(Wang *et al.*, 2017)	Wang L	A segmentation and classification scheme for single tooth in MicroCT images basedon 3D level set and k-means+.
	Johari M	Detection of vertical root fractures in intact and endodontically treatedpremolar teeth by designing a probabilistic neural network: an ex vivo study.
(Miki *et al.*, 2017)	Miki Y	Classification of teeth in cone-beam CT using deep convolutional neural network.PG - 24-29
(Raith *et al.*, 2017)	Raith S	Artificial Neural Networks as a powerful numerical tool to classify specificfeatures of a tooth based on 3D scan data.
	Kebschull M	Exploring Genome-Wide Expression Profiles Using Machine Learning Techniques.PG - 347-364
(Gurcan *et al.*, 2017)	Gurcan MN	Developing the Quantitative Histopathology Image Ontology (QHIO): A case studyusing the hot spot detection problem.
(Yilmaz, Kayikcioglu and Kayipmaz, 2017)	Yilmaz E	Computer-aided diagnosis of periapical cyst and keratocystic odontogenic tumor oncone beam computed tomography.
	Hwang JJ	Strut analysis for osteoporosis detection model using dental panoramicradiography.
(Christodoulou *et al.*, 2018)	Christodoulou A	A new methodology for the measurement of the root canal curvature and its 3Dmodification after instrumentation.
	Yoon DC	Digital Radiographic Image Processing and Analysis.PG - 341-359
	Katkar RA	Optical Coherence Tomography.PG - 421-434
(T. *et al.*, 2019)	Urakawa T	Detecting intertrochanteric hip fractures with orthopedist-level accuracy using adeep convolutional neural network.
	Tolpadi AA	Inverse Biomechanical Modeling of the Tongue via Machine Learning and SyntheticTraining Data.
(Zhang *et al.*, 2018)	Zhang K	An effective teeth recognition method using label tree with cascade networkstructure.
	Lignell A	Spatial Genomic Analysis: A Multiplexed Transcriptional Profiling Method thatReveals Subpopulations of Cells Within Intact Tissues.
(Hiraiwa *et al.*, 2018)	Hiraiwa T	A deep-learning artificial intelligence system for assessment of root morphologyof the mandibular first molar on panoramic radiography.
(Egger *et al.*, 2018)	Egger J	Fully Convolutional Mandible Segmentation on a valid Ground- Truth Dataset.PG - 656-660
(Song *et al.*, 2018)	Song B	Automatic classification of dual-modalilty, smartphone-based oral dysplasia and malignancy images using deep learning.
(Hatvani *et al.*, 2018)	Hatvani J	A Tensor Factorization Method for 3D Super-Resolution with Application to DentalCT.
(Murata *et al.*, 2018)	Murata M	Deep-learning classification using convolutional neural network for evaluation of maxillary sinusitis on panoramic radiography.
(Hu *et al.*, 2019)	Hu Z	Artifact correction in low-dose dental CT imaging using Wasserstein generativeadversarial networks.
(Chen *et al.*, 2019)	Chen H	A deep learning approach to automatic teeth detection and numbering based onobject detection in dental periapical films.
(Fujioka *et al.*, 2019)	Fujioka T	Distinction between benign and malignant breast masses at breast ultrasound usingdeep learning method with convolutional neural network.
Oral medicine		
(Suzuki *et al.*, 2012)	Suzuki S	Systems analysis of inflammatory bowel disease based on comprehensive geneinformation.
(Orphanidou-vlachou *et al.*, 2014)	Orphanidou-Vlachou E	Texture analysis of T1 - and T2 -weighted MR images and use of probabilisticneural network to discriminate posterior fossa tumours in children.
(Dobashi *et al.*, 2014)	Dobashi K	Japanese Guideline for Occupational Allergic Diseases 2014.PG - 421-42

(Ranzinger *et al.*, 2014)	Ranzinger R	GlycoRDF: an ontology to standardize glycomics data in RDF.PG - 919-25
(Courtot *et al.*, 2015)	Courtot M	flowCL: ontology-based cell population labelling in flow cytometry.PG - 1337-9
(Banerjee *et al.*, 2015)	Banerjee S	Fourier-transform-infrared-spectroscopy based spectral-biomarker selectiontowards optimum diagnostic differentiation of oral leukoplakia and cancer.
(Ning and Beiko, 2015)	Ning J	Phylogenetic approaches to microbial community classification.PG - 47
	Patil S	Nanorobots: Changing Trends in Cancer Therapy.PG - i-ii
(Tang *et al.*, 2015)	Tang JR	A Fuzzy-C-Means-Clustering Approach: Quantifying Chromatin Pattern ofNon-Neoplastic Cervical Squamous Cells.
	Inoue M	Dysphagia Rehabilitation in Japan.PG - S72-3
(J. Li *et al.*, 2015)	Li J	Cytoskeletal binding proteins distinguish cultured dental follicle cells andperiodontal ligament cells.
(J. Wang *et al.*, 2016)	Wang J	DNA methylation is critical for tooth agenesis: implications for sporadicnon-syndromic anodontia and hypodontia.
(Saxena *et al.*, 2019)	Saxena S	Design, architecture and application of nanorobotics in oncology.PG - 236-41
(Lefebvre *et al.*, 2016)	Lefebvre A	A Non-Destructive Method for Distinguishing Reindeer Antler (Rangifer tarandus)from Red Deer Antler (Cervus elaphus) Using X-Ray Micro-Tomography Coupled with
	Hussain A	Development of an ANN optimized mucoadhesive buccal tablet containingflurbiprofen and lidocaine for dental pain.
(Harmati *et al.*, 2016)	Harmati M	Stressors alter intercellular communication and exosome profile of nasopharyngealcarcinoma cells.
(Conte and Bartzela, 2016)	Phan M	Tooth agenesis and orofacial clefting: genetic brothers in arms?PG - 1299-1327
(Sarkar *et al.*, 2016)	Sarkar R	Risk prediction for oral potentially malignant disorders using fuzzy analysis ofcytomorphological and autofluorescence alterations in habitual smokers.
(Dey *et al.*, 2017)	Dey S	Pre-cancer risk assessment in habitual smokers from DIC images of oralexfoliative cells using active contour and SVM analysis.
(Li *et al.*, 2017)	Li Y	Assessment of dental ontogeny in late Miocene hipparionines from the Lamagoufauna of Fugu, Shaanxi Province, China.
(Liu *et al.*, 2017)	Liu Y	Quantitative prediction of oral cancer risk in patients with oral leukoplakia.PG - 46057-46064
(García *et al.*, 2016)	Rodriguez-Garcia MA	Integrating phenotype ontologies with PhenomeNET.PG - 58
(Ishioka *et al.*, 2018)	Ishioka J	Computer-aided diagnosis of prostate cancer on magnetic resonance imaging using aconvolutional neural network algorithm.
(Lysenko *et al.*, 2018)	Lysenko A	An integrative machine learning approach for prediction of toxicity-related drugsafety.
(Boone *et al.*, 2018)	Boone K	Antimicrobial peptide similarity and classification through rough set theoryusing physicochemical boundaries.
(Kim *et al.*, 2018)	Kim DW	Machine learning to predict the occurrence of bisphosphonate-relatedosteonecrosis of the jaw associated with dental extraction: A preliminary report.
Orthodontic		
(Wilmes, Panayotidis and Drescher, 2011)	Wilmes B	Fracture resistance of orthodontic mini-implants: a biomechanical in vitro study.PG - 396-401
(Moghimi, Talebi and Parisay, 2012)	Moghimi S	Design and implementation of a hybrid genetic algorithm and artificial neuralnetwork system for predicting the sizes of unerupted canines and premolars.
	Gilbert A	An in-office wire-bending robot for lingual orthodontics.PG - 230-4;quiz 236
(Kau, 2011)	Kau CH	A radiographic analysis of tooth morphology following the use of a novel cyclicalforce device in orthodontics.
(Auconi *et al.*, 2011)	Auconi P	A network approach to orthodontic diagnosis.PG - 189-97
(Lochmatter, Steineck and Brauchli, 2012)	Lochmatter D	Influence of material choice on the force delivery of bimaxillary toothpositioners on canine malpositions.
(Janakiraman *et al.*, 2015)	Janakiraman N	Integration of 3-dimensional surgical and orthodontic technologies withorthognathic "surgery-first" approach in the management of unilateral condylar
(Jung and Kim, 2016)	Jung SK	New approach for the diagnosis of extractions with neural network machinelearning.
	Wan Hassan WN	User acceptance of a touchless sterile system to control virtual orthodonticstudy models.
(X. Wang *et al.*, 2016)	Wang X	Objective method for evaluating orthodontic treatment from the lay perspective:An eye-tracking study.
(Nurazreena *et al.*, no date)	Wan Hassan WN	Assessing agreement in measurements of orthodontic study models: Digital caliperon plaster models vs 3-dimensional software on models scanned by structured-light

(Patcas *et al.*, 2019)	Patcas R	Facial attractiveness of cleft patients: a direct comparison betweenartificial-intelligence-based scoring and conventional rater groups.
(Allareddy *et al.*, 2019)	Allareddy V	Orthodontics in the era of big data analytics.
Other		
(Koprowski *et al.*, 2018)	Koprowski R	Image Processing in Ophthalmology.PG - 1545632
(Sato *et al.*, 2018)	Sato M	Three-dimensional multimodality fusion imaging as an educational and planningtool for deep-seated meningiomas.
(Podgorski *et al.*, 2018)	Podgorski JE	Prediction Modeling and Mapping of Groundwater Fluoride Contamination throughoutIndia.
	Yoshida GJ	[The emerging role of artificial intelligence in clinical and basic medicine].PG - 112-113
(Lanza, Koprowski and Sconocchia, 2018)	Lanza M	Improving accuracy of corneal power measurement with partial coherenceinterferometry after corneal refractive surgery using a multivariate polynomial
	Mori Y	Real-Time Use of Artificial Intelligence in Identification of Diminutive PolypsDuring Colonoscopy: A Prospective Study.
(Chan *et al.*, 2018)	Chan YK	Artificial Intelligence in Medical Applications.PG - 4827875
	Mupparapu M	Artificial intelligence, machine learning, neural networks, and deep learning:Futuristic concepts for new dental diagnosis.
Paediatric Dentistry		
(‘Building Sustainable Health and Education Partnerships : Stories From Local Communities ABSTRACT’, 2015)	Blank MJ	Building sustainable health and education partnerships: stories from localcommunities.
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