Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

TRENDS IN THE USE OF ARTIFICIAL INTELLIGENCE IN DENTISTRY IN EUROPE

Madrid, academic year 2022/2023

Identification number: 106

SUMMARY AND KEYWORDS

Introduction: As developments in artificial intelligence (AI) expand, so do its applications in dentistry; these are important to define so that oral health clinicians can be updated on what possibilities are already at their disposal and what they can expect to come. **Objectives:** The purpose of this systematic review was to determine the trends in AI in dentistry in Europe through revealing which countries are most involved in its research, which fields of dentistry AI is most applied, and which domains of AI are being most developed within dentistry. **Methodology:** The databases Medline Complete and Dentistry & Oral Sciences Source were utilised to find the 17 articles published between 2019 and 2022 that were included. Article inclusion was based on individual relevance to AI and dentistry, having been published in one of the 30 listed European countries of interest, having been published in English between 2018 and 2022, and being a research study rather than a review. Then, the following variables were collected from each article: country of publication, country affiliations of authors, article keywords, study type, publication year, and the overall dental field(s) the article was most related to. **Results:** The main findings were that of European countries, the United Kingdom published the most articles related to AI in dentistry, that publications related to AI in dentistry mostly focused on radiology, and that deep learning was the most common domain of AI within publications related to dentistry. **Conclusions:** In Europe, contributions to AI in dentistry disproportionately stem from certain countries over others and focus on radiology above all. In the future, it would be interesting to further research why so many countries have fallen behind the current European pioneers and follow-up on which fields of dentistry AI continues to grow, as well as compare trends globally.

Keywords: dentistry; artificial intelligence; machine learning; deep learning; Europe.

RESUMEN Y PALABRAS CLAVE

Introducción: A medida que se expanden los desarrollos en la inteligencia artificial (IA), también lo hacen sus aplicaciones en odontología; es importante definirlos para que los profesionales de salud bucodental puedan estar actualizados sobre las posibilidades que ya existen y lo que pueden esperar en el futuro. **Objetivos:** El propósito de esta revisión sistemática fue determinar las tendencias de IA en odontología en Europa por revelar cuáles países están más involucrados en su investigación, qué campos de odontología se aplican más IA y qué dominios de IA se están desarrollando más dentro de la odontología. **Metodología:** Se utilizaron las bases de datos Medline Complete y Dentistry & Oral Sciences Source para encontrar los 17 artículos incluidos, publicados entre 2019 y 2022. La inclusión del artículo se basó en la relevancia individual a IA y la odontología, la publicación en uno de los 30 enumerados países de interés, la publicación en inglés entre 2018 y 2022 y ser un estudio de investigación. Se recopiló la siguiente información de cada artículo: país de publicación, países de afiliación de los autores, palabras clave, tipo de estudio, año de publicación y los campos dentales más relacionados con el artículo. **Resultados:** Los principales descubrimientos fueron que, de los artículos relacionados con IA en odontología en Europa, el Reino Unido publicó la mayoría de los artículos y que se centraron principalmente en radiología y en el dominio de IA del aprendizaje profundo. **Conclusiones:** En Europa, las contribuciones a IA en odontología provienen de manera desproporcionada de ciertos países y se centran sobre todo en la radiología. En el futuro, sería interesante seguir investigando por qué tantos países se han quedado atrás y hacer un seguimiento de los campos de la odontología en que IA sigue creciendo, así como comparar las tendencias a nivel mundial.

Palabras Clave: odontología; inteligencia artificial; aprendizaje automático; aprendizaje profundo; Europa.

TABLE OF CONTENTS

1. INTRODUCTION

1.1. What is Artificial Intelligence?

1.1.1. The Origin of Modern A.I.

The term Artificial intelligence (AI/A.I.) was first conceived in 1956, primarily by computer scientist John McCarthy, alongside Marvin Minsky, Shannon Rochester, and Nathan Rochester (1,2). It has since become known as the ability of technology to replace human intelligence for tasks requiring problem solving, optic recognition, or linguistic understanding (1). Even before the term AI existed, the concept was already far in the works. In the early 1950s, Alan Turing developed what became known as the "Turing Test", which was meant to assess whether one could class a machine as *intelligent* (2). Essentially, if the machine was able to interact with a human, and if that human was not able to perceive with certainty whether they were interacting with a machine or another human, then the machine could be deemed as possessing intelligence (2).

AI may sound quite futuristic, but it is already highly intertwined with the world we live in. To give some well-known examples, AI is involved in hate speech and terrorist group detection on social media platforms, email spam filtration, automated telephone operators or chat systems, "virtual-assistants" such as Amazon's Alexa or Apple's Siri, Netflix suggestions, self-driving cars, facial recognition, and finance opportunity and risk assessment (1).

Human intelligence is learned through experiences, memories, observation, language, and challenges as we age and develop. The ability of the brain to absorb information, problem solve, and plan is what makes it so special. Incidentally, as humans can learn and be taught, so can computers.

1.1.2. Types of A.I.

In terms of an AI's ability to perform certain tasks, it depends on how advanced the AI is. All of the AI that exists today is classed at **narrow/weak AI**. This means that it can perform programmed tasks "within a narrowly defined range" (1). The succeeding level of AI would be **general/strong AI** (1). This AI would be defined as being able to operate on the same level as the human brain. Though the level of general/strong AI has not yet been achieved, it is predicted to be reached by the year 2025 (2). If a machine were able to surpass human intelligence, it would be classed as **super AI** (1).

Regarding computer learning, there are two levels. The more basic level is called machine learning (ML). The more complex level is called deep learning (DL). (1,2)

1.1.2.1. Machine Learning

The term *machine learning* was conceived by Arthur Samuel in 1959 (1). ML is now known as the ability of a machine to self-train without explicit programming (1). The goal is pattern detection within given data in order to generate outcome predictions and even decision making. Moreover, the machines can evolve and improve themselves through error feedback and minimization (1). However, pattern detection first requires pattern demonstration (2).

There are three learning types within ML: supervised, unsupervised, and reinforced learning. **Supervised learning** requires input data to be pre-classified (e.g. labelled radiographs) before it begins labelling things on its own. This is useful for problems or predictions requiring categorical classification or variable regression. **Unsupervised learning** occurs when unlabelled data is given and the machine is forced to classify it independently; it does so through the identification of differences. This type of learning is useful for clustering problems where it is needed to group items based on correlations, which can in turn identify things such as obscured signs of different diseases. **Reinforced learning** is based on rewards and trial and error. It can be used for decision efficiency mapping. Simplified, a programmer could set a goal for a machine and then it would learn through evaluating all the ways it could reach said goal, noting the benefit vs. tolls of each decision until it has mapped the path with the most net benefit. (1)

Transfer learning is another separate subset of ML that is based on a machine applying its method of solving a previous task to solving another similar task (2).

The drawback of ML is that it requires a lot of structure and is limited by its difficulty functioning with multi-dimensional data or tasks which require data that is extensively more diverse, such as the recognition of handwriting or the processing of natural language (1).

1.1.2.2. Deep Learning

The advantage of DL is that it does not have the same limitations as ML, since it can handle significantly more varied data and dimensionality. This makes DL more effective at image recognition and natural language processing (NLP). For image recognition, DL machines break down aspects of the image into identifiable parts before putting it back together as a whole. Examples of uses of NLP would be for applications such as predictive text, automated online chat systems, or speech recognition. DL machines mine servers for text and data in order to recognize patterns and self-teach. (1)

DL's superiority comes from the integration of perceptrons, which are manufactured neurons meant to mimic human neurons and processing. Perceptrons were first implemented by Frank Rosenblatt in [also] in 1956. However, the stacking of perceptrons in the creation of artificial neural networks (ANN) was first done in 1965 by mathematician Alexey Grigorevich. (2)

Nowadays, the layered neural networks have evolved to convolutional neural networks (CNN), which contain hidden neural layers, and are what allow for complex problem solving. (1,2)

1.2. How is Artificial Intelligence applied to dentistry?

Like in medicine, there are many ways in which AI proves useful in terms of healthcare in dentistry. There is a constant need for more data storage and sorting with the digitization of health records. AI has the power to make sense of that data for medical research, epidemiology, model development, risk predictions, improvement of efficiency, and even decision making. IBM's supercomputer, Watson, can already be used at a clinical level for pathology diagnosis hypotheses based on the input of clinical history information, comparing it to published research and treatment (Tx) plans. Watson can then list its predictions alongside its level of certainty. (1)

In dentistry, AI is already replacing some basic operations. From scheduling regular patient appointments, to a "voice command operated dental chair," to appointment length and efficiency-tracking for dental students at Columbia university (3–5).

However, it must be remembered that research with CNNs only began in 2015, and that prior to more specific clinical application, many more rigorous studies are required to strengthen AI performance (6,7). Medical AI still requires many more multi-level datasets from varied populations to strengthen generalised interactions (6,7).

Clinicians are imperfect; they are subject to bias, memory loss, and variability (7,8). In these aspects, AI can help. However, AI cannot replace certain aspects of human-to-human treatment, such as physical examination and non-verbal communication; and experienced dentists are still crucial to training AI (6,8). AI helps with diagnosing, but, ultimately, clinicians should possess the knowledge for deciding when and when not to treat a patient by incorporating a holistic approach, building a relationship with their patients, and trying to influence positive change in patient lifestyles that would have otherwise lead AI to thinking that their oral health was doomed (9).

1.2.1 Fields of Applications of A.I. in Dentistry

1.2.1.1. Radiology

Diagnostic imaging is at the forefront of dental applications of AI. The AI most implemented are supervised learning CNNs (6). AI programs can now identify caries in periapical (PA) and bitewing (BW) radiographs (Rx) with more accuracy than experienced dentists (6). AI can segment lesions, detect initial lesions, and identify previous restorations, periapical pathologies, root fractures, anatomical landmarks, facial defects, foreign objects, and supernumerary and impacted teeth (3,6,8,9). In the near future, AI will be able to detect early pathologies with nearly as much accuracy on an orthopantomography (OPG) as it currently can through cone beam computed tomography (CBCT) (9).

1.2.1.2. Oral Pathology

AI is able to detect maxillary sinusitis, “dentigerous cysts, odontogenic keratocysts, ameloblastomas” with similar accuracy as experienced oral pathologists, with the advantage of being significantly faster due to its instantaneous response time (9). AI is also better than clinicians at distinguishing patients with xerostomia from those with Sjögren’s syndrome through the identification of salivary gland steatosis in ultrasound images (USI) (8).

For TMJ conditions, AI can use NLP to evaluate patients’ own descriptions of their experience combined with jaw opening values to distinguish TMJ osteoarthritis and other temporomandibular disorders from other pathologies with similar symptoms (3,8).

For root caries risk prediction, the AI solely considers the lifestyle and demography of patients (9). For identifying whether a white oral mucosal lesion is oral lichen planus, AI analyses the "expression of inflammatory cytokines genes" (8).

Lastly, in patients about to receive irradiation to the head and neck, AI merges gene expression, medical history, and diagnostic imaging to formulate an "oral cancer risk prediction profile" and predict from CT scans the radiation dose to be received by the mandible, to better plan treatments prior to irradiation (9).

1.2.1.3. Oral Surgery

AI can predict the level of postoperative facial swelling after third molar extraction (8). Additionally, AI can predict, based on a patient's medical history, their individual risk of "bisphosphonate-related osteonecrosis of the jaw" (BRONJ) following an extraction (9).

1.2.1.4. Implantology

AI is used to plan implant placement positioning and to create surgical guides (5,6). Through PAs and OPGs, AI can also identify "up to 11 different implant systems" (9).

1.2.1.5. Restorative Dentistry

AI shade selection accuracy outperforms traditional shade guides but has no advantage over spectrophotometers (9).

1.2.1.6. Aesthetic Dentistry

There are currently over 15 smile design softwares available, which all run on AI. They can alter tooth shape and alignment based on patient photos to provide mock-ups prior to Tx. (5)

Facial attractiveness and perceived age can also be scored by AI, but this cannot change an individual's personal notion of beauty (3,8).

1.2.1.7. Prosthodontics

Computer aided design and manufacturing (CAD/CAM) is an example of AI that is already widely utilised clinically. It allows clinicians to scan preparations intraorally to design and manufacture fixed prosthetics (4). Whilst making dental preparations, intraoral scanners can provide feedback on margins, axial wall inclination, irregularities, etc (5).

Nowadays, AI can also accurately predict whether indirect composite resin (CR) crowns will debond. However, it is not known how the AI comes to this conclusion. (9)

Testing was done in-vitro with an AI automated "laser ablation system" in order to perform tooth preparations. The method was found to be very safe and precise, however, it required too much time to be clinically viable. (3,8)

For prosthetic treatment planning, AI can currently predict whether teeth will need to be extracted, endodontically treated, or restored. The AI had been programmed to think conservatively. (9)

1.2.1.8. Orthodontics

For orthodontic evaluations, AI can accurately identify cephalometric landmarks and stage cervical vertebrae, as well as automatically differentiate surgical from non-surgical cases based on the lateral Rx (9,10). AI also can predict whether extractions are needed, but struggles to individualise which teeth should be extracted in each case (5,9).

In order for patients to visualise treatment outcomes, AI can simulate the facial changes that would occur after orthodontic treatment or orthognathic surgery (3,5,10).

For online aligner services, AI is used to analyse smile selfies taken on one's phone, so that an orthodontist can monitor the treatment virtually (5)

1.2.1.9. Endodontics

AI can localise apical foramen in teeth, determine canal working lengths, and predict endodontic retreatment success (3,4,10).

1.2.1.10. Periodontics

AI can analyse subgingival plaque, interleukin, leukocyte, and IgG levels to create "microbial profiles" which differentiate between chronic and aggressive periodontitis (5,8). AI can also differentiate between healthy periodontium, gingivitis, and different grades of periodontitis solely from a patient's radiograph, medical, and clinical history (8).

Clinicians struggle with subjective classification of periodontal stages by bone loss levels, which AI makes up for with objectivity. However, the accuracy of the classification decreases in molars due to the AI struggling with multi-radicular teeth. AI tends to stage periodontitis in molars more gravely. (9)

AI can also predict caries in children due to a found correlation between parental periodontal and caries data (5).

1.2.1.11. Forensic Dentistry

AI can provide age predictions based on developmental staging of mandibular third molars and OPG analysis. AI can also perform virtual facial reconstruction from cephalograms. (5)

1.3. What are the ethical concerns regarding the use of Artificial Intelligence in medicine?

The four principles of healthcare ethics are said to be: "respect for autonomy, beneficence, nonmaleficence, and justice" (11).

Regarding the respect for the patient autonomy, it is debated whether informed consents should be required when clinicians utilise AI in the dental clinic (11). Though AI often outperforms experienced professionals in many tasks, errors based on misconstrued associations when learning are possible. There is the possibility of data selection bias due to the either the "overly sick" or the "overly affluent" being those that come to the dental clinic (7). Wealthier countries being those that would likely provide the most health data would lead to data gaps in unstudied foreign populations (11). It would be necessary to inform patients on the prediction accuracy of any AI used in their diagnosis (11). Additionally, it was previously explained how AI requires massive amounts of data in order to learn, however, patients are technically required to consent to the release of their medical information to the machines (9).

The basis of beneficence would be to maximise patient benefits whilst minimising injury (11). AI does indeed add a lot of benefit in terms of risk assessment and early pathology diagnoses. However, at AIs current stage there remains too much maleficence. Within the European Union, personal information is protected through the General Data Protection Regulation (GDPR) (11). The GDPR differs from regulations in the United States (US) in that data without identifiable information can be freely given in the US, whilst the GDPR explicitly restricts the non-consensual disclosure of any personal data (11). Thus, privacy remains a concern for patients and a blockade for AI training.

Furthermore, AI currently only solves problems in a way that hides its rationale. AI has shown that it can possess classing tendencies which can later not be explained nor verified, which make them untrustworthy. Classing bias could lead to mass Tx errors amongst populations. (5,8,9)

When such errors occur, proper legislation needs to be in place in order to decide who gets held accountable and how justice shall be served. At the moment, the AI itself is not considered responsible (8).

Another aspect of justice is equity. AI is expensive. Once AI begins to be distributed to clinics, it will be difficult to ensure that all patients have access to it. It is not just to deprive certain socioeconomic groups of the diagnostic capabilities that others can afford. (11)

Apart from concerns for patient well being, it is also notable that AI produces a significant effect on the environment. During the learning and training stages of advanced AI, CO_2 emissions range approximately from the emissions of a roundtrip flight per passenger "between New York City and San Francisco" to "more than the average lifetime emissions of a US car" (7).

1.4. Where is Artificial Intelligence in dentistry headed in the future?

What will be the experience of clinicians and patients in a dental clinic in the future? It is hoped that dentists and AI will work together to provide more efficient care and improved bedside manner to their patients. Time spent filling out medical histories and reviewing diagnostic imaging will be streamlined in order to maximise the patient-dentist interaction (5,7). As soon as patients sit in the dental chair, it will be able to record their "weight, vital signs, and anxiety" level (4). AI will also be able to adjust the room to fit patients' recorded preferences regarding the room's temperature, music, and lighting (5). Additionally, NLP and translation will allow for speech-to-text record keeping and live feedback from the AI during treatments, in order to "minimise human error"(5,7).

Patients' wearable health trackers would be able to sync up with the AI to better personalise advice based on behaviour and continuous self-monitoring (4,7).

Explainable AI is already in development to solve the issue regarding lack of processing transparency (7). This new field will allow AI to explain its interpretations (7). With this it is hoped that the field of medicine will be able to develop a better understanding of multifactorial diseases (5).

It is hoped that eventually AI will independently propose designs for implant type and placement with CBCTs ("ideal position based on tissue thickness, emergence profile, bone type/thickness") and removable partial dentures (RPD) with intraoral scans (5).

Currently researchers are looking into how AI could be used to predict and compensate for prosthetic shape distortion during 3D printing. This ability would allow clinicians to acquire an accurately fitting prosthesis in fewer visits and would diminish costs. (9)

Bioprinting is also in the works for the reconstruction by cell layers of lost soft and hard tissues (4).

For dental students, evaluation of dental preparations will be done by intraoral scanners rather than professors in order to eliminate grading subjectivity (5).

Insurance claims will be approved or denied immediately through AI evaluation of diagnostic imaging and clinical histories (5). Additionally, AI will aid clinicians in adherence to clinical guides required by insurance policies during treatment, for example informing which specific photographs are requested (4).

Office AI will even automatically develop and launch marketing campaigns based on clinic finance analyses (4).

The drawback of such a powerful force to come could be that as clinicians begin to rely more heavily on the AI, they will lose confidence in their own judgement. It will be more difficult to speak out against a super computer in order to defend what they may think is actually best for their patient (11). For now, AI is meant to augment human intelligence, rather than replace it; however, that is not guaranteed for the future (2,6).

1.5. What is the purpose of reviewing the trends in Artificial Intelligence in dentistry in Europe?

By defining the current applications and research of AI in dentistry in Europe, oral health clinicians can be updated on what possibilities are already at their disposal and what they can expect to come. Additionally, legislators can get an idea of what sort of legal structure they must prepare alongside the continents' rapidly enhancing technology.

2. OBJECTIVES

2.1. General Objective

- To define the trends in artificial intelligence in dentistry in Europe

2.2. Specific Objectives

- To reveal which European countries are most involved in the publication of research and development of artificial intelligence in dentistry
- To reveal which fields of dentistry artificial intelligence is most applied in Europe
- To reveal which domains of artificial intelligence within the field of dentistry are being most developed in Europe

3. MATERIALS AND METHODS

The following article was carried out following the PRISMA guidelines for a systematised review (12,13).

For the purpose of researching the topic, the database search resources of Universidad Europea de Madrid's CRAI Dulce Chacón library were used. Two databases were chosen: Medline Complete and Dentistry & Oral Sciences Source (DOSS). Many levels of searches were done on Wednesday the 14th, 2022 in order to record different statistics. It was decided that, for the review's search, the European countries of interest would be defined as all EU member states, Norway, Switzerland, and the United Kingdom (UK).

European countries of interest (30 total):

- EU member states (27 total)
    - Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden (14)
- Norway
- Switzerland
- United Kingdom

Inclusion criteria: relevance to artificial intelligence, relevance to dentistry, articles published in one of the European countries previously listed, articles published between 2018 and 2022, articles in English, research studies

Exclusion criteria: non-relevance to artificial intelligence, non-relevance to dentistry, articles not published in one of the European countries previously listed, articles published before 2018 or after 2022, articles without doi reference, articles without full text available, articles not in English, systematic reviews

3.1. First Search

The initial advanced search was conducted on both databases, separately. The search equation was as follows: “artificial intelligence or machine learning or deep learning” [All Fields] AND “dentistry or dentist or dental” [All Fields] AND “europe or european” [All Fields], Limiters: Full Text, Publication date 2018-2022, Languages: English.

Results from Medline: 63.

Results from DOSS: 13.

Total results: 76.

3.2. Second Search

The second advanced search was conducted solely on Medline, due to its unique ability to filter by country of publication. It was conducted 30 times, once per country of interest listed above, as written. The only exception to this procedure was for the UK, which was written as “united kingdom or uk or england or britain or scotland or northern ireland or wales”. The second search equation was as follows: “artificial intelligence or machine learning or deep learning” [All Fields] AND “dentistry or dentist or dental” [All Fields] AND “**insert each country listed individually**” [CY Country], Limiters: Publication date 2018-2022. The number of results for each country were recorded in Table 1.

This search did not exclude articles based on language or full text availability as it was done purely to document the number of publications per country of interest.

3.3. Removal of Duplicate Records

In order to identify and remove duplicate records between Medline and DOSS in search 1, the title of each of the 9 articles from the DOSS results were entered individually into the Medline database in addition to the first search formula (AND "*article title*" [All Fields]). Duplicate records: 10. Records left: 66.

3.4. Risk of Bias

When screening through the 66 articles that the database searches produced, the category of exclusion that could be considered most subjective would have to be the relation to dentistry. Since dentistry itself is so interdisciplinary and intertwined with medicine, one could argue relevance for many of the excluded articles. It was attempted that all included articles explicitly mentioned a facet of dentistry in some way. However, this methodology inevitably leads to the subjective scale and variability of dental relevance across the included studies.

The language inclusion criteria of English would have excluded publication results from countries other than Ireland and the UK had they been published in their native tongue. It can be assumed that this could lead to a slight increase in publication results for search 1 from the English speaking countries compared to the non-English speaking countries.

4. RESULTS

4.1. Article Selection Process

The results from search 1 were first screened for exclusion based on their title, keywords, country of publication, and abstracts. The number of and reasons for exclusions are included in Figure 1. Records included: 17.

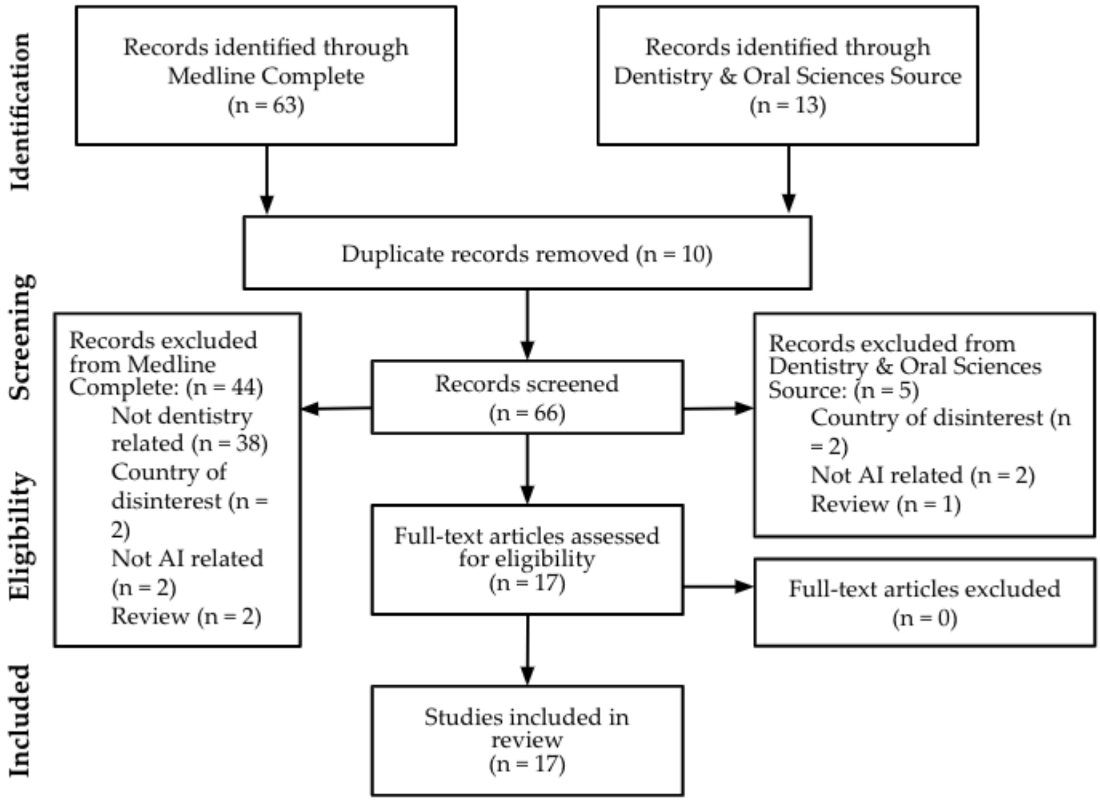

Figure 1. PRISMA Reference Flow Chart. Hybrid of the 2009 and 2020 PRISMA flowchart models (12,13).

4.2. Data Items & Collection

From the remaining 17 articles, the following variables were recorded: country of publication (as listed by the database), country affiliations of authors, article keywords, study type, publication year, and the overall dental field(s) each article was most related to. The keywords were separated into two categories–A.I. related or dentistry related.

4.3. Second Search Results

From Search 2, Table 1 summarises the number of results per European country of interest for publications related to AI in Dentistry. The following countries yielded no results (no publications) during the search: Bulgaria, Belgium, Croatia, Estonia, Finland, Hungary, Latvia, Lithuania, Luxembourg, Malta, Norway, Portugal, Republic of Cyprus, Slovakia, Slovenia, Spain, and Sweden.

Table 1. Distribution of Article Publications per European Country Related to A.I. in Dentistry on Medline Complete

Country	Number of Publications
United Kingdom	588
Switzerland	385
Germany	109
Netherlands	70
Denmark	27
Ireland	31
Italy	9
France	9
Poland	6
Greece	3
Romania	2
Austria	1
Czech Republic	1
	Total Publications = 1241

The distribution shows that the three countries with the highest number of publications were the United Kingdom, followed by Switzerland, then Germany. The remaining countries had significantly lower numbers of publications, with Romania, Austria, and the Czech Republic being amongst those with the fewest.

4.4. Included Study Characteristics

For Search 1, Table 2 summarises the countries of publication and of author affiliation per article. The distribution of each variable can be found in Tables 5-7, with the countries of author affiliation being separated by European vs. non-European.

Table 2. Article Countries

Article	Country of Publication	Countries of Author Affiliation
"Deep learning–based metal artefact reduction in PET/CT imaging" (15)	Germany	• Switzerland • The Netherlands • Denmark
"Computed Tomography Radiomics Kinetics as Early Imaging Correlates of Osteoradionecrosis in Oropharyngeal Cancer Patients" (16)	Switzerland	• United States • Italy • Australia
"Dental Erosion Evaluation with Intact-Tooth Smartphone Application" (17)	Switzerland	• Italy • United Kingdom

"Fully automatic segmentation of craniomaxillofacial CT scans for computer-assisted orthognathic surgery planning using the nnU-Net framework" (18)	Germany	• France
"Deep learning analysis using FDG-PET to predict treatment outcome in patients with oral cavity squamous cell carcinoma" (19)	Germany	• United States • Japan
"Comparison of deep learning segmentation and multigrader-annotated mandibular canals of multicenter CBCT scans" (20)	United Kingdom	• Finland • Thailand • United Kingdom
"Preliminary study on the application of deep learning system to	United Kingdom	• Japan

diagnosis of sjögren's syndrome on ct images" (21)		
"Usefulness of a deep learning system for diagnosing sjögren's syndrome using ultrasonography images" (22)	United Kingdom	• Japan
"Metagenome-genome-wide association studies reveal human genetic impact on the oral Microbiome" (23)	United Kingdom	• China
"Using artificial intelligence to determine the influence of dental aesthetics on facial attractiveness in comparison to other facial modifications" (24)	United Kingdom	• Switzerland • Germany
"Facial attractiveness of cleft patients: a direct comparison between artificial-intelligence-	United Kingdom	• Switzerland • China

based scoring and conventional rater groups" (25)		
"Machine learning assisted Cameriere method for dental age estimation" (26)	United Kingdom	• China
"The validation of orthodontic artificial intelligence systems that perform orthodontic diagnoses and treatment planning" (27)	United Kingdom	• Japan
"Nodal-based radiomics analysis for identifying cervical lymph node metastasis at levels I and II in patients with oral squamous cell carcinoma using contrast-enhanced computed tomography" (28)	Germany	• Japan
"Combining virtual reality and 3D-printed	United Kingdom	• United Kingdom

models to simulate patient-specific dental operative procedures—A study exploring student perceptions" (29)		
"Comparing a Fully Automated Cephalometric Tracing Method to a Manual Tracing Method for Orthodontic Diagnosis" (30)	Switzerland	• Greece • United States
"Development of intra-oral automated landmark recognition (ALR) for dental and occlusal outcome measurements" (31)	United Kingdom	• United Kingdom

Table 3, below, summarises AI keywords and dentistry keywords used per article. The distribution of each variable can be found in Tables 8 and 9.

Table 3. Article Keywords

Article	A.I. Related Keywords	Dentistry Related Keywords

"Deep learning–based metal artefact reduction in PET/CT imaging" (15)	• Deep learning • Artificial intelligence	• Positron emission tomography (PET) • Computed X-ray tomography • Artefacts
"Computed Tomography Radiomics Kinetics as Early Imaging Correlates of Osteoradionecrosis in Oropharyngeal Cancer Patients" (16)	• Functional principal component analysis	• Osteoradionecros is • Computed tomography (CT) • Radiomics • Radiotherapy • Head and neck cancer • Oropharyngeal cancer
"Dental Erosion Evaluation with Intact-Tooth Smartphone Application" (17)	• Machine learning	• Basic erosive wear examination index • Caries • Dental erosion • Intact-tooth
"Fully automatic segmentation of	• Deep learning • Computer-assiste	• Orthognathic surgery

craniomaxillofacial CT scans for computer-assisted orthognathic surgery planning using the nnU-Net framework" (18)	d	• Computed tomography
"Deep learning analysis using FDG-PET to predict treatment outcome in patients with oral cavity squamous cell carcinoma" (19)	• Deep learning	• Squamous cell carcinoma of head and neck • Positron emission tomography
"Comparison of deep learning segmentation and multigrader-annotated mandibular canals of multicenter CBCT scans" (20)	• Deep learning	• Mandibular canal • Cone beam computed tomography
"Preliminary study on the application of deep learning system to diagnosis of sjögren's syndrome on ct images"	• Deep learning	• Sjögren's syndrome • Computed tomography

(21)		
"Usefulness of a deep learning system for diagnosing sjögren's syndrome using ultrasonography images" (22)	• Deep learning	• Sjögren's syndrome • Ultrasonography
"Metagenome-genome-wide association studies reveal human genetic impact on the oral microbiome" (23)	• Machine learning	• Oral microbiome
"Using artificial intelligence to determine the influence of dental aesthetics on facial attractiveness in comparison to other facial modifications" (24)	• Artificial neural networks • Artificial intelligence • Convolutional neural networks	• Cosmetic dentistry • Corrective orthodontics
"Facial attractiveness of cleft patients: a direct comparison between artificial-intelligence-based scoring and conventional rater	• Artificial intelligence • Convolutional neural networks	• Oral surgery • Orthodontics • Facial aesthetics

groups" (25)		
"Machine learning assisted Cameriere method for dental age estimation" (26)	• Machine learning	• Dental age • Tooth development • Cameriere
"The validation of orthodontic artificial intelligence systems that perform orthodontic diagnoses and treatment planning" (27)	• Artificial intelligence • Support vector machines	• Orthodontic diagnosis • Corrective orthodontics
"Nodal-based radiomics analysis for identifying cervical lymph node metastasis at levels I and II in patients with oral squamous cell carcinoma using contrast-enhanced computed tomography" (28)	• Machine learning • Support vector machines	• Cervical lymph nodes • Squamous cell carcinoma • Radiomics • Metastasis
"Combining virtual reality and 3D-printed models to simulate patient-specific dental	• Virtual reality (VR)	• Dental care • Dental education • Three-dimensional printing

operative procedures—A study exploring student perceptions" (29)		• Tooth preparation
"Comparing a Fully Automated Cephalometric Tracing Method to a Manual Tracing Method for Orthodontic Diagnosis" (30)	• Artificial intelligence • Deep learning	• Cephalometrics • Digital tracing • Manual tracing
"Development of intra-oral automated landmark recognition (ALR) for dental and occlusal outcome measurements" (31)	• Artificial intelligence • Machine learning • Software development tools	• Dental arch • Cleft palate • Dental landmark recognition

Table 4, below, summarises study types, publication years, and dental fields of focus per article. The distribution of each variable can be found in Tables 10-12.

Table 4. Article Study Types, Years of Publication, and Dental Fields

Article	**Study Type**	**Publication Year**	**Dental Field**
"Deep	Experimental,	2021	Radiology

learning–based metal artefact reduction in PET/CT imaging" (15)	Retrospective		
"Computed Tomography Radiomics Kinetics as Early Imaging Correlates of Osteoradionecrosis in Oropharyngeal Cancer Patients" (16)	Case-control, Retrospective	2021	Radiology
"Dental Erosion Evaluation with Intact-Tooth Smartphone Application" (17)	Cohort, Prospective	2022	Restorative Dentistry
"Fully automatic segmentation of craniomaxillofacial CT scans for computer-assiste	Case-control, Retrospective	2022	Radiology, Oral Surgery

d orthognathic surgery planning using the nnU-Net framework" (18)			
"Deep learning analysis using FDG-PET to predict treatment outcome in patients with oral cavity squamous cell carcinoma" (19)	Case-control, Retrospective	2020	Radiology, Oral Pathology
"Comparison of deep learning segmentation and multigrader-anno tated mandibular canals of multicenter CBCT scans" (20)	Experimental, Retrospective	2022	Radiology, Oral Surgery, Implantology
"Preliminary	Experimental	2019	Radiology, Oral Pathology

study on the application of deep learning system to diagnosis of sjögren's syndrome on ct images” (21)			
“Usefulness of a deep learning system for diagnosing sjögren’s syndrome using ultrasonography images” (22)	Experimental	2020	Radiology, Oral Pathology
“Metagenome-genome-wide association studies reveal human genetic impact on the oral microbiome” (23)	Cohort, Prospective	2021	Oral Microbiology
“Using artificial intelligence to	Experimental	2022	Aesthetic dentistry

determine the influence of dental aesthetics on facial attractiveness in comparison to other facial modifications" (24)			
"Facial attractiveness of cleft patients: a direct comparison between artificial-intellige nce- based scoring and conventional rater groups" (25)	Experimental	2019	Aesthetic dentistry
"Machine learning assisted Cameriere method for dental age estimation" (26)	Experimental, Retrospective	2021	Forensic Dentistry / Dental Anthropology

“The validation of orthodontic artificial intelligence systems that perform orthodontic diagnoses and treatment planning” (27)	Experimental	2022	Orthodontics
“Nodal-based radiomics analysis for identifying cervical lymph node metastasis at levels I and II in patients with oral squamous cell carcinoma using contrast-enhanced computed tomography” (28)	Experimental, Retrospective	2021	Radiology, Oral Pathology
“Combining virtual reality and 3D-printed	Experimental	2020	Education, Prosthodontics

models to simulate patient-specific dental operative procedures—A study exploring student perceptions” (29)			
“Comparing a Fully Automated Cephalometric Tracing Method to a Manual Tracing Method for Orthodontic Diagnosis” (30)	Experimental	2022	Orthodontics
“Development of intra-oral automated landmark recognition (ALR) for dental and occlusal outcome measurements” (31)	Experimental	2021	Orthodontics, Oral Surgery, Forensic Dentistry / Dental Anthropology

Table 5, below, summarises the number of publications per European country.

Table 5. European Countries of Publication

Country (3 total)	**Number of Articles**
United Kingdom	10
Germany	4
Switzerland	3

Amongst the included studies, the United Kingdom published the most articles.

Table 6, below, summarises the number of times a European country was referenced as being affiliated with the articles' authors.

Table 6. European Countries of Author Affiliation

Country (9 total)	**Number of Articles**
United Kingdom	4
Switzerland	3
Italy	2
Denmark, Finland, France, Germany, Greece, The Netherlands	1 each

Amongst the included studies, the United Kingdom was the European country with the most author affiliations.

Table 7, below, summarises the number of times a Non-European country was referenced as being affiliated with the articles' authors.

Table 7. Non-European Countries of Author Affiliation

Country (5 total)	Number of Articles
Japan	4
China	3
United States	3
Australia	1
Thailand	1

Amongst the included studies, Japan was the non-European country with the most author affiliations.

Table 8, below, summarises the number of times each AI term was utilised as an official keyword by all articles.

Table 8. AI Keywords

Keyword (10 total)	Number of Articles
Deep learning	7
Artificial intelligence	6
Machine learning	5
Convolutional neural networks	2
Support vector machines	2
Artificial neural networks, Computer-assisted, Functional principal component analysis,	1 each

Software development tools, Virtual reality	

Amongst the included studies, ‘deep learning’ was the most utilised AI keyword.

Table 9, below, summarises the number of times each dentistry term was utilised as an official keyword by all articles.

Table 9. Dentistry Keywords

Keyword (38 total)	**Number of Articles**
Computed tomography	5
Orthodontics	3
Positron emission tomography, Radiomics, Sjögren’s syndrome, Squamous cell carcinoma	2 each
Artefacts, Basic erosive wear examination index, Cameriere, Caries, Cephalometrics, Cervical lymph nodes, Cleft palate, Cosmetic dentistry, Dental age, Dental arch, Dental care, Dental education, Dental erosion, Dental landmark recognition, Digital tracing, Facial aesthetics, Head and neck cancer, Intact-tooth, Mandibular canal,	1 each

Manual tracing, Metastasis, Oral microbiome, Oral surgery, Oropharyngeal cancer, Orthodontic diagnosis, Orthognathic surgery, Osteoradionecrosis, Radiotherapy, Three-dimensional printing, Tooth development, Tooth preparation, Ultrasonography

Amongst the included studies, 'computed tomography' was the most utilised dentistry keyword.

Table 10, below, summarises the number of articles which implemented each type of study.

Table 10. Article Study Types

Study Types (3 total)	Number of Articles
Experimental	12
Case-Control	3
Cohort	2

Amongst the included articles, study types were mostly experimental in nature.

Table 11, below, summarises the number of articles published per year.

Table 11. Article Publication Years

Year (4 total)	Number of Articles
2019	2
2020	3
2021	6
2022	6

Amongst the included studies, publications related to artificial intelligence in dentistry have tripled since 2019.

Table 12, below, summarises the number of times a dental field was the focus of an article. Some articles had multiple fields of focus.

Table 12. Dental Fields of Focus

Dental Field (10 total)	Number of Articles
Radiology	10
Oral Pathology	4
Oral Surgery	3
Orthodontics	3
Aesthetic Dentistry	2
Forensics / Anthropology	2
Education, Oral microbiology, Prosthodontics, Implantology	1 each

Amongst the included studies, the dental field of most focus was Radiology.

5. DISCUSSION

5.1. Interpretation of Results

Regarding countries of publication viewed in both search 1 and 2, results were fairly congruent, with the UK, Germany, and Switzerland dominating as the top three producers across both searches. The subsequent most producing countries for search 2 and European countries of author affiliation were most frequently Northern European countries. As mentioned when discussing this review's risks of bias, this correlation is likely related to the amount of English language proficiency in those countries. Even though search 2 did not filter out articles by language, there is still a massive language bias due to English being the current universal language of science.

For the many countries that yielded no results, further research would be needed in order to pin-point why that was. It would also be interesting to investigate other correlations to publication output per country such as national economics, GDP per capita, investments into research and education, healthcare models and perceptions.

Within the 5 year span of included articles, publications increased in number, though 2021 and 2022 were equal. One could hypothesise that the European COVID-19 lockdown had an influential role in these outputs. It is possible that a couple of the articles that were set to be published in 2020 got delayed, and thus were published in 2021 instead. Had the pandemic not occurred, we might have seen values even more consistent with increased output per year, rather than the illusion of a small plateau. In order to test this theory, publication output within other fields during the same 5 years could be analysed for any growth discrepancies due to COVID-19.

As for the findings regarding which study types were observed, through reading the articles included, it was noted that the experimental studies occurred when the purpose of the study was to test the AI itself, whereas most of the other cohort or case-control studies were solely using already functional AI to study something else.

Within the 17 articles, most dental fields featured representation. However, the amount of representation was disproportionate, and notable absences included fields such as endodontics and paediatric dentistry. Nonetheless, technological advances in other fields will still impact those not directly mentioned. Radiology for one, the most highly represented field throughout the review, is indispensable to all dental specialties. Thus, leaps in object identification and analysis from PET, CBCT scans, USI, or conventional X-Rays—exemplified in the articles through automated osteoradionecrosis risk predictions, Sjögren's syndrome diagnostics, noninvasive lymph node metastasis detection, oral squamous cell carcinoma treatment prognostics, dental age estimation, "automated cephalometric tracing", orthognathic surgical planification, or image correction due to metallic interference—highly benefit all dental fields (15,16,18,19,20,21,22,27,28,30). Radiology is also the most convenient dental field in which to experiment with and train AI, as it can be conducted in-vitro with existing files and would, consequently, have much less ethical red tape to get through prior to commencing a study.

5.2. Limitations

Despite the fact that all of the included articles were technically registered by the databases as having been published from within the listed European countries of interest, so many have authors without European affiliation and even 7 articles were completely written by authors without any European affiliation. This makes it difficult to acknowledge the content as a European [trend] at all, if the information seems solely imported. Another review evaluating global trends would be necessary in order to compare Europe's contributions to that of the rest of the world, but one could fear that it may be at risk of falling behind its competitors.

The other limitation of this review was that it heavily relied on database informatics to reliably filter in or out articles based on the search equations. As was evident from the record screening process, many articles still did not meet the inclusion criteria. Potentially, other articles, which would have otherwise met the inclusion criteria, were inaccurately excluded by the database filtration system, and, thus, excluded from this review. These conditions led to a rather small sample size of included articles, affecting how representative one would consider the gathered data to be.

5.3. Implications

A future where AI can be incorporated into every dental clinic is bright. Solely from the included studies there are many valuable examples of AI in dentistry's potential. Firstly, Fujima's 2020 study introduced a new opportunity for individualising treatments and predicting the chance of "disease-free survival" for oral cancer patients through the application of DL to biomarkers on PET scans (19). In Liu's 2021 study, ML was used to distinguish which oral pathologies were correlated more with the oral microbiome and which were more correlated with genetics—this discovery also aids in individualising treatment approaches for different oral pathologies (23).

Patients can even take the AI home with them. In Butera's 2019 study, an app was used to track dental erosion and give patients management techniques. This exemplified the value of such apps for the continuous virtual follow-up of patients while allowing the AI behind them to learn from the data being shared. Future applications could focus more broadly on oral health to improve patient compliance whilst providing larger data samples for AI learning. (17)

In terms of supporting clinicians, Kise's 2019 and 2020 studies demonstrated how AI could outperform inexperienced professionals when evaluating CBCT scans and USI (21,22). Woodsend's 2022 study also demonstrated AI's application to digital models through successful "automated landmark recognition" (31). The aid provided by the AI systems would save valuable time for clinicians during patient evaluations and would help "lower variability" between experts (20). Consequently, AI should be viewed as a useful "diagnostic support" for dentists, though not a replacement (21,22).

Even dental students were shown to benefit from the use of AI in Tower's 2021 study, where VR simulations were used to improve operator confidence, as it allowed students to practise dental preparations of real patient cases (29).

However, there is still much room for growth. As Järnstedt's 2022 study pointed out, studies must work with more heterogeneous datasets while training DL systems in order to further improve their accuracy (20). Järnstedt's study illustrated how such training could be done, by introducing images from different types of scanners and of different ethnicities when analysing an AI's ability to perform mandibular canal segmentation from a CBCT scan (20). AI's attempts to evaluate facial attractiveness also occasionally fell short in Patcas's 2019 and Obwegeser's 2022 studies as it can be difficult for AI to predict the effect and compete with subjective human perception when rarer features are introduced (24, 25). Lastly, when evaluating the ability of AI to diagnose orthodontic patients and develop treatment plans, Shimizu's 2022 study proved the AI currently incapable (27). It can be said that, for the moment, AI could be used to improve the patient experience and dental professional efficiency without risk of replacing the dentist.

6. CONCLUSIONS

Regarding the research of AI in dentistry within Europe, this review of articles from the last 5 years has allowed for the identification of various trends. Research tends to be mostly experimental in nature and the number of publications each year has been increasing. The UK, Switzerland, and Germany were the top contributors to research in this field, however, many non-European countries can also claim credit through their contributing researchers. Of AI developments in dental radiology, developments most commonly focused on computed tomography.

Specific objective findings:

- Of European countries, the United Kingdom published the most articles related to AI in dentistry.
- Within the fields of dentistry, publications related to AI in dentistry mostly focused on radiology.
- Deep learning was the most common domain of AI within publications related to dentistry.

7. REFERENCES

1. Lidströmer N, Aresu F, Ashrafian H. Basic Concepts of Artificial Intelligence: Primed for Clinicians. In: Lidströmer N, Ashrafian H, editors. Artificial Intelligence in Medicine [Internet]. Cham: Springer International Publishing; 2022 [cited 2022 Nov 14]. p. 3–20. doi: 10.1007/978-3-030-64573-1_1.
2. Ergen M. What is Artificial Intelligence? Technical Considerations and Future Perception. Anatol J Cardiol. 2019 Oct 1;22(Suppl 2):5-5–7. doi: 10.14744/AnatolJCardiol.2019.79091.
3. Ahmed N, Abbasi MS, Zuberi F, Qamar W, Halim MSB, Maqsood A, et al. Artificial Intelligence Techniques: Analysis, Application, and Outcome in Dentistry-A Systematic Review. BioMed Res Int. 2021 Jun 22;2021:9751564–9751564. doi: 10.1155/2021/9751564.
4. Mitra R, Tarnach G. Artificial intelligence - A boon for dentistry. Int Dent J Stud Res. 2022 Apr 1;10(2):37-37–42. doi: 10.18231/j.idjsr.2022.009.
5. Yo-wei Chen, Stanley K, Att W. Artificial intelligence in dentistry: current

applications and future perspectives. Quintessence Int. 2020 Mar 1;51(3):248-248–57. doi: 10.3290/j.qi.a43952.

6. Rodrigues JA, Krois J, Schwendicke F. Demystifying artificial intelligence and deep learning in dentistry. Braz Oral Res. 2021 Jan 1;35:1-1–7. doi: 10.1590/1807-3107bor-2021.vol35.0094.
7. Schwendicke F, Samek W, Krois J. Artificial Intelligence in Dentistry: Chances and Challenges. J Dent Res. 2020 Jul 1;99(7):769-769–74. doi: 10.1177/0022034520915714.
8. Shan T, Tay FR, Gu L. Application of Artificial Intelligence in Dentistry. J Dent Res. 2021 Mar 1;100(3):232-232–44. doi: 10.1177/0022034520969115.
9. Pethani F. Promises and perils of artificial intelligence in dentistry. Aust Dent J. 2021 Jun 1;66(2):124-124–35. doi: 10.1111/adj.12812.
10. do Nascimento Gerhardt M, Shujaat S, Jacobs R. AIM in Dentistry. In: Lidströmer N, Ashrafian H, editors. Artificial Intelligence in Medicine [Internet]. Cham: Springer International Publishing; 2022 [cited 2022 Nov 14]. p. 905–18. doi: 10.1007/978-3-030-64573-1_319.
11. Lehmann LS. Ethical Challenges of Integrating AI into Healthcare. In: Lidströmer N, Ashrafian H, editors. Artificial Intelligence in Medicine [Internet]. Cham: Springer International Publishing; 2022 [cited 2022 Nov 14]. p. 139–44. doi: 10.1007/978-3-030-64573-1_337.
12. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul 21;6(7):e1000097–e1000097. doi: 10.1371/journal.pmed.1000097.
13. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. PLoS Med. 2021 Mar 29;18(3):e1003583–e1003583. doi: 10.1371/journal.pmed.1003583.
14. Country profiles [Internet]. [cited 2022 Nov 12]. Available from: https://european-union.europa.eu/principles-countries-history/country-profil

es_en

15. Arabi H, Zaidi H. Deep learning-based metal artefact reduction in PET/CT imaging. Eur Radiol. 2021 Aug 1;31(8):6384-6384–96. doi: 10.1007/s00330-021-07709-z.

16. Barua S, Elhalawani H, Volpe S, Al Feghali KA, Yang P, Ng SP, et al. Computed Tomography Radiomics Kinetics as Early Imaging Correlates of Osteoradionecrosis in Oropharyngeal Cancer Patients. Front Artif Intell. 2021 Apr 9;4:618469–618469. doi: 10.1007/s00330-021-07709-z.

17. Butera A, Maiorani C, Gallo S, Pascadopoli M, Buono S, Scribante A. Dental Erosion Evaluation with Intact-Tooth Smartphone Application: Preliminary Clinical Results from September 2019 to March 2022. Sensors [Internet]. 2022 Jul 8 [cited 2022 Dec 15];22(14). doi: 10.3390/s22145133.

18. Dot G, Schouman T, Dubois G, Rouch P, Gajny L. Fully automatic segmentation of craniomaxillofacial CT scans for computer-assisted orthognathic surgery planning using the nnU-Net framework. Eur Radiol. 2022 Jun 1;32(6):3639-3639–48. doi: 10.1007/s00330-021-08455-y.

19. Fujima N, Andreu-Arasa VC, Meibom SK, Mercier GA, Salama AR, Truong MT, et al. Deep learning analysis using FDG-PET to predict treatment outcome in patients with oral cavity squamous cell carcinoma. Eur Radiol. 2020 Nov 1;30(11):6322-6322–30. doi: 10.1007/s00330-020-06982-8.

20. Järnstedt J, Sahlsten J, Jaskari J, Kaski K, Mehtonen H, Lin Z, et al. Comparison of deep learning segmentation and multigrader-annotated mandibular canals of multicenter CBCT scans. Sci Rep. 2022 Nov 3;12(1):18598–18598. doi: 10.1038/s41598-022-20605-w.

21. Kise Y, Ikeda H, Fujii T, Fukuda M, Ariji Y, Fujita H, et al. Preliminary study on the application of deep learning system to diagnosis of Sjögren's syndrome on CT images. Dentomaxillofacial Radiol. 2019 Sep 1;48(6):N.PAG. doi: 10.1259/dmfr.20190019.

22. Kise Y, Shimizu M, Ikeda H, Fujii T, Kuwada C, Nishiyama M, et al.

Usefulness of a deep learning system for diagnosing Sjögren's syndrome using ultrasonography images. Dentomaxillofacial Radiol. 2020 Mar 1;49(3):N.PAG. doi: 10.1259/dmfr.20190348.

23. Liu X, Tong X, Zhu J, Tian L, Jie Z, Zou Y, et al. Metagenome-genome-wide association studies reveal human genetic impact on the oral microbiome. Cell Discov. 2021 Dec 7;7(1):117–117. doi: 10.1038/s41421-021-00356-0.
24. Obwegeser D, Timofte R, Mayer C, Eliades T, Bornstein MM, Schätzle MA, et al. Using artificial intelligence to determine the influence of dental aesthetics on facial attractiveness in comparison to other facial modifications. Eur J Orthod. 2022 Aug 1;44(4):445-445–51. doi: 10.1093/ejo/cjac016.
25. Patcas R, Timofte R, Volokitin A, Agustsson E, Eliades T, Eichenberger M, et al. Facial attractiveness of cleft patients: a direct comparison between artificial-intelligence-based scoring and conventional rater groups. Eur J Orthod. 2019 Aug 1;41(4):428-428–33. doi: 10.1093/ejo/cjz007.
26. Shen S, Liu Z, Wang J, Fan L, Ji F, Tao J. Machine learning assisted Cameriere method for dental age estimation. BMC Oral Health. 2021 Dec 15;21(1):1-1–10. doi: 10.1186/s12903-021-01996-0.
27. Shimizu Y, Tanikawa C, Kajiwara T, Nagahara H, Yamashiro T. The validation of orthodontic artificial intelligence systems that perform orthodontic diagnoses and treatment planning. Eur J Orthod. 2022 Aug 1;44(4):436-436–44. doi: 10.1093/ejo/cjab083.
28. Tomita H, Yamashiro T, Heianna J, Nakasone T, Kimura Y, Mimura H, et al. Nodal-based radiomics analysis for identifying cervical lymph node metastasis at levels I and II in patients with oral squamous cell carcinoma using contrast-enhanced computed tomography. Eur Radiol. 2021 Oct 1;31(10):7440-7440–9. doi: 10.1007/s00330-021-07758-4.
29. Towers A, Dixon J, Field J, Martin R, Martin N. Combining virtual reality and 3D-printed models to simulate patient-specific dental operative procedures—A study exploring student perceptions. Eur J Dent Educ. 2022

May 1;26(2):393-393–403. doi: 10.1111/eje.12715.

30. Tsolakis IA, Tsolakis AI, Elshebiny T, Matthaios S, Palomo JM. Comparing a Fully Automated Cephalometric Tracing Method to a Manual Tracing Method for Orthodontic Diagnosis. J Clin Med [Internet]. 2022 Nov 20 [cited 2022 Dec 14];11(22). doi: 10.3390/jcm11226854.
31. Woodsend B, Koufoudaki E, Lin P, McIntyre G, El-Angbawi A, Aziz A, et al. Development of intra-oral automated landmark recognition (ALR) for dental and occlusal outcome measurements. Eur J Orthod. 2022 Jan 1;44(1):43-43–50. doi: 10.1093/ejo/cjab012.

8. ANNEXES

Annex 1. Index of Abbreviations

AI/A.I.	artificial intelligence
ANN	artificial neural networks
BRONJ	bisphosphonate-related osteonecrosis of the jaw
BW	bitewing
CAD/CAM	computer aided design and manufacturing
CBCT	cone beam computed tomography
CNN	convolutional neural networks
CR	composite resin
DL	deep learning
DOSS	dentistry & oral sciences source
EU	european union
GDPR	general data protection regulation
IA	la inteligencia artificial
ML	machine learning
NLP	natural language processing
OPG	orthopantomography
PA	periapical

PET	positron emission tomography
RPD	removable partial denture
Rx	radiograph
TMJ	temporomandibular joint
Tx	treatment
UK	united kingdom
US	united states
USI	ultrasound images
VR	virtual reality
VRF	vertical root fracture

Annex 2. Index of Figures & Tables

Annex 3. First Page of Reference Articles