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Article

Exploring the Practical Applications of Artificial Intelligence, Deep Learning, and Machine Learning in Maxillofacial Surgery: A Comprehensive Analysis of Published Works

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Abstract: Artificial intelligence (AI), deep learning (DL) or machine learning (ML) is the ability of computer systems, machines and enginery to work devise procedures like humans. These technologies provide opportunities and possibilities to advance diagnostics and in planning also in the field of human medicine and dentistry. The purpose of this literature review was to ascertain the applicability and significance of AI, as well as to highlight its uses in maxillofacial surgery. The primary inclusion criterion for this publication was an original paper written in English focusing on the use of AI, DL or ML in maxillofacial surgery. The sources of information were PubMed, Scopus and Web of Science, and the queries were made on 31st of December 2023. The search strings used were "artificial intelligence maxillofacial surgery", "machine learning maxillofacial surgery" and "deep learning maxillofacial surgery". Following the removal of duplicates, all remaining publications that were returned by the searches and were screened by three independent operators to minimize the risk of bias. The analysis of publications from 1992 to 2023 identified certain records, of which 324 were finally selected. These were calculated according to the year of publication with a continuous increase (excluding 2012 and 2013) of $R^2 = 0.9295$. Generally, in orthognathic dentistry and maxillofacial surgery, artificial intelligence and machine learning have gained popularity over the past few decades. When we included the keywords "planning in maxillofacial surgery" and "planning in orthognathic surgery", the set of published papers significantly increased to the number of 7535 publications. The first publication appeared in 1965, with an increasing trend (excluding 2014-2018), with an R^2 value of 0.8642. These tools have been found useful for diagnosis, treatment planning in head and neck surgical oncology, cosmetic and aesthetic surgery, and in oral pathology. In orthognathic surgery, they have been utilised for diagnosis, treatment planning, assessment of treatment needs, cephalometric analyses, and orthognathic surgeries, among other applications. The review confirms that the current use of artificial intelligence and machine learning in maxillofacial surgery is focused mainly on the evaluation of digital diagnostic methods especially radiology, treatment plans and postoperative results. However, as these technologies are integrated in maxillofacial surgery and robotic surgery in head and neck region, it is expected that in the future they will be gradually utilized to plan and comprehensively evaluate the success of maxillofacial surgeries.

Keywords: artificial intelligence; deep learning; machine learning; maxillofacial surgery; evidence-based practice

1. Introduction

Everyday surgical practice requires the maxillofacial surgeon to make often immediate and complex decisions in given surgical situations, while not jeopardizing the success of the surgical

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procedure or the health of the patients [1]. Such medical education, training, critical, quick, and rational thinking, as well as the logical progression of a surgical procedure, facilitate an algorithmic way of thinking. Every planned clinical and paraclinical procedure is often analysed and taken into account, which subsequently allows solving all unexpected and rare critical surgical situations [2]. The high workload of the surgeon often does not allow the systematic use of this approach, as it is very time-consuming and represents a significant mental burden on the surgeon himself/herself. The decision-making process itself can be strongly influenced by personal experiences, fatigue, mental state or personality characteristics of the surgeon . Increased mental stress can subsequently lead to inaccuracies and even errors in all stages of patient treatment - diagnosis, therapeutic decision, surgical procedure and follow-up [3]. Thanks to advancements and refinements of computing systems and algorithms, the exponential production and recording of health data, and the creation of large usable data sets, artificial intelligence (AI), deep learning (DL) and machine learning (ML) are rapidly evolving in and within the healthcare sector. All the mentioned technologies could represent a real support for medical reasoning, pontentially limiting cognitive biases and thus also medical errors, especially in the diagnosis and planning of surgical treatment [4]. Current and future methods and techniques provided by AI hold high potential to improve a surgeon's practice in all phases of surgical patient management including screening, diagnosis, therapeutic decision-making, surgical approach, surgery itself, follow-up, etc. Currently, there is an increasing number of algorithms that surpass human mental abilities and already play crucial roles in specific medical fields. For example in gynaecology in the detection of breast cancer in mammograms or in the forensic medicine and antropology (forensic pathology or forensic science). During the application of medical knowledge and expertise to legal matters, particularly in the investigation of crimes, determining the cause and manner of death, and in the criminal justice system, objective scientific evidence is provided to support legal proceedings [5–7]

The use of AI, DL or ML in maxillofacial surgery is a relatively recent development. While AI, DL and ML has been commonly used in other medical fields for several decades, its application in maxillofacial surgery or dentistry has only recently begun[8,9]. History of the first use AI, DL or ML in maxillofacial applications defined as computerized synthetic human cognitive function, was published and applied in 1987 by Richter and al. Richter and the team published and applied a model to determine the optimal diagnostic approach for chronic cholecystitis comprehensive management strategies. Computer model was used to measure the frequency of appropriate surgery, inappropriate surgery, complications, death, and medical costs [10]. The first direct application of AI in maxillofacial surgery was subsequently described and used by Stoker and al. in 1992. During this time, the first stereolithographic model was constructed and made using AI with application of computer graphics. Technology was employed using standardized cephalometric analyses in one case. The stereolithographic models constructed from digital image data (computed tomography and magnetic resonance) allowed the surgeon to view the external and internal anatomy prior to surgery [11]. The first common use of AI in maxillofacial surgery was the development of a computer-aided surgical simulation system for orthodontics and orthognathic surgery in the early 2000s [12]. This system allowed surgeons to create a virtual surgical treatment plan and simulate the outcome of the surgery preoperatively, which in turn helped improve the accuracy and outcome of the surgery. Since then, AI, DL and ML have been used for various tasks in dentoalveolar and maxillofacial surgery, including surgical anatomy, diagnosis, treatment planning, and intraoperative navigation itself. AI has been used to develop algorithms for the automatic detection and segmentation of anatomical structures in medical images, such as preoperative CT and MRI scans, which can aid in the diagnosis and planning of surgical treatment of maxillofacial conditions [13]. The rapid development of artificial intelligence is being used in the development of modern surgical navigation systems and procedures that can help surgeons in real time during surgery to refine and speed up surgical performance.

These computerized systems use not only preoperative images (CT, MRI) and intraoperative data, but also 3D analysis of the soft and hard parts of the orofacial system to provide the surgeon with real-time feedback on the position and orientation of surgical instruments, as well as the location

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of critical anatomical structures. Possibly aesthetic and functional predictability of surgical performance can be also provided [14]. As AI technology continues to evolve, it is likely to play an increasingly important role in modern maxillofacial surgery in the future.

To fully exploit the potential of AI in maxillofacial surgery, it is very important for maxillofacial surgeons to understand the technical elements of AI and its possible applications in the head and neck region. The aim of this publication is to summarize all the current possibilities of use and application of AI in diagnostics, surgical anatomy, preoperative planning, navigation and operative procedures in maxillofacial surgery. Medical education and training forward the development of critical, rational, and logical thought processes contributing to an algorithmic approach to reasoning. By carefully analyzing and considering every clinical and paraclinical aspect, healthcare professionals can effectively manage even the most unforeseen and rare situations.[15] Various ways AI is being used in maxillofacial surgery to improve patient outcomes and surgical efficiency such as diagnosis and treatment, surgical navigation, predictive analytics, virtual AI powered peri-surgical assistance, prosthesis and epithesis design, manufacturing, visualisation and prediction of after surgery results for patient's better understanding of the procedure.

Diagnosis and treatment

The application of artificial intelligence (AI) and machine learning (ML) in maxillofacial surgery has the potential to revolutionize diagnosis and treatment planning. Advanced technologies can amplify accuracy, enhance patient outcomes, and boost also streamline clinical workflows.[16] AI algorithms can be assistants in the diagnostic process by analyzing large volumes of data, such as x-rays or different images and patient records, identify patterns and relations that may be difficult for human clinicians to detect[17]. Machine learning algorithms can be likely taught to identify irregularities in radiographic images, resulting in improved diagnostic accuracy, more precise treatment strategies and to be untilized daily at clinical practice.[18] In the article authored by Zhang et al., five uses of machine learning methods in radiological images were examined: image segmentation, computer-assisted detection and diagnosis, functional brain research and neurological disease identification, image classification and retrieval, and image registration. Machine learning methods are engaged in computer-assisted systems to support radiologists in daily diagnostic tasks, research and practice, the application of these techniques in radiology continues to develop.[18] Within the world of maxillofacial surgery, AI might be able to aid in discovering specific anatomical features, furthermore improve preoperative preparation and minimize the likelihood of surgical complications. In oral surgery and dentistry AI models have shown significant promise in recognizing implant types, predicting the success of implants, and optimizing implant designs. [19] The unintentional excessive use of "decision shortcuts", made possible by the inquisitive approach, gives rise to cognitive biases, which represent a way of thinking that systematically and predictably leads to errors in judgment under particular circumstances.[20] AI and ML as diagnosing tool might be already part of daily practice but responsibility to choose correct information and make the final right decision should remain with medical practitioner.

Surgical navigation

Utilizing artificial intelligence for surgical navigation constitutes one potential direction for the implementation of an AI in surgical fields, including oral and maxillofacial surgery.

Novel concepts of surgical navigation systems are emerging on the market incorporating use of AI technology to varying extents. The principle of surgical navigation using stereotaxic system was developed at the beginning of 20th century and published in 1908 by Horsley and Clarke[21]. Surgical navigation systems have gone through development, improvements, different versions based on different concepts have been created. The availability of patient specific data and its use became attainable after introduction and clinical use of Ct and MRI in 1980s[22]. Throughout the years surgical navigation systems were developing and clinicians in different fields such as oncology, traumatology, neurosurgery and other were performing surgical procedures with big help of navigation. Specifically in maxillofacial surgery, use of surgical navigation can be traced back to 1994

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when removal of skull base tumor was performed with its help. Since then surgical navigation has become essential tool for surgical procedures such as trauma or oncological and reconstructive cases.[23–26]

Theoretical overview exploring surgical navigation, presenting concepts throughout the history and its use in clinical setting has been published by Novelli et al affirming that surgical navigation is an effective instrument to use for improvement in oral surgery.[27]

Computing speed advancements, exponential increase in data load, and the regular routine data collection have expedited the rapid progress of AI in clinical healthcare industry. One of the newer surgical navigation systems developed is system utilizing augmented reality and artificial intelligence (ARAI). ARAI system is comprised of a display mechanism suspended over the surgical field projecting 3D medical images specific to patient's anatomy. The results of cadaveric research in spinal surgery indicated that surgical navigation system precisely identified starting points, and the overlay of the virtual anatomy was accurately aligned with the actual anatomy. System using AI and augmented reality could increase effectiveness of minimally invasive surgery, increasing also speed of the procedure.[28]

Different study suggests the use of surface registration based on automated machine learning (ML) enhances the precision of the image-guided surgical navigation system. The system involves utilizing a neural network model to generate a new point-cloud that corresponds with facial data collected by a passive probe of an optical tracking system is extracted from facial information obtained through computerized tomography. Such approach allows to acquire accurate registration and alignment of the date, facilitatin improved and faster diagnosis, treatment planning and surgical outcomes in various medical fields including maxillofacial surgery.

The cutting-edge surface registration concept involves utilizing a neural network model to generate a new point-cloud that corresponds with facial data collected by a passive probe of an optical tracking system (OTS). This new point-cloud is extracted from the facial information obtained through computerized tomography. Such innovative approach allows for more accurate registration and alignment of the patient's facial data, facilitating improved diagnosis, treatment planning, and surgical outcomes in various medical fields.[29] Maxillofacial surgery is undoubtedly surgical field that would and will benefit from use of AI, ML and augmented reality in different types of surgical procedures such as trauma, oncological surgery, reconstructive or orthognathic surgery.

Predictive analytics

Machine learning and use of predictive analytics using AI involves learning algorithms to analyze patient's data offer possibility for predictive insights, recommendations, different points of view and help in diagnostics, surgical and therapeutical decision-making. Algorithms should be able collect, combine and analyze patient's historical data, general data and real-time patient's informations and data to identify patterns to guide surgeon for most effective actions. AI is becoming omnipresent component within modern technologies in different fields, whether medical, technical or educational. Detecting radiographic alterations is one of the notable applications of AI and has become useful tool in predicting results in dental implant cases with peri-implantitis complications. [30] Among the many, another potential applications of radiographic studies analysis is the field of head and neck oncology. Early prediction, diagnosis and prognostic prediction for malignant lesions can be implemented together with surgical tools in the field of robotics, as guided resection enhancing safety and reducing possibility of human error.[31]

Actual use of neural networks in maxillofacial surgery is discussed in study written by Nayans Jha et al. The study is summarizing current literature on the application of AI technologies diagnosing various subtypes of TMJ disorders, analysing also quality of the studies, evaluating the diagnostic precision of current AI models.

Study findings suggest that Ai algorithms designed for automated TMD diagnosis can serve as a decision support tool in conjunction with medical diagnostic imagining techniques, input data types, and other features. The study included case-control studies, pointing out at high risk of bias in patient selection. Small datasets and lack of external validation have been found in most of the

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studies. Further research, larger datasets and greater accuracy can ensure efficacy of developed models.[32]

Current clinical use of AI has been described in article written by Alicia Dean et al. about computer-assisted and navigated piezoelectric surgery (CANPS). CANPS is surgical technique combining piezoelectric device with surgical navigation working synergistically. It integrates benefits of piezo surgery and navigation providing continuous monitoring of the piezoelectric device tip. Combination of at-the-time monitoring of the device with monitoring and navigation allows surgeon to proceed without necessity of the direct observation.[33]

Not only in oncology, radiology, TMD analysis but also in aesthetic surgery AI might have big potential. By helping the surgeon with proper diagnosis, analysis of soft and hard tissues and big data collection about surgical possibilities, AI might be able to predict surgical result, helping surgeon with pre and perioperative surgical decisions. To reach great outcomes, AI with integrated human surgical intuition could be the right tool.[34–36]

AI and machine learning have potential and ability to process large data volumes to achieve precise work. The speed, accuracy and effectivity of analysing followed by results, it all brings big advantage comparing to human efficiency. Hypothetically even minor changes in radiographic or any other test results can be identified and AI might be able to detect pathologies earlier than human.

However application of AI and ML in predictive analytics arises numerous ethical issues.

In the field of aesthetical medical care, the use of AI to classify attractiveness and beauty can raise ethical issues. Potential discrimination based on gender and ethnicity could lead to spread of racial division and reduce diversity in aesthetical cosmetic surgical procedures.[37]

To improve diversity and enhance applicability, gathering datasets from wide range of sources including various ethnicities, gender, ages is required. Currently, lack of representation of black patients and providers in blepharoplasty or rhinoplasty procedures, can impact accuracy of algorithms.[38] Measurements acquired from AI provide only numerical expressions of opinions and subjective evaluations of publishing healthcare providers. AI's definition is therefore subject to cultural and personal influences.[39]

In the future where AI's predictive analysis can be fully used and trusted in every day's clinical practice the complexity of data collections of whole population, different ethnicities, surgical procedures must reach wide, complex and organized data volume. Then predictive analysis of AI and ML can assist in decision making and as useful tool.

Powered virtual assistance

Virtual assistance which has commonly been used in daily life is voice-activated virtual assistant, such as Alexa, google Assistant, Siri and others. User friendly AI virtual assistants, efficient, used in smart phones, laptops, cars or smart home systems are already available in the market and efficiently implemented.

Use of virtual assistant based on AI has been studied and discussed in the article written by Jyoti Mago at al. The study evaluated usefulness of four-voice based virtual assistance in oral and maxillofacial radiology report writing. The findings of this small study indicate while AI assistants were helpful in providing response to questions, there is still significant room for growth in terms of topics and information delivered.[40] Another potential way of use of AI assistance is to enhance patient management and organizational workflow. During COVID-19 pandemic, chatbots could provide automatic triage for acute cases and support management and referral assistance. Implementation of virtual assistant (VA) providing guidelines, instruction and navigation is in healthcare organisations such as WebMD[41], Mayo clinic's first aid[42] and different others. As telehealth services and need for their use increases, AI-based virtual assistants can extend capability of medical professional's workforce by ensuring safety for both side, patients and medical staff. Conversational chatbots have not only potential to be standard tool in system helping during pandemic but furthermore could serve as reinforce to routine daily clinical work.[43]

Prosthetic design and manufacturing

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Digital technologies are being increasingly standardized and integrated into routine daily treatment protocols.[44,45] In prosthodontic field, clinical laboratories have already been incorporated in daily digital technologies practice by computer-aided design/computer-aided manufacturing (CAD/CAM).[45,46] The systematic review of articles about use and performance of AI in prosthodontics have been published by Yu-Dong Zhang. Conclusion of the review on relatively low number of studies with an honest overview of the reality and latest development. The review findings suggest that incorporating an AI in prosthodontics is conceivable for clinicians. However, implementation and practicality will depend also on economic feasibility and demand.[47] In oncological and severe facial trauma surgical cases, even after local or microvascular flap reconstruction, patients need prosthetic rehabilitation to improve psychological and social comfort. Maxillofacial prosthetic rehabilitation is restorative procedure restoring function and aesthetics. The associated aesthetic and psychological issues make high-quality prosthetic restoration necessary part of the process of the whole treatment.[48] Prior to CAD/CAM technology, skilled hand-carving of a wax cast was necessary for prosthetic facial reconstruction. Advances in computer development have made digitalisation of the process and digital design possible.[49,50] Collaboration between medical professional, skilled computer engineer and AI program is still and should stay essential in the process. However, there are not only benefits but also potential liability risk of diagnostic and creative part of the job becoming too reliant on an AI system.[51]

Orthognathic surgery, analysis and prediction

Facial, dentofacial and skeletal anomalies and irregularities have negative impact on an individual's well-being. Orofacial appearance becomes crucial aspect contributing to an individual's social well-being and oral health-related life quality.[52] Facial appearance is affected by skeletal structural framework. Facial anomaly can be therefore reflection of the skeletal irregularities that might require treatment to resolve problem with dental occlusion. In many instances, it's often not possible to resolve problem with orthodontic treatment only but together with orthognathic surgery.[53] For successful orthognathic surgery, precise preoperative planning is essential. Currently, 3D planning is golden standard comprising of CT scan, 3D facial photography, intraoral scanning, 3D analysis. In the past and still at the present, some clinics use only 2D preoperative analysis and dental impressions for casts, and then manual models for surgery preparation. Big discrepancies, missed details, missing detailed 3D analysis of soft tissues and hard tissues or airways[54]. 3D virtual surgical planning gives surgeon more detailed surgical plan resulting in complex plan and improvement in quality and effectivity of surgery and results.[53,55] ML as subset of an AI is applied frequently to improve diagnostic computer support. The process involves integrating algorithms into machines, allowing to learn from data, make predictions, help to solve problems without need for human input.[56] Use of ML and an AI for analysis, assessment, surgical prediction and proposal of therapeutic strategy might improve effectiveness of the treatment of skeletal anomalies and orthognathic surgery. But affecting appearance of the human requires conversation between doctor and a patient, doctor has to listen to patient's expectations and use not only purely scientific approach but also artistic eye and empathy creating new aesthetical and functional face. There are skeletal anomalies where use of AI, virtual planning, creation and approach can bring big impact and benefit the patient.

The article „Pierre Robin Sequence and 3D Printed Personalized Composite Appliances in Interdisciplinary Approach presents approach in the treatment of an congenital condition called Pierre Robin Sequence.

The condition affects development of the lower jaw, tongue, airway and therefore is affecting breathing, feeding and speech. Standard treatment involves surgery, in more severe cases tracheostomy, use of external devices and mandibular distraction. All of the mentioned is associated with significant morbidity and might not always provide optimal results. The use of virtual analysis and creation together with 3D printing technology tailoring customized personalized appliances brings cost-effective, time-effective, non-invasive way of treatment.[57] AI, ML, virtual world can bring advancements for craniomaxillofacial surgery adult and pediatric patients if used correctly.

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Maxillofacial robotic surgery

In the future, the combination of AI, ML and DL and robotic surgery has the potential to bring about significant progress in both the didactic and technical execution of surgical procedures in the maxillofacial region. The integration of AI with robotics can enhance surgical precision, improve outcomes, and revolutionize the field of maxillofacial surgery. [58]

Robotic surgery, also known as robot-assisted surgery, involves the use of robotic systems to assist surgeons during surgical procedures. These innovative systems typically consist of robotic arms equipped with surgical instruments and a control console from which the surgeon operates. The surgeon's movements are translated into precise movements of the robotic arms, allowing for enhanced dexterity, stability, and manoeuvrability during also in head and neck surgery. [59,60]

According to a study conducted by Yanice H. Yang et al., currently, AI technology is not yet capable of surpassing human surgeons in terms of performance. However, the study also reveals that AI algorithms, based on computer vision, are able to generate results that align with the assessments of expert surgeons in terms of technical proficiency. This suggests that there is potential for AI to contribute to the enhancement of surgical skills by providing a standardized approach for evaluating surgical techniques .[61]

Despite the promising potential, the integration and combination of AI, DL and ML and robotics in maxillofacial surgery holds great promise, and opens up new possibilities for advanced surgical techniques and decision-making processes, it is important to recognize that there are still challenges to overcome, other than skillset. These include ensuring data privacy and security, addressing ethical concerns, validating AI algorithms for surgical safety and efficacy, and providing comprehensive training for surgeons to effectively utilize AI and robotic systems.[58]

In conclusion, the union of AI and robotic surgery holds significant potential to bring progress to the field of maxillofacial surgery. By leveraging AI to assist in surgical planning, navigation, instrument guidance, decision support, and training, surgeons can enhance their technical capabilities and improve patient outcomes. Continued research and development in this area will pave the way for a future where AI-powered robotic surgery becomes a viable alternative in maxillofacial procedures.

2. Materials and Methods

2.1. The Framework, the Protocol and Research Questions

This paper presents a literature review registered in PubMed, Scopus and Web of Science. The main inclusion criterium of this publication was an original paper in English focused:

"Artficial inteligence in maxillofacial surgery", "Deep learning in maxillofacial surgery", "Machine learning in maxillofacial surgery", "planning in maxillofacial surgery" and "planning in orthognathic surgery". Subsequently, basic questions were determined, to which we this paper aims to answer. The reviewed questions are simple and clearly defined. This literature review answers the defined research questions by gathering and summarizing all empirical evidence that meets pre-specified eligibility criteria for the use of AI, DL and ML in maxillofacial surgery and intended for the practitioners of the maxillofacial community who prefer evidence-based practice (EBP).

Research questions:

1. What is the quantity of publications per year focused on maxillofacial AI, DL and ML utilization? Is it increasing? Identify the annual publication count. (1992–2023)

2. What is the focus of publications within the field of maxillofacial surgery and what proportion of the focus is devoted to specific specialized maxillofacial topics in the latest publications on AI, DL, ML and planning in maxillofacial surgery from the first publication?

3. If we include planning and computation in maxillofacial surgery as part of AI, DL and ML, how many articles have been published, and when was the first article published?

This paper performs two kinds of analysis:

1. Quantitative assessment of maxillofacial AI, DL and ML publications in the past three decades.

2. Possibilities of using AI, DL and ML within the field of maxillofacial surgery in contemporary literature from 1992 to the present.

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3. Number of publications used in maxillofacial planning and computed planning in online databases per year from 1965.

2.2. Evaluating the Past Publications

To compare the prevalence of the presence of information on artificial intelligence and its use in maxillofacial surgery, we conducted search in medical databases Pubmed, Scopus and Web of Science. The search was focused on publication title, abstract and keywords. The search combination included "artificial intelligence maxillofacial surgery " or "deep learning maxillofacial surgery" or "machine learning maxillofacial surgery".

Subsequently, we searched for terms that referred to planning in maxillofacial surgery itself. Our primary focus was on the occurrence of planning itself in the combination of title, abstract, and keyword keywords "planning maxillofacial surgery" and "planning orthognathic surgery". Secondarily, we specified and searched for "computed planning maxillofacial surgery" and "computed planning orthognathic surgery". The results were compared.

3. Results

For AI, DL, and ML, 324 publications were identified since 1992, with a continuous increase (excluding 2012 and 2013) of R2 = 0.9295 (Figure 1). The publications most often related to the use in diagnosis, treatment planning, radiological assessment, surgical navigation, predictive analysis, virtual assistance, prosthetic analysis and manufacturing technologies. However, a new chapter in human medicine and surgery is opened by the possibility of using AI together with robotic surgery in the future. The possibility of an autonomous treatment algorithm over which the surgeon would only perform a control role or supervision.

Pearson's correlation analysis reveal the strong positive correlation between year and number of articles for AI, DL, ML r=0,622, n=21, p=0,003.

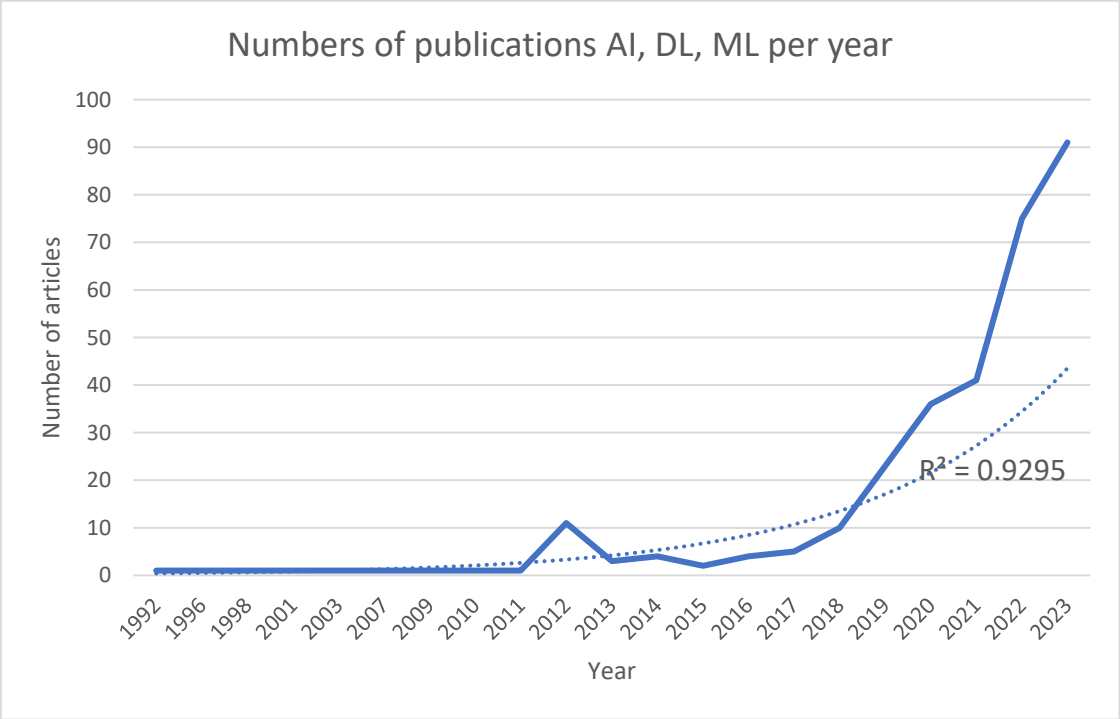

Figure 1. Numbers of publication per year with the phrases artificial intelligence, deep learning and machine learning in maxillofacial surgery.

A separate part of the use of AI is in planning in orthognathic surgery and in computed planning, where the dominant use of AI, DL and ML was found in the publications also in maxillofacial surgery. For planning in maxillofacial surgery and planning in orthognathic surgery, the total number of

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publications was 7535, with the first publication in 1965, also with an increasing trend (excluding 2014-2018), R2 = 0.8642 (Figure 2).

Pearson's correlation analysis also reveal the very strong positive correlation between year and number of articles for computed planning articles r=0,879, n=50, p<0,001 and strong positive correlation between year and planning in total r=0,785, n=59, p<0,001.

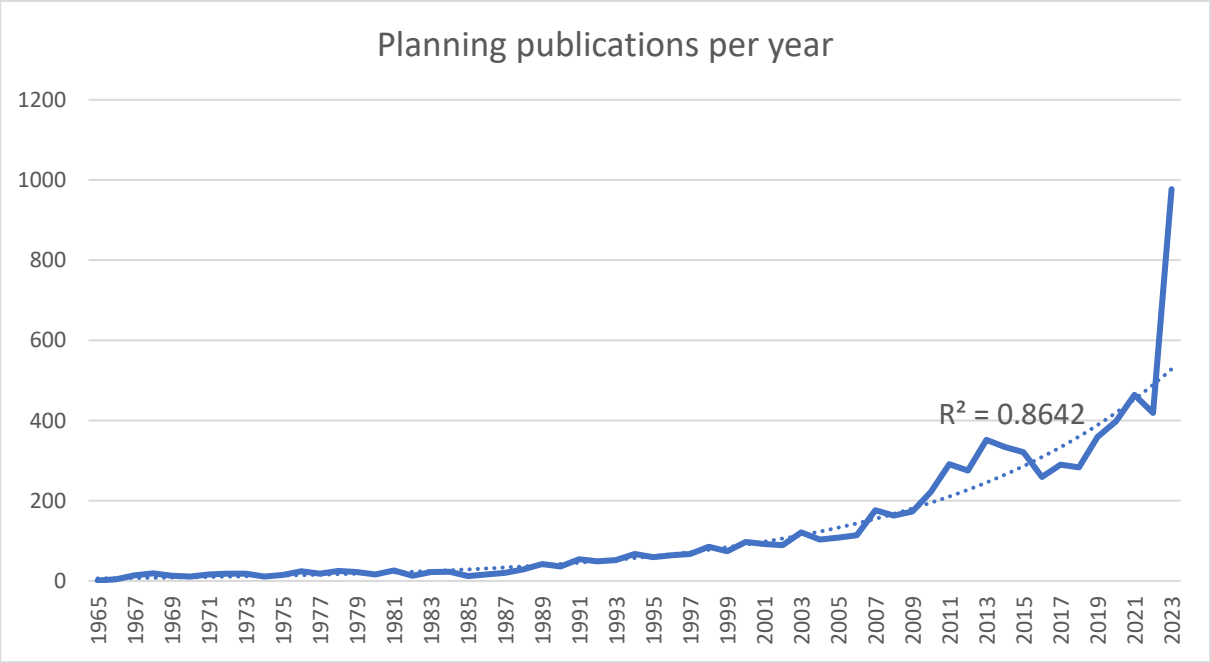

Figure 2. Numbers of planning publication in maxillofacial surgery per year.

For "computed planning maxillofacial " and "computed planning orthognathic", the first publication in 1972 was present with a total number of 3122. Also with an increasing trend, R2=0.9362 (Figure 3).

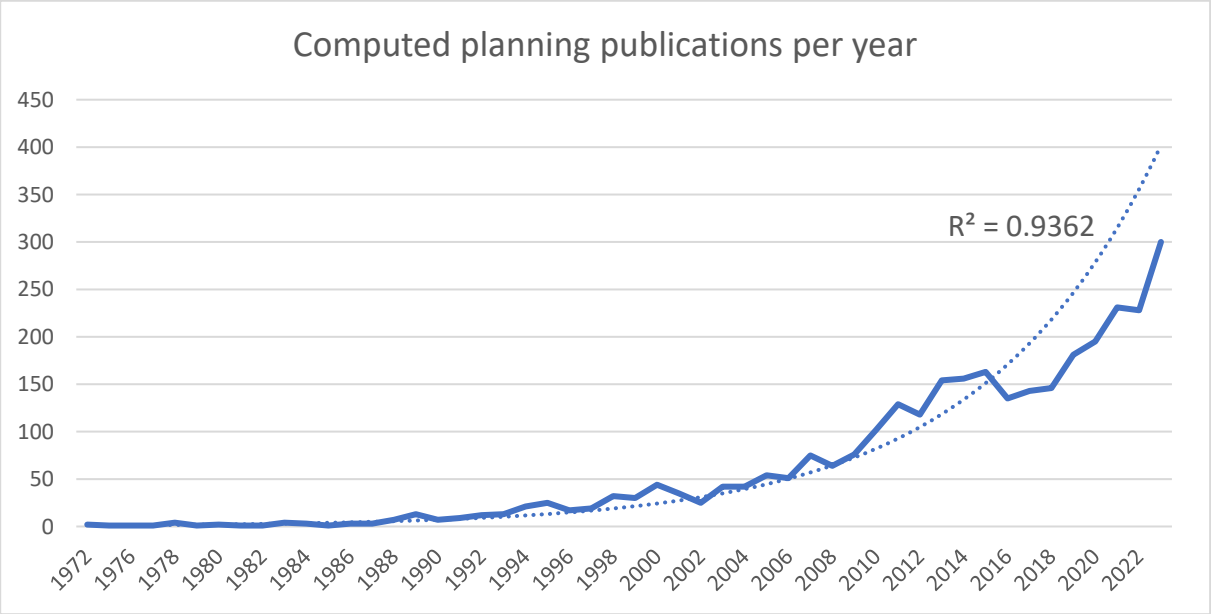

Figure 3. Numbers of computed planning publication in maxillofacial surgery per year.

Finally, we compared the number of publications with key words " planning orthognathic and planning maxillofacial" and "computed planning maxillofacial ". A significant difference was found

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in orthognathic planning, where, according to current literature, AI, DL and ML has the most dominant use.

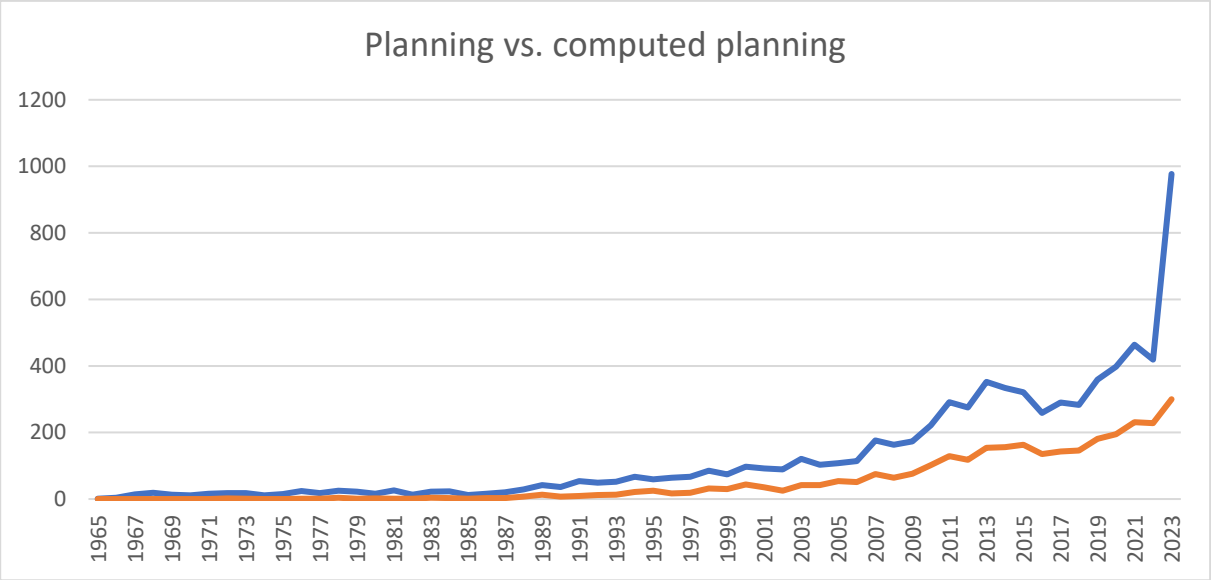

Figure 4. Comparison of the numbers of computed planning publication in maxillofacial surgery per year.

4. Conclusions

In conclusion, the application of artificial intelligence (AI), deep learning (DL) and machine learning (ML) in maxillofacial surgery holds tremendous promise for transforming various aspects of the field of surgery. The utilization of AI algorithms, DL and ML techniques can revolutionize diagnosis and treatment planning by leveraging the power of data analysis and pattern recognition. These technologies can enhance the diagnostic process, aiding clinicians in identifying subtle patterns and trends that may be challenging for humans to detect.

Moreover, AI-powered surgical navigation systems offer improved precision and speed during procedures, while predictive analytics provide valuable insights and recommendations to support decision-making. Virtual assistants, driven by AI, can improve patient management and streamline organizational workflows, leading to more efficient and effective care delivery. Additionally, AI can play a significant role in prosthetic design and manufacturing, leveraging digital technologies and CAD/CAM systems to optimize outcomes.

In the context of orthognathic surgery and maxillofacial planning, AI, DL, and ML techniques can improve preoperative computerized planning and improve treatment efficiency. By analyzing patient-specific data, these technologies can help develop personalized treatment plans and optimize surgical outcomes. A review of the literature confirmed that this area of application is therefore already significantly dominant in maxillofacial surgery. In contrast, the least utilized area of artificial intelligence in maxillofacial surgery is the application of robotic surgery. The validation of the potential for autonomous surgery, along with its benefits and the potential risks associated with decision-making during surgical procedures, remains uncertain.

Furthermore, the integration of AI and robotics in maxillofacial surgery holds great potential to further enhance surgical precision and overall outcomes. By combining AI's analytical capabilities with robotic assistance, surgeons can benefit from improved accuracy and efficiency during procedures.

However, it is crucial to address several important challenges associated with the use of AI in maxillofacial surgery. Ethical considerations, including patient privacy and data security, must be carefully managed to ensure the responsible and ethical use of AI technologies. Algorithm validation and rigorous testing protocols are essential to establish the reliability and safety of AI systems in

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clinical practice. Additionally, comprehensive training and education for surgeons and medical professionals are necessary to effectively and safely incorporate AI into their workflows.

In conclusion, AI has the potential to significantly advance the field of maxillofacial surgery by improving diagnostics, treatment planning, surgical precision, and patient outcomes. However, it is crucial to harness these technologies responsibly, in collaboration with medical practitioners, to ensure the integration of AI aligns with established ethical standards and complements the expertise of healthcare professionals.

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References

1. Karamanoukian RL, Ku JK, and Lee GK, "Surgical Decision Making," *Semin Plast Surg.* , vol. 27, no. 3, pp. 131–135, 2013.
2. P. Croskerry, "The Importance of Cognitive Errors in Diagnosis and Strategies to Minimize Them," *Academic Medicine*, vol. 78, no. 8, pp. 775–780, Aug. 2003, doi: 10.1097/00001888-200308000-00003.
3. G. Norman, "Research in clinical reasoning: past history and current trends," *Med Educ*, vol. 39, no. 4, pp. 418–427, Apr. 2005, doi: 10.1111/j.1365-2929.2005.02127.x.
4. Almeida AP, Albuquerque R, Pereira T, and Pinho AC, "Artificial intelligence and maxillofacial surgery: narrative review and future perspectives," *Int J Oral Maxillofac Surg.*, vol. 50, no. 6, pp. 736–742, 2021.
5. A. Thurzo *et al.*, "Use of Advanced Artificial Intelligence in Forensic Medicine, Forensic Anthropology and Clinical Anatomy," *Healthcare*, vol. 9, no. 11, p. 1545, Nov. 2021, doi: 10.3390/healthcare9111545.
6. A.-I. Piraianu *et al.*, "Enhancing the Evidence with Algorithms: How Artificial Intelligence Is Transforming Forensic Medicine," *Diagnostics*, vol. 13, no. 18, p. 2992, Sep. 2023, doi: 10.3390/diagnostics13182992.
7. N. Galante, R. Cotroneo, D. Furci, G. Lodetti, and M. B. Casali, "Applications of artificial intelligence in forensic sciences: Current potential benefits, limitations and perspectives," *Int J Legal Med*, vol. 137, no. 2, pp. 445–458, Mar. 2023, doi: 10.1007/s00414-022-02928-5.
8. A. Thurzo, M. Strunga, R. Urban, J. Surovková, and K. I. Afrashtehfar, "Impact of Artificial Intelligence on Dental Education: A Review and Guide for Curriculum Update," *Educ Sci (Basel)*, vol. 13, no. 2, p. 150, Jan. 2023, doi: 10.3390/educsci13020150.
9. A. Thurzo *et al.*, "Where Is the Artificial Intelligence Applied in Dentistry? Systematic Review and Literature Analysis," *Healthcare*, vol. 10, no. 7, p. 1269, Jul. 2022, doi: 10.3390/healthcare10071269.
10. J. M. Richter, M. R. Christensen, J. F. Simeone, D. A. Hall, and M. D. Silverstein, "Chronic cholecystitis. An analysis of diagnostic strategies.," *Invest Radiol*, vol. 22, no. 2, pp. 111–7, Feb. 1987.
11. N. G. Stoker, N. J. Mankovich, and D. Valentino, "Stereolithographic models for surgical planning: preliminary report.," *J Oral Maxillofac Surg*, vol. 50, no. 5, pp. 466–71, May 1992, doi: 10.1016/s0278-2391(10)80317-9.
12. L. Verner, "Computer-aided simulation in orthognathic surgery," *Journal of Cranio-Maxillofacial Surgery*, pp. 65–69, 2003.
13. S. Ghafoor, M. Lee, H. J. Park, B. Kim, and K. Lee, "Artificial Intelligence in Maxillofacial Imaging: Current Applications and Future Directions," *J Clin Med*, vol. 7, no. 9, pp. 240–241, 2018.
14. P. Kuo and C. Chen, "Integration of augmented reality and image-guided techniques to improve the safety and accuracy of maxillofacial surgery," *J Dent Sci*, vol. 12, no. 3, pp. 223–227, 2017.
15. K. H. Keskinbora, "Medical ethics considerations on artificial intelligence," *Journal of Clinical Neuroscience*, vol. 64, pp. 277–282, Jun. 2019, doi: 10.1016/j.jocn.2019.03.001.
16. T. Joda, M. M. Bornstein, R. E. Jung, M. Ferrari, T. Waltimo, and N. U. Zitzmann, "Recent Trends and Future Direction of Dental Research in the Digital Era," *Int J Environ Res Public Health*, vol. 17, no. 6, p. 1987, Mar. 2020, doi: 10.3390/ijerph17061987.
17. F. Schwendicke, W. Samek, and J. Krois, "Artificial Intelligence in Dentistry: Chances and Challenges," *J Dent Res*, vol. 99, no. 7, pp. 769–774, Jul. 2020, doi: 10.1177/0022034520915714.

 doi:10.20944/preprints202404.1758.v1

18. Z. Zhang and E. Sejdić, "Radiological images and machine learning: trends, perspectives, and prospects", doi: 10.1016/j.compbiomed.2019.02.017.
19. M. Revilla-León *et al.*, "Artificial intelligence applications in implant dentistry: A systematic review," *J Prosthet Dent*, vol. 129, no. 2, pp. 293–300, Feb. 2023, doi: 10.1016/j.prosdent.2021.05.008.
20. K. Y. Ngiam and I. W. Khor, "Big data and machine learning algorithms for health-care delivery," *Lancet Oncol*, vol. 20, no. 5, pp. e262–e273, May 2019, doi: 10.1016/S1470-2045(19)30149-4.
21. Victor Horsley and R.H. Clarke, "THE STRUCTURE AND FUNCTIONS OF THE CEREBELLUM EXAMINED BY A NEW METHOD." [Online]. Available: https://academic.oup.com/brain/article/31/1/45/460098
22. L. Leksell and B. Jernberg, "Stereotaxis and tomography a technical note," *Acta Neurochir (Wien)*, vol. 52, no. 1–2, pp. 1–7, Mar. 1980, doi: 10.1007/BF01400939.
23. G. Novelli, G. Tonellini, F. Mazzoleni, A. Bozzetti, and D. Sozzi, "Virtual surgery simulation in orbital wall reconstruction: Integration of surgical navigation and stereolithographic models," *Journal of Cranio-Maxillofacial Surgery*, vol. 42, no. 8, pp. 2025–2034, Dec. 2014, doi: 10.1016/j.jcms.2014.09.009.
24. I. Azarmehr, K. Stokbro, R. B. Bell, and T. Thygesen, "Surgical Navigation: A Systematic Review of Indications, Treatments, and Outcomes in Oral and Maxillofacial Surgery," *Journal of Oral and Maxillofacial Surgery*, vol. 75, no. 9, pp. 1987–2005, Sep. 2017, doi: 10.1016/j.joms.2017.01.004.
25. D. Sozzi, A. Filippi, G. Canzi, E. De Ponti, A. Bozzetti, and G. Novelli, "Clinical Medicine Surgical Navigation in Mandibular Reconstruction: Accuracy Evaluation of an Innovative Protocol," *J. Clin. Med*, 2022, doi: 10.3390/jcm.
26. A. Dean, S. Heredero-Jung, J. Solivera, A. Sanjuan, | Francisco, and J. Alamillos-Granados, "Computer-assisted and navigated piezoelectric surgery: A new technology to improve precision and surgical safety in craniomaxillofacial surgery," 2022, doi: 10.1002/lio2.786.
27. G. Novelli *et al.*, "Introduction to Surgical Navigation in Oral Surgery: A Case-Series," 2023, doi: 10.3390/oral3020013.
28. K. B. Siemionow, K. M. Katchko, P. Lewicki, and C. J. Luciano, "Augmented reality and artificial intelligence-assisted surgical navigation: Technique and cadaveric feasibility study," 2020, doi: 10.4103/jcvjs.JCVJS_48_20.
29. H. Yoo and T. Sim, "Automated machine learning (AutoML)-based surface registration methodology for image-guided surgical navigation system," *Med Phys*, vol. 49, no. 7, pp. 4845–4860, Jul. 2022, doi: 10.1002/mp.15696.
30. C.-W. Wang *et al.*, "Machine learning-assisted immune profiling stratifies peri-implantitis patients with unique microbial colonization and clinical outcomes," *Theranostics*, vol. 11, no. 14, pp. 6703–6716, 2021, doi: 10.7150/thno.57775.
31. M. Fernando and M. Guerra, "Artificial intelligence in maxillofacial surgery. Future or present?", doi: 10.20986/recom.2022.1372/2022.
32. N. Jha, K.-S. Lee, and Y.-J. K. Id, "Diagnosis of temporomandibular disorders using artificial intelligence technologies: A systematic review and meta-analysis," 2022, doi: 10.1371/journal.pone.0272715.
33. A. Dean, S. Heredero-Jung, J. Solivera, A. Sanjuan, | Francisco, and J. Alamillos-Granados, "Computer-assisted and navigated piezoelectric surgery: A new technology to improve precision and surgical safety in craniomaxillofacial surgery," 2022, doi: 10.1002/lio2.786.
34. T. Jarvis, D. Thornburg, A. M. Rebecca, and C. M. Teven, "Artificial Intelligence in Plastic Surgery," *Plast Reconstr Surg Glob Open*, vol. 8, no. 10, p. e3200, Oct. 2020, doi: 10.1097/GOX.0000000000003200.
35. Y. M. Bichu, I. Hansa, A. Y. Bichu, P. Premjani, C. Flores-Mir, and N. R. Vaid, "Applications of artificial intelligence and machine learning in orthodontics: a scoping review", doi: 10.1186/s40510-021-00361-9.
36. H. Chinski, R. Lerch, D. Tournour, L. Chinski, and D. Caruso, "An Artificial Intelligence Tool for Image Simulation in Rhinoplasty," *Facial Plastic Surgery*, vol. 38, no. 02, pp. 201–206, Apr. 2022, doi: 10.1055/s-0041-1729911.
37. D. C. Murphy and D. B. Saleh, "Artificial Intelligence in plastic surgery: What is it? Where are we now? What is on the horizon?," *Ann R Coll Surg Engl*, vol. 102, no. 8, pp. 577–580, Aug. 2020, doi: 10.1308/RCSANN.2020.0158.
38. P. J. Ullrich *et al.*, "The Racial Representation of Cosmetic Surgery Patients and Physicians on Social Media," *Aesthet Surg J*, vol. 42, no. 8, pp. 956–963, Aug. 2022, doi: 10.1093/asj/sjac099.
39. R. Patcas, D. A. J. Bernini, A. Volokitin, E. Agustsson, R. Rothe, and R. Timofte, "Applying artificial intelligence to assess the impact of orthognathic treatment on facial attractiveness and estimated age," *Int J Oral Maxillofac Surg*, vol. 48, no. 1, pp. 77–83, Jan. 2019, doi: 10.1016/j.ijom.2018.07.010.
40. J. Mago, K. S. Muttanahally, R. Vyas, and A. Tadinada, "Usefulness of Artificial Intelligence-based Virtual Assistants in Oral and Maxillofacial Radiology Report Writing," *World Journal of Dentistry*, vol. 12, no. 2, pp. 97–102, Apr. 2021, doi: 10.5005/jp-journals-10015-1807.
41. "WebMD. Amazon. [2021-03-21]. https://www.amazon.com/gp/product/B01MRM361G.".

 doi:10.20944/preprints202404.1758.v1

42. "Mayo Clinic First Aid. Amazon. [2021-03-21]. https://www.amazon.com/mayo-clinic-first-aid/dp/b0744ljcv2.".
43. T. Jadczyk, W. Wojakowski, M. Tendera, T. D. Henry, G. Egnaczyk, and S. Shreenivas, "Artificial Intelligence Can Improve Patient Management at the Time of a Pandemic: The Role of Voice Technology," *J Med Internet Res*, vol. 23, no. 5, p. e22959, May 2021, doi: 10.2196/22959.
44. S. A. Bernauer, J. Müller, N. U. Zitzmann, and T. Joda, "Influence of Preparation Design, Marginal Gingiva Location, and Tooth Morphology on the Accuracy of Digital Impressions for Full-Crown Restorations: An In Vitro Investigation," *J Clin Med*, vol. 9, no. 12, p. 3984, Dec. 2020, doi: 10.3390/jcm9123984.
45. T. Miyazaki and Y. Hotta, "CAD/CAM systems available for the fabrication of crown and bridge restorations," *Aust Dent J*, vol. 56, pp. 97–106, Jun. 2011, doi: 10.1111/j.1834-7819.2010.01300.x.
46. B. Saravi *et al.*, "Clinical Performance of CAD/CAM All-Ceramic Tooth-Supported Fixed Dental Prostheses: A Systematic Review and Meta-Analysis," *Materials*, vol. 14, no. 10, p. 2672, May 2021, doi: 10.3390/ma14102672.
47. S. A. Bernauer, N. U. Zitzmann, and T. Joda, "The Use and Performance of Artificial Intelligence inProsthodontics: A Systematic Review," 2021, doi: 10.3390/s21196628.
48. N. Ariani *et al.*, "Current State of Craniofacial Prosthetic Rehabilitation," *Int J Prosthodont*, vol. 26, no. 1, pp. 57–67, Jan. 2013, doi: 10.11607/ijp.3220.
49. L. Ciocca, R. Mingucci, G. Gassino, and R. Scotti, "CAD/CAM ear model and virtual construction of the mold," *J Prosthet Dent*, vol. 98, no. 5, pp. 339–343, Nov. 2007, doi: 10.1016/S0022-3913(07)60116-4.
50. I. Susic, M. Travar, and M. Susic, "The application of CAD / CAM technology in Dentistry," *IOP Conf Ser Mater Sci Eng*, vol. 200, p. 012020, May 2017, doi: 10.1088/1757-899X/200/1/012020.
51. C.-W. W. Y.-C. C. Mel Mupparapu, "Artificial intelligence, machine learning, neural networks, and deep learning: Futuristic concepts for new dental diagnosis".
52. P. Larsson, L. Bondemark, and B. Häggman-Henrikson, "The impact of oro-facial appearance on oral health-related quality of life: A systematic review," *J Oral Rehabil*, vol. 48, no. 3, pp. 271–281, Mar. 2021, doi: 10.1111/joor.12965.
53. E. C. Olivetti *et al.*, "3D Soft-Tissue Prediction Methodologies for Orthognathic Surgery—A Literature Review," *Applied Sciences*, vol. 9, no. 21, p. 4550, Oct. 2019, doi: 10.3390/app9214550.
54. A. Thurzo, V. Kurilová, and I. Varga, "Artificial Intelligence in Orthodontic Smart Application for Treatment Coaching and Its Impact on Clinical Performance of Patients Monitored with AI-TeleHealth System," *Healthcare*, vol. 9, no. 12, p. 1695, Dec. 2021, doi: 10.3390/healthcare9121695.
55. T.-Y. Wu, H.-H. Lin, L.-J. Lo, and C.-T. Ho, "Postoperative outcomes of two- and three-dimensional planning in orthognathic surgery: A comparative study," *Journal of Plastic, Reconstructive & Aesthetic Surgery*, vol. 70, no. 8, pp. 1101–1111, Aug. 2017, doi: 10.1016/j.bjps.2017.04.012.
56. Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *Nature*, vol. 521, no. 7553, pp. 436–444, May 2015, doi: 10.1038/nature14539.
57. A. Thurzo, B. Šufliarsky, W. Urbanová, M. Cverha, M. Strunga, and I. Varga, "Pierre Robin Sequence and 3D Printed Personalized Composite Appliances in Interdisciplinary Approach," 2022, doi: 10.3390/polym14183858.
58. H.-H. Liu, L.-J. Li, B. Shi, C.-W. Xu, and E. Luo, "Robotic surgical systems in maxillofacial surgery: a review," *Int J Oral Sci*, vol. 9, no. 2, pp. 63–73, Jun. 2017, doi: 10.1038/ijos.2017.24.
59. E. Loh and T. Nguyen, "Artificial intelligence for medical robotics," in *Endorobotics*, Elsevier, 2022, pp. 23–30. doi: 10.1016/B978-0-12-821750-4.00002-5.
60. J. Shah, A. Vyas, and D. Vyas, "The History of Robotics in Surgical Specialties," *Am J Robot Surg*, vol. 1, no. 1, pp. 12–20, Jun. 2014, doi: 10.1166/ajrs.2014.1006.
61. J. H. Yang *et al.*, "Using AI and computer vision to analyze technical proficiency in robotic surgery," *Surg Endosc*, vol. 37, no. 4, pp. 3010–3017, Apr. 2023, doi: 10.1007/s00464-022-09781-y.