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Artificial Intelligence for Oral and Maxillo-Facial Surgery

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ABSTRACT:
Artificial Intelligence (AI) refers to computer systems designed to mimic human reasoning and thinking, learn from acquired knowledge, and make decisions. Machine learning, a branch of AI, leverages mathematical models to allow computers to learn and adapt without explicit programming. This approach employs both structured and semi-structured data to train models, enabling them to produce accurate results or predictions. As these systems accumulate experience, their performance continues to enhance over time.
In the realm of healthcare, the integration of AI holds significant promise for oral and maxillofacial surgery (OMFS). This medical specialty focuses on surgical procedures involving the mouth, jaws, face, and related structures. The use of AI in OMFS presents exciting opportunities for enhanced surgical planning, precision, and patient outcomes. This review article examines various AI applications within OMFS, highlighting how this evolving technology could revolutionize surgical techniques and patient care. By exploring recent developments, challenges, and future directions, we aim to offer a thorough overview of the current advancements in AI within this specialized healthcare field.

I. INTRODUCTION

Artificial Intelligence (AI), a burgeoning branch of computer science, is making significant strides in healthcare. First introduced at Dartmouth University in 1956(6), AI refers to "the theory and development of computer systems capable of performing tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and language translation". Key areas within AI include machine learning (ML), deep learning (DL), artificial neural networks (ANNs), and Robotics.(1)
In recent decades, AI has become increasingly prominent in healthcare, revolutionizing various aspects of the field. This surge in AI's application is largely due to advancements in computing power, a dramatic rise in data generation, and the routine collection of data. (1)

Oral and maxillofacial surgery (OMFS), a specialized branch of medicine focused on surgical procedures involving the mouth, jaws, face, and related structures, stands to gain immensely from AI integration. The field of OMFS is on the brink of a transformative era, driven by rapid AI advancements. AI holds considerable promise for improving diagnostic precision, optimizing surgical planning, enhancing patient outcomes, and minimizing complications. As AI technologies like machine learning and deep learning advance, they are increasingly applied to OMFS, including in areas such as image analysis, predictive modeling, and robotic-assisted surgery. Additionally, AI is being utilized for tasks like diagnosis, cephalometrics, preoperative planning, intraoperative measurements, outcome evaluation, and postoperative follow-up. This article examines the current landscape of AI in OMFS, highlighting its applications, advantages, limitations, and future prospects in this dynamic and rapidly evolving field.(3)

CLINICAL APPLICATION OF AI IN THE FIELD OF OMFS

1.Preoperative analysis of impacted teeth

AI-based models can assist in preoperative analysis of impacted teeth by predicting the likelihood of tooth eruption-related risks, thereby aiding in determining the need for surgical extraction.(4) These networks accurately predict molar segmentation maps and orientation lines, which can be integrated into standard image viewing software for quick and easy prediction of third molar eruption during adolescence. By complementing dental practitioners with precise AI tools, routine care can be optimized, leading to synergistic and ever-increasing diagnostic accuracy. Additionally, some studies have validated new AI-driven tools for fast, accurate, and consistent automated measurement of molar angulations on dental panoramic radiographs, helping to assess the surgical difficulty of planned procedures.(5)

2.Dental implant planning

Moufti et al. compared the segmentation of a tooth-bounded mandibular edentulous area performed by an AI model and a human investigator, finding that the AI model demonstrated acceptable accuracy.(9) This represents the first stage of implant planning. Automation of bone-level assessment using CBCT also has the potential to reduce the overall time and cost of dental implant treatment. AI algorithms trained with clinical input data can predict the success of osseointegration procedures and dental implants, as well as optimize implant design prior to surgery.(2)

3.Localisation of Cephalometric Landmarks and Diagnosis of Skeletal Malocclusion

Accurate localization of cephalometric landmarks is crucial for effective orthodontic diagnosis and treatment. Inconsistencies in identifying these landmarks can negatively impact both diagnosis and treatment outcomes. To address this challenge, automated landmark detection using machine learning techniques on lateral cephalometric radiographs has emerged as a promising approach.(10)

Current methods for fully automatic identification of cephalometric landmarks have shown significant efficiency improvements, increasing their potential for widespread application.(11). Previous research demonstrated that systems using the random forest technique can instantly identify 19 landmarks. When implementing automatic cephalometric landmark detection in clinical practice, computational performance becomes vital, especially when identifying multiple landmarks simultaneously.(2)

Diagnosing and planning treatment for patients with dentofacial abnormalities often involves a combination of orthodontic and surgical interventions.(12)Skeletal analysis is essential in this process, utilizing posteroanterior and lateral cephalograms to assess the anteroposterior, lateral, and vertical dimensions of the jaws and face.(13) Accurate diagnosis relies heavily on correctly identifying landmarks on cephalograms, which is crucial for achieving successful treatment outcomes.(2)

Recent research has explored the use of deep learning algorithms for cephalometric analysis, revealing promising advancements. AI has also been applied to automatically detect and categorize skeletal malocclusions using 3D craniofacial scans. Kim et al. (2020) proposed a method utilizing a convolutional neural network (CNN) for bone categorization, which has shown over 90% sensitivity, specificity, and accuracy in vertical and sagittal skeletal diagnoses.(17) Additionally, machine learning techniques have proven useful in identifying cephalometric predictors for the need for orthognathic surgery in patients with treated unilateral cleft lip and palate.(18) The integration of AI into these processes could reduce the labor-intensive nature of manual assessments and enhance diagnostic precision.(19)

Although many recent studies have focused on the accuracy of AI programs for cephalometric landmark detection, a comprehensive systematic review or meta-analysis of this emerging field has yet to be conducted.(10

4. Planning of Orthognathic Surgery

Precise preoperative planning is essential for successful outcomes in orthognathic surgery (OGS). Traditional 2D surgical planning methods, which rely on radiographs and models, have limitations, especially for patients with significant facial asymmetry. These methods can lead to problems such as bone contact issues and inconsistencies in pitch, roll, and yaw rotations in 2D designs.(28.29)

Advancements in 3D imaging have transformed the field by introducing computer-aided surgical simulation using CBCT images. This 3D imaging-based planning simplifies cephalometric analysis, splint production, and surgical simulation.(30) It allows for clearer visualization of dental abnormalities, including yaw rotations, occlusal plane canting, and variations in mandibular body/ramus length. The integration of virtual surgical planning with 3D imaging and 3D printing offers enhanced visualization of anatomical structures and has significantly improved treatment outcomes. There is considerable potential for AI to further enhance orthognathic surgery planning, complementing existing methods in 3D imaging and printing.(31,32)

5.Radiographic Image Quality Improvement

The quality of radiographic images can be compromised by various interferences during image acquisition and transmission.(33) Deep learning techniques have shown significant promise in addressing the limitations of conventional methods, such as sparse-based or filtering techniques, for improving image quality.(35)One notable application of deep learning is in image denoising, particularly for enhancing the quality of low-dose CT images. Convolutional neural networks and generative adversarial networks have been used effectively for noise reduction and image deblocking.(36)

Integrating deep learning into low-dose CT research is a recent advancement aimed at reducing patient exposure while preserving image quality. Ongoing experiments are exploring how deep learning and machine learning technologies can be leveraged for denoising, with the goal of maximizing benefits in low-dose CT applications.(37)

Another important issue in diagnostic imaging is motion artifacts caused by patient or organ movements.(38) AI has been applied to dental CT and cone beam CT (CBCT) images to mitigate metal artifacts. Dental crowns and implants, which have high attenuation coefficients, can cause scattering, photon starvation, and beam hardening, resulting in dark and bright streak artifacts that affect diagnostic accuracy.(39) Advanced AI techniques, including sophisticated image reconstruction algorithms and deep learning approaches, are being used to reduce metal artifacts in dental CT and CBCT images, thereby improving diagnostic precision.(40)

6. Diagnosis and segmentation of Maxillofacial Cysts and Tumors.

Accurately classifying and diagnosing various maxillofacial cysts and tumors presents significant challenges for physicians. The integration of AI into the automated diagnosis of these conditions offers considerable potential in clinical practice.(19) For example, Abdolali et al. developed a model that uses asymmetry analysis to automatically segment radicular cysts, dentigerous cysts, and keratocysts.(20) Similarly, Rana et al. utilized a surgical navigation program to segment keratocysts and measure their volume. Other researchers are focused on creating AI models trained with 2D/3D images to classify maxillofacial lesions and tumors.(21,22)

However, the initial phase of lesion detection still requires manual input, and fully automating the identification of cysts and tumors remains a challenge.Notably, a systematic review by Santer et al., which included 13 studies, highlighted the promising potential of AI in detecting suspicious lymph nodes in patients with locally advanced head and neck squamous cell carcinoma. The review found that AI demonstrated a mean accuracy of 86% for lymph node detection.(23)

7.Surgical navigation

AI-enhanced navigation systems significantly improve accuracy in complex surgeries. Multivariate linear regression analysis has shown notable associations between the accuracy of navigation-assisted mandibular reconstruction and factors such as condyle preservation, reconstruction type, osteosynthesis plate type, and the number of bony segments. Navigation-assisted midface reconstruction has demonstrated higher accuracy in achieving final surgical outcomes compared to mandibular reconstruction. Computer-assisted techniques and intraoperative navigation offer promising alternatives or complements to existing surgical methods, particularly for more intricate maxillofacial reconstructions.(24)

8.Predictive analytics

AI models are transforming patient care by forecasting outcomes and enabling personalized treatment plans. Leveraging capabilities such as learning, problem-solving, and decision-making, AI analyzes extensive datasets—including electronic health records (EHRs), imaging, and genetic data—to predict disease progression, optimize treatment plans, and enhance recovery rates. Machine learning (ML) and deep learning (DL) techniques are pivotal in predictive analytics, facilitating early condition detection, precision in drug discovery, and tailored treatments based on individual patient profiles.

However, ethical considerations such as data privacy, bias, and accountability are crucial for the responsible implementation of AI in healthcare. The potential of AI predictive analytics to revolutionize clinical decision-making and healthcare delivery is significant. Nonetheless, adherence to ethical guidelines and ongoing model validation are essential to ensure the safe and effective use of AI in augmenting human judgment in medical practice.(25)

9. Robotic-assisted surgery:

AI-powered robots are increasingly assisting surgeons in cranial surgical procedures, including dental implants, tumor resections, biopsies, and temporomandibular joint surgeries, enhancing precision and accuracy. These robotic systems improve surgical outcomes by reducing the need for revisions, ensuring precise resections, and minimizing blood loss, complications, and hospitalization time.(2) Research has demonstrated that AI-aided surgery enhances the accuracy and safety of oral implant procedures compared to traditional freehand techniques, often reducing the need for revision surgeries and implant repositioning. Additionally, AI-driven approaches allow for more precise resection of tumors and cysts, potentially decreasing the need for additional procedures.(27)

Despite these advancements, the use of robotic surgery for treating head and neck diseases is still experimental. The long-term effects on surgical morbidity, oncologic control, and quality of life remain to be fully established. Further well-designed studies are necessary before robotic-assisted surgery can be recommended as a standard treatment paradigm.(2)

II. DISCUSSION

AI is significantly transforming healthcare, leveraging its ability to mimic human cognition to learn, think, and make decisions. Its impact is profound, enhancing medical practices and patient outcomes through advanced data analysis and predictive insights. The scope of AI in healthcare is vast, offering problem-solving capabilities beyond human capacity. By 2019, 46% of UK healthcare organizations had adopted AI, underscoring its critical role in the field.

AI encompasses various interrelated processes, including:

- **Machine Learning (ML):** Uses data sets, such as health records, to train algorithms that can categorize information and predict outcomes.
- **Deep Learning:** A subset of ML that utilizes extensive data, complex algorithms, and neural networks to handle more sophisticated tasks.
- **Natural Language Processing (NLP):** Employs ML to interpret and understand human language, aiding in the analysis of documentation, notes, and research.
- **Robotic Process Automation (RPA):** Applies AI to automate administrative and clinical workflows, enhancing patient experiences and facility operations.

Key applications of AI in healthcare today include:

- **Healthcare Analytics:** Utilizes ML to analyze historical data, improve decision-making, and optimize health outcomes.
- **Precision Medicine:** Creates personalized treatment plans by considering a patient's medical history, lifestyle, and genetic information.
- **Disease Prediction:** Employs predictive models to assess the likelihood of developing specific conditions or diseases.
- **Test Interpretation and Diagnosis:** Uses ML to analyze medical scans, such as MRIs and X-rays, for diagnosing conditions like cancerous lesions.

The use of AI in oral and maxillofacial surgery (OMFS) has become increasingly prevalent, impacting various aspects of the specialty. AI applications in OMFS include diagnosis, cephalometrics, preoperative planning, intraoperative measurements, outcome evaluation, and postoperative follow-up.(41)

Recent literature highlights Nine key AI applications in OMFS:

1. **Preoperative analysis of impacted teeth**
2. **Dental implant planning**
3. **Localisation of Cephalometric Landmarks and Diagnosis of Skeletal Malocclusion**
4. **Planning of Orthognathic Surgery**
5. **Radiographic Image Quality Improvement**
6. **Diagnosis and segmentation of Maxillofacial Cysts and Tumors.**
7. **Surgical navigation**
8. **Predictive analytics**
9. **Robotic-assisted surgery** (2)

AI significantly enhances diagnostic procedures in healthcare by facilitating the recognition of diseases, abnormalities, and fractures. High-quality AI models offer crucial prognostic indicators that aid in surgical planning and aftercare. For example, AI can revolutionize implantology by predicting implant failure risks based on imaging data and patient-specific factors. However, AI systems often lack transparency, making their decision-making processes difficult to understand, which can foster skepticism among patients and healthcare professionals. To promote adoption and ensure transparency, developing explainable AI models and involving experienced clinicians is vital.

For effective AI implementation in healthcare, it is essential to evaluate AI systems using reliable, prospective databases and publish results in peer-reviewed journals. Studies should detail both positive and negative predictive values and their impacts on patient outcomes. Oral and maxillofacial surgery (OMFS) professionals should focus on practical applications and patient

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outcomes when assessing AI models, not just theoretical accuracy. OMFS residency programs should include AI curricula to improve understanding of AI models and algorithms, with expert-led lectures and encouragement for residents to conduct high-quality research. International collaboration among OMFS surgeons can generate diverse, high-quality training data to foster innovation.

The U.S. Food and Drug Administration (FDA) is developing a framework to ensure AI models' safety and efficacy, necessitating robust review processes and performance monitoring. OMFS professionals can enhance their role in dental implantology by creating accurate AI-aided clinical models and utilizing AI for comprehensive patient care, such as detecting pathologies in panoramic imaging. Despite challenges like ethical concerns, data privacy, and the "Black Box" problem, AI has substantial potential to improve surgical and non-surgical practices, enhance cost efficiency, and patient care. Addressing regulatory and bureaucratic barriers and establishing clear frameworks will help integrate AI effectively into OMFS.

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