2-1-2022

Artificial intelligence in dentistry, orthodontics and orthognathic surgery: A literature review

Tania Arshad Siddiqui

Rashna Hoshang Sukhia

Dinaz Ghandhi

LITERATURE REVIEW

Artificial intelligence in dentistry, orthodontics and Orthognathic surgery: A literature review

Tania Arshad Siddiqui,[1] Rashna Hoshang Sukhia,[2] Dinaz Ghandhi[3]

Abstract

Artificial intelligence is the ability of machines to work like humans. The concept initially began with the advent of mathematical models which gave calculated outputs based on inputs fed into the system. This was later modified with the introduction of various algorithms which can either give output based on overall data analysis or by selection of information within previous data. It is steadily becoming a favoured mode of treatment due to its efficiency and ability to manage complex conditions in all specialities. In dentistry, artificial intelligence has also popularised over the past few decades. They have been found useful for diagnosis in restorative dentistry, oral pathology and oral surgery. In orthodontics, they have been utilised for diagnosis, assessment of treatment needs, cephalometrics, treatment planning and orthognathic surgeries etc. The current literature review was planned to highlight the uses of artificial intelligence in dentistry, specifically in orthodontics and orthognathic surgery.

Keywords: Artificial intelligence, Dentistry, Orthodontics, Orthognathic surgery, Diagnosis.

DOI: https://doi.org/10.47391/JPMA.AKU-18

Introduction

Artificial intelligence (AI) has been defined as the ability of a computer to perform tasks intelligently, equivalent to a human being, incorporating understanding and processing language with reasoning skills and problem-solving ability. AI can be sub-classified into fields like machine learning (ML), cognitive computing, deep learning, natural language processing, fuzzy logic, robotics, and expert systems.[1] ML is a part of AI whereby algorithms are used to predict outcomes by machines without the need of human input. Another part of AI is the neural networks that are designed like the interconnecting neurons of the brain and these algorithms mimic the brain function. In deep learning, different computational neural network (CNN) layers are utilised which can analyse the data input. These are also referred to as convolutional neural networks.[2]

Artificial intelligence in dentistry: AI has been used in dentistry for a very long time now, but the knowledge and awareness of dentists regarding AI is questionable. Abouzeid et al.[3] conducted a cross-sectional study to assess the knowledge, attitude and perception of dentists towards robotics and AI. The study sample consisted of dental students, graduates/interns, and postgraduate residents. Overall, there was limited knowledge (58.3%) regarding AI, but the attitude was positive (67.4%) as the study group showed high willingness to treat (83.3%) and recommend treatment (84.5%) with these modalities. While a general lack of awareness is seen, it is notable that the level of motivation towards the learning of AI and robotics is high. Hence, reforms in dental education should be considered where early learning of AI is incorporated into the system. In a systematic review by Ahmed et al.,[1] it was found that AI is a multi-disciplinary, multi-functional and multi-purpose tool that can be effectively used for precise, accurate and improved patient care by the treating dentists. It enables the prediction of expected outcomes and allows the exploration of possible treatment outcomes. This is in accordance with a study by Chen et al.[4] which found AI to be a comprehensive system that can not only provide high-quality patient care, but can also be used for innovations in research and development. Its most important feature is that it allows effective communication between healthcare providers in the form of "instant information exchange". Revilla-Leon et al.[5] conducted a systematic review to identify the effectiveness of AI in different presenting complaints of patients in restorative dentistry. The accuracy in the diagnosis of caries was found to be 76-88.3%, while the prediction of caries was 83.6-97.1%. The AI had 88.3-95.7% accuracy in diagnosing vertical fracture of the tooth, while the finishing line accuracy ranged 90.6-97.4%. The study concluded that AI is a "powerful tool for diagnosing caries, vertical root fracture, detecting tooth preparation

[1]Department of Orthodontics, Foundation University College of Dentistry and Hospital, Foundation University, Islamabad, [2]Department of Orthodontics, Aga Khan University and Hospital, Karachi, [3]Department of Oral and Maxillofacial Surgery, Altamash Institute of Dental Medicine, Karachi, Pakistan.

Correspondence: Rashna Hoshang Sukhia. Email: rashna.aga@aku.edu

margins, and predicting restoration failure". Limitations in the number of original research work has been recognised in these systematic reviews and further studies are still needed for better in-depth understanding of the technology.

Baliga[6] in his commentary highlighted the importance of AI in paediatric dentistry. With the introduction of four-dimensional (4D) goggles, movies, animations and virtual reality-based games, digital technology can now be effectively used for behaviour modification in children through more playful interactions. These advantages are also extended into a pedagogical environment for interactive teaching and learning through virtual simulations.

Grischke et al.[7] in their systematic review, which included 41 articles on ML, 53 articles on AI, and 49 original research on robotics, discussed the benefits of robotic tooth brushing and reported that "dentronics" will enhance reliability, reproducibility, accuracy and efficiency with a better understanding of disease pathogenesis. They found it to be an important tool for risk assessment strategies, diagnosis, disease prediction and better treatment outcomes.

Revilla-Leon et al.,[5] in their systematic review, assessed the applications of AI in implant dentistry by evaluating their recognition of implant success, type, design, optimisation and success prediction. They reported accuracy for the type using periapical radiograph and orthopantomogram to be around 93.8-98%, and the recognition of success rate to be around 62.4-80.5%. They, therefore, concluded that there was a great potential in AI for type recognition, recognition of success, prediction, design and optimisation in implant dentistry.

Hung et al.[8] reviewed ML algorithms to predict survival with oral cancer and the factors affecting it, and reported that extreme gradient-boosting ML algorithms showed the best performance with mean absolute error of 13.55, mean square error of 486.55 and root mean square error of 22.06. They concluded that cancer survival prediction and medical decision-making were possible with AI.

ML models have been applied to orthopantomograms for automatic tooth detection. They have also been utilised for Computer-aided design and Computer-aided manufacturing (CAD/CAM) and 3D printing for surgical guides and orthodontic brackets to predict extractions in orthodontic treatment planning etc, but they did not specify combinations of extractions using CNN. ML models can combine all the data for clinical decision-making. Other applications are landmark tracing, cervical vertebrae staging and skeletal classification.[9] CNN and artificial neural network (ANN) have been used for diagnosis in restorative dentistry, salivary gland disease, maxillary sinusitis, maxillofacial cysts, cervical lymph nodes, metastasis, osteoporosis, cancers and bone loss.[2]

Artificial intelligence in orthodontics: In the field of research in orthodontics, various advancements have been made utilising AI.

AI and orthodontic treatment need: Thanthornwong[10] utilised orthodontic impressions and facial photographs to evaluate orthodontic treatment need. The variables they used to construct the prediction model were missing teeth, overjet, overbite, anterior and posterior openbite, a diastema, anterior and posterior crossbite, anterior and posterior displacement, supernumerary teeth, ectopic eruption, anteroposterior molar relationship, and upper and lower lip to E-line. They had a sample size of 1,000 participants, and utilised 80% of the data as training data and created a prediction model which was then tested on 20% of the data which was called the test data. A sample of 20 patients was utilised to validate the data-sets. They constructed five models, of which the one with the highest level of specificity (100%), sensitivity (95%) and accuracy (96%) was chosen. Two orthodontists with more than five years of experience predicted the treatment need. Data of 200 patients was entered into the model which was calculated for treatment need using the model. The higher scores indicated treatment need, while lower scores indicated no treatment need. A high level of agreement was found when this network was validated (kappa value -1.00 with orthodontist A, kappa value -0.894 with orthodontist B). They concluded that the prediction model was an effective modality for the evaluation of treatment needs.

Wang et al.[11] evaluated the effects of treatment need through aesthetics using eye-tracking devices. Eye-tracking devices use anthropometric landmarks to determine the responses for areas of interest, which were the eyes, mouth and nose. The study sample consisted of 88 subjects who were shown pictures of normal individuals along with pre- and post-treatment ones in smiling and repose views. The results of the eye tracking device were compared with mixed-effect linear regression and support vector machine (SVM). SVM was further compared using Index of Orthodontic Treatment Need-Aesthetic Component (IOTN-AC) for the evaluation of accuracy of treatment need and outcome. The mouth was highlighted as the area of interest in smiling photographs for normal, pre- and post-orthodontic treatment. SVM was found to be highly accurate in identifying treatment needs between normal and pre-treatment photographs (97.2%) and for treatment outcomes between pre- and post-treatment (93.4%).

AI in orthodontic diagnosis: AI has been extensively explored for effective and efficient diagnosis as well as patient care. Bichu et al.,[12] in their scoping review of 62 shortlisted articles, found that 33 articles emphasised the use of AI for diagnosis and treatment planning. CNN and ANN have been utilised for extraction prediction, orthodontic treatment need, cephalometric analysis, and age and gender discrimination. Neural networks have a role to play in diagnostic interpretations utilising computed tomography (CT), cone-beam computed tomography (CBCT), lateral cephalograms, bitewing, facial photographs and orthopantomograms.[2]

Kok et al.[13] used different algorithms to determine their accuracy in the assessment of cervical vertebrae maturation through the Lamparski method. The data was obtained from 300 cephalograms. They found an accuracy rate in the range of 78.7-93% for cervical vertebral maturational stage 1(CVS 1) with the highest being for ANN (93%), {k-nearest neighbours [k-NN] (78.7%), Naïve Bayes [NB] (92.1%), SVM (84.8%), random forest [RF] (91.8%)}. Decision tree (DT) gave the highest accuracy for the determination of vertebral body shape at 97.1%. Amasya et al.[14] measured data on 498 cephalograms for cervical vertebral maturation (CVM) staging using ANN (kappa score - 0.926), SVM (kappa score - 0.874), RF (kappa score - 0.908) and DT (kappa score - 0.921).

Cephalometric analysis: Numerous studies have been conducted in the past few years which have focussed on assessments of lateral cephalograms. The main focus has been on the accuracy of "automated landmark location" before conducting the actual analysis. Kim et al.,[15,16] using CNN on lateral cephalograms and CBCT for posterior-anterior cephalometric landmark tracing, found a high level of accuracy (88.43%, 80.4%). An error of 2mm, however, was reported for landmark identification for Postero-anterior (PA) cephalograms, but overall results were satisfactory.

A higher level of landmark identification was obtained when CNN was modified using an algorithm for "biomedical image segmentation" called U-Net.[17] The level of accuracy achieved was 92%. Dobratulin et al.[17] concluded that the results obtained were similar to landmark identification by a group of orthodontists. Lee et al.,[18] using the Bayesian Convolutional Neural Networks (BCNN)BN, found a 90.11% level of accuracy. We believe that accurate landmark location and identification are imperative in conducting an accurate cephalometric analysis. This was determined by Shin et al.[19] who conducted a study on 840 lateral and frontal cephalograms to predict the need for orthognathic surgery on skeletal malocclusion using a recurrent neural network (RNN) algorithm. The algorithm uses sequential data input which is stored in its internal memory. Sequential data input requires that all information be introduced in a sequence of steps. These steps are then followed for the assessment of new data incorporated into the system. A high level of accuracy (95.4%) was obtained with this system for the assessment of patients requiring orthognathic surgeries.

Recently, AI has been used specifically for cephalometric analyses. Silva et al.[20] used CEFBOT (RadioMemory Ltd., Belo Horizonte, Brazil), an AI-based cephalometry software, to measure 30 lateral cephalograms using Arnett's analysis. CEFBOT successfully performed measurements in 9/10 variables. The measured variables were re-evaluated after 15 days and correlated with human findings. Repeated measures of CEFBOT gave a high-reliability level (Intra-class correlation [ICC] >0.94) and they were not statistically different from the human findings.

AI in orthodontic treatment planning: The interest in AI for orthodontic treatment plans and outcomes has gained gradual interest with time. Earlier works consisted of the construction of mathematical models which could correctly identify patients in need of extractions. Takada et al.[21] and Yagi et al.[22] conducted a two-part research where they configured a mathematical model which could tell the need for and the desired pattern of extractions for a case. It was developed with the purpose of projecting an unexpected treatment outcome with extractions and to correctly identify the traits which led to the model's decision-making for choosing extractions. The input data consisted of patients' standardised photographs, radiographs and orthodontic casts. The model would identify features of presenting malocclusion and place it next to the nearest template already in the system. Multiple decisions were taken depending on the traits of the case. An overall computation of the outcomes was done before the final result was given. The accuracy of the model was tested against the decisions of the clinicians and an accuracy rate of 90.4% was obtained. The traits leading to extraction decisions were overjet and upper and lower arch length discrepancy. The model created was modified and tested to determine extraction patterns versus clinicians. An accuracy of 86% was obtained with correction of incisor inclination and overjet and overbite as the causes for extractions. The model was further evolved by Xie et al.[23] using ANN. The model was tested for its ability to differentiate between extraction and non-extraction cases along with possible causes for extractions. The model had 80% accuracy in identifying extraction patients aged 11-15 years. The factors responsible for extraction were incompetent lips and proclined lower incisors.

Different programmes have been tested to determine their accuracy for extraction/non-extraction decision-making. Jung and Kim.[24] used the language R programme for the machine model to create a programme which could correctly identify extractions patients. The model was further tested for its ability to detect identical and differential extraction patterns based on 5 treatment plan groups which had been built into the system. The model was compared with the clinical plans of an experienced orthodontist. The model achieved an accuracy of 93% in identifying patients needing extractions with overall 84% accuracy in the extraction plan.

The advancement in AI has led to the emergence of different programmes. Li et al.[25] compared ANN with k-NN. Their neural network showed 94% accuracy of prediction of extraction versus non-extraction treatment. They also reported the accuracy of anchorage patterns to be around 92.8%. They found curve of Spee, angle ANB (angle formed between point A [point of deepest convexity on the labial cortical plate of the maxilla above the maxillary central incisor], nasion and point B [point of of deepest convexity on the labial cortical plate of the mandible below the mandibular central incisor]) and crowding in the upper arch to be the most important features for prediction of their neural networks.

Over the years, orthodontic record-keeping has become more technologically advanced as dynamic records of patients are more preferred than the traditional static forms. Tanikawa and Yamashiro[26] explored the possibility of an AI system that could be used by stereophotogrammetry to differentiate between extraction and orthognathic surgery cases. The model was constructed using landmark-based geometric morphometric methods (GMMs), and ML and two AI systems were developed. Data of a presenting case would be collected using anthropometric landmarks of the face and compared with the data of the previous patients already in the system. The systems showed a success rate of 54% for surgical and 98% for extraction cases at a system error of <1mm. However, when the system error was at <2mm, a success rate of 100% was achieved.

Artificial intelligence in orthognathic surgery: With the continuing advancements in technology, AI has been extensively explored in the field of surgery, ranging from ophthalmology[27] and spinal surgery[28] to knee arthroplasty.[29] Benefits include complex movements over shorter periods with high levels of precision.[30]

The preparation of patients requiring orthognathic surgeries can become a long and tedious procedure combining clinical and laboratory work. The traditional methods require the fabrication of acrylic splints which are used by surgeons as intraoperative guides. This is prone to errors as materials used undergo dimensional changes due to inherent properties or may fracture due to pressure. To overcome these limitations, Woo et al.[31] devised a surgical set of robotic arms which transferred information from the virtual screen to the operating room. The robotic arm was primarily designed to facilitate the surgeons during the procedure. The robotic arm could undergo movements at 6 degrees. On-screen movements centred on specific points were called tool centre points. These were located on a virtual simulation of the maxillomandibular complex around which axis movements were done. Overall, highly accurate and predictable movements of the jawbones were produced. Despite the advantages, Grischke et al.[7] found these procedures high in cost.

Mandibular surgeries are often associated with shifting of the condylar heads during repositioning of the segments. They can lead to the development of condylar sags post-surgically. To overcome these limitations, Lee et al.[32] devised an electromagnetic tracker device that could record movements of the condylar heads real-time. Other benefits included 3D coronal and sagittal views to ascertain the position of the condylar heads in the fossa.

AI has also been explored for the creation of surgical splints. Elnagar et al.[33] in their research developed a 3D diagnostic model for diagnosis and a virtual orthodontic-orthognathic treatment plan. The model was fabricated using scanning and CBCT images which were combined to form a single model. The outcome led to the fabrication of a 3D splint using 3D printing as an intraoperative guide for the surgeons.

Ethical concerns with AI: With the emerging trend of using AI, a matter of ethical concern has also been raised. Mörch et al.[34] found 45 ethical issues with the use of AI in dentistry. These revolved around six principles of ethics, namely, prudence (concerned with deliberating well about what is good and advantageous to oneself, others, and life as a whole), equity (social justice or fairness), privacy (shielding one's personal life from unwanted scrutiny), responsibility (the ability to recognise, interpret and act upon multiple principles and values according to the standards within a given field and/or context), democratic participation, and, solidarity (voluntary union or fellowship amongst people). With the quick acceptance of AI in dentistry, it has become imperative that recommendations be developed and brought into effect to overcome the ethical concerns recognised.

Conclusion

AI is a rapidly advancing modality in orthodontics which is enhancing patient care and management. It allows clinicians precision and accuracy in patient care. There is a substantive opportunity for AI to be utilised in the field of dentistry However, the ethical aspects must be taken into account as machines and computing systems cannot replace empathic human nature. Further research is still recommended to warrant its use in everyday dentistry.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

References

1. 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;2021:e9751564. doi: 10.1155/2021/9751564.
2. Khanagar SB, Al-Ehaideb A, Maganur PC, Vishwanathaiah S, Patil S, Baeshen HA, et al. Developments, application, and performance of artificial intelligence in dentistry - A systematic review. J Dent Sci 2021;16:508-22. doi: 10.1016/j.jds.2020.06.019.
3. Abouzeid HL, Chaturvedi S, Abdelaziz KM, Alzahrani FA, AlQarni AAS, Alqahtani NM. Role of Robotics and Artificial Intelligence in Oral Health and Preventive Dentistry - Knowledge, Perception and Attitude of Dentists. Oral Health Prev Dent 2021;19:353-63. doi: 10.3290/j.ohpd.b1693873.
4. Chen YW, Stanley K, Att W. Artificial intelligence in dentistry: current applications and future perspectives. Quintessence Int 2020;51:248-57. doi: 10.3290/j.qi.a43952.
5. Revilla-León M, Gómez-Polo M, Vyas S, Barmak BA, Galluci GO, Att W, et al. Artificial intelligence applications in implant dentistry: A systematic review. J Prosthet Dent 2021:S0022-3913(21)00272-9. doi: 10.1016/j.prosdent.2021.05.008. [ahead of print.]
6. Baliga MS. Artificial intelligence - The next frontier in pediatric dentistry. J Indian Soc Pedod Prev Dent 2019;37:315. doi: 10.4103/JISPPD.JISPPD_319_19.
7. Grischke J, Johannsmeier L, Eich L, Griga L, Haddadin S. Dentronics: Towards robotics and artificial intelligence in dentistry. Dent Mater 2020; 36: 765-78. doi: 10.1016/j.dental.2020.03.021.
8. Hung M, Park J, Hon ES, Bounsanga J, Moazzami S, Ruiz-Negrón B, et al. Artificial intelligence in dentistry: Harnessing big data to predict oral cancer survival. World J Clin Oncol 2020;11:918-34. doi: 10.5306/wjco.v11.i11.918.
9. Pethani F. Promises and perils of artificial intelligence in dentistry. Aust Dent J 2021;66:124-35. doi: 10.1111/adj.12812.
10. Thanathornwong B. Bayesian-Based Decision Support System for Assessing the Needs for Orthodontic Treatment. Healthc Inform Res 2018;24:22-8. doi: 10.4258/hir.2018.24.1.22.
11. Wang X, Cai B, Cao Y, Zhou C, Yang L, Liu R, et al. Objective method for evaluating orthodontic treatment from the lay perspective: An eye-tracking study. Am J Orthod Dentofacial Orthop 2016;150:601-10. doi: 10.1016/j.ajodo.2016.03.028.
12. Bichu YM, Hansa I, Bichu AY, Premjani P, Flores-Mir C, Vaid NR. Applications of artificial intelligence and machine learning in orthodontics: a scoping review. Prog Orthod 2021;22:18. doi: 10.1186/s40510-021-00361-9.
13. Kök H, Acilar AM, ?zgi MS. Usage and comparison of artificial intelligence algorithms for determination of growth and development by cervical vertebrae stages in orthodontics. Prog Orthod 2019;20:41. doi: 10.1186/s40510-019-0295-8.
14. Amasya H, Yildirim D, Aydogan T, Kemaloglu N, Orhan K. Cervical vertebral maturation assessment on lateral cephalometric radiographs using artificial intelligence: comparison of machine learning classifier models. Dentomaxillofac Radiol 2020;49:e20190441. doi: 10.1259/dmfr.20190441.
15. Kim H, Shim E, Park J, Kim YJ, Lee U, Kim Y. Web-based fully automated cephalometric analysis by deep learning. Comput Methods Programs Biomed 2020;194:e105513. doi: 10.1016/j.cmpb.2020.105513.
16. Kim MJ, Liu Y, Oh SH, Ahn HW, Kim SH, Nelson G. Evaluation of a multi-stage convolutional neural network-based fully automated landmark identification system using cone-beam computed tomographysynthesized posteroanterior cephalometric images. Korean J Orthod 2021;51:77-85. doi: 10.4041/kjod.2021.51.2.77.
17. Dobratulin K, Gaidel A, Kapishnikov A, Ivleva A, Aupova I, Zelter P. The efficiency of deep learning algorithms for detecting anatomical reference points on radiological images of the head profile. In: 2020 International Conference on Information Technology and Nanotechnology (ITNT). Samara, Russia: IEEE, 2020; pp 1-6. doi: 10.1109/ITNT49337.2020.9253067.
18. Lee JH, Yu HJ, Kim MJ, Kim JW, Choi J. Automated cephalometric landmark detection with confidence regions using Bayesian convolutional neural networks. BMC Oral Health 2020;20:270. doi: 10.1186/s12903-020-01256-7.
19. Shin W, Yeom HG, Lee GH, Yun JP, Jeong SH, Lee JH, et al. Deep learning based prediction of necessity for orthognathic surgery of skeletal malocclusion using cephalogram in Korean individuals. BMC Oral Health 2021;21:130. doi: 10.1186/s12903-021-01513-3.
20. Silva TP, Hughes MM, Menezes LDS, de Melo MFB, Takeshita WM, Freitas PHL. Artificial intelligence-based cephalometric landmark annotation and measurements according to Arnett's analysis: can we trust a bot to do that? Dentomaxillofac Radiol 2021:20200548. doi: 10.1259/dmfr.20200548. [ahead of print]
21. Takada K, Yagi M, Horiguchi E. Computational formulation of orthodontic tooth-extraction decisions. Part I: to extract or not to extract. Angle Orthod 2009;79:885-91. doi: 10.2319/081908-436.1.
22. Yagi M, Ohno H, Takada K. Computational formulation of orthodontic tooth-extraction decisions. Part II: which tooth should be extracted? Angle Orthod 2009;79:892-8. doi:

10.2319/081908-439.1.
23. Xie X, Wang L, Wang A. Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment. Angle Orthod 2010;80:262-6. doi: 10.2319/111608-588.1.
24. Jung SK, Kim TW. New approach for the diagnosis of extractions with neural network machine learning. Am J Orthod Dentofacial Orthop 2016;149:127-33. doi: 10.1016/j.ajodo.2015.07.030.
25. Li P, Kong D, Tang T, Su D, Yang P, Wang H, Zhao Z, Liu Y. Orthodontic Treatment Planning based on Artificial Neural Networks. Sci Rep 2019;9:2037. doi: 10.1038/s41598-018-38439-w.
26. Tanikawa C, Yamashiro T. Development of novel artificial intelligence systems to predict facial morphology after orthognathic surgery and orthodontic treatment in Japanese patients. Sci Rep 2021;11:15853. doi: 10.1038/s41598-021-95002-w.
27. Pandey SK, Sharma V. Robotics and ophthalmology: Are we there yet? Indian J Ophthalmol 2019;67:988-94. doi: 10.4103/ijo.IJO_1131_18.
28. Overley SC, Cho SK, Mehta AI, Arnold PM. Navigation and Robotics in Spinal Surgery: Where Are We Now? Neurosurgery 2017;80:S86-99. doi: 10.1093/neuros/nyw077.
29. Bautista M, Manrique J, Hozack WJ. Robotics in Total Knee Arthroplasty. J Knee Surg 2019;32:600-6. doi: 10.1055/s-0039-1681053.
30. Andras I, Mazzone E, van Leeuwen FWB, De Naeyer G, van Oosterom MN, Beato S, et al. Artificial intelligence and robotics: a combination that is changing the operating room. World J Urol 2020;38:2359-66. doi: 10.1007/s00345-019-03037-6.
31. Woo SY, Lee SJ, Yoo JY, Han JJ, Hwang SJ, Huh KH, et al. Autonomous bone reposition around anatomical landmark for robot-assisted orthognathic surgery. J Craniomaxillofac Surg 2017;45:1980-8. doi: 10.1016/j.jcms.2017.09.001.
32. Lee SJ, Yang HJ, Choi MH, Woo SY, Huh KH, Lee SS, et al. Real-time augmented model guidance for mandibular proximal segment repositioning in orthognathic surgery, using electromagnetic tracking. J Craniomaxillofac Surg 2019;47:127-37. doi: 10.1016/j.jcms.2018.10.016.
33. Elnagar MH, Aronovich S, Kusnoto B. Digital Workflow for Combined Orthodontics and Orthognathic Surgery. Oral Maxillofac Surg Clin North Am 2020;32:1-14. doi: 10.1016/j.coms.2019.08.004.
34. Mörch CM, Atsu S, Cai W, Li X, Madathil SA, Liu X, et al. Artificial Intelligence and Ethics in Dentistry: A Scoping Review. J Dent Res 2021;100:1452-60. doi: 10.1177/00220345211013808.