



Review article

# Scope and performance of artificial intelligence technology in orthodontic diagnosis, treatment planning, and clinical decision-making - A systematic review



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**KEYWORDS**

Artificial intelligence;  
Automated  
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diagnosis;  
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networks;  
Convolutional neural  
networks

**Abstract** *Background/purpose:* In the recent years artificial intelligence (AI) has revolutionized in the field of dentistry. The aim of this systematic review was to document the scope and performance of the artificial intelligence based models that have been widely used in orthodontic diagnosis, treatment planning, and predicting the prognosis.

*Materials and methods:* The literature for this paper was identified and selected by performing a thorough search for articles in the electronic data bases like Pubmed, Medline, Embase, Cochrane, and Google scholar, Scopus and Web of science, Saudi digital library published over the past two decades (January 2000–February 2020). After applying the inclusion and exclusion criteria, 16 articles were read in full and critically analyzed. QUADAS-2 were adapted for quality analysis of the studies included.

*Results:* AI technology has been widely applied for identifying cephalometric landmarks, determining need for orthodontic extractions, determining the degree of maturation of the cervical vertebra, predicting the facial attractiveness after orthognathic surgery, predicting the need for orthodontic treatment, and orthodontic treatment planning. Most of these artificial intelligence models are based on either artificial neural networks (ANNs) or convolutional neural networks (CNNs).

*Conclusion:* The results from these reported studies are suggesting that these automated systems have performed exceptionally well, with an accuracy and precision similar to the trained examiners. These systems can simplify the tasks and provide results in quick time which can save the dentist time and help the dentist to perform his duties more efficiently. These systems can be of great value in orthodontics.

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**Introduction**

Orthodontics is one among the nine specialties of dentistry that mainly deals with the diagnosis of malocclusion and ultimately aims at preventing and correcting them. It is mainly concerned with the craniofacial skeleton, with more emphasis on modifying the dentoalveolar area.

An accurate diagnosis and treatment planning are considered as a key to the success of orthodontic treatment, orthodontist needs to be very precise in diagnosing and treatment planning. Orthodontic diagnosis is mainly based on the patient's dental and medical history, clinical examination, study models, and cephalometric radiographs which is considered as the most useful tool for orthodontic diagnosis, since it is used to assess the discrepancies related to the dental and the craniofacial skeleton.

In the last few decades the field of dentistry has widely revolutionized. Newer technologies have been developed that are based on the principles of mimicking the functioning of the human brain. These are mainly based on the artificial intelligence (AI) technologies that have made a significant contribution. These automatized technologies have been used as powerful tools in predicting the diagnosis and helping the clinicians in treatment planning.<sup>1</sup> These AI based systems have been used as tools for assisting orthodontists in providing a standard patient care and maximizing the chances of achieving the set goals.<sup>2</sup> The specialist can apply the AI technology for better clinical decision making.<sup>3</sup> AI technology can be defined as simulating the human intelligence through a machine that can think and act rationally.<sup>4,5</sup>

There are many subfields of AI that have been commonly used in different areas mainly the biological and medical diagnostics, they mainly include machine learning (ML), artificial neural networks (ANNs), convolutional neural networks (CNNs) and deep learning (DL).<sup>6</sup>

These neural networks are the mathematical computing models that can actually simulate the functioning of human brain and they can be trained with the clinical data sets and can be used for variety of tasks in the dental and medical diagnostics.<sup>7</sup>

This systematic review was taken up with an aim to document the scope and performance of the artificial intelligence based models that have been widely used in orthodontic diagnosis, treatment planning, and predicting the prognosis.

**Materials and methods****Information sources, search strategy and study selection**

This systematic review was carried after referring the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Diagnostic Test Accuracy (PRISMA-DTA).<sup>8</sup> The literature for this paper was identified and selected by performing a thorough search in the electronic data bases like Pubmed, Medline, Embase, Cochrane, Google scholar, Scopus, Web of science, and Saudi digital library published over the past two decades (January 2000–February 2020) by using of keywords such as artificial intelligence, automated orthodontic diagnosis,

**Table 1** Description of the PICO (P= Population, I= Intervention, C= Comparison, O= Outcome) elements.

Research question	What is the scope and performance of the artificial intelligence based models that have been widely used in orthodontic diagnosis, treatment planning and predicting the prognosis.
Population	Patients clinical images, radiographs, cephalograms involving oral and maxillofacial structures
Intervention	AI based models for diagnosis, treatment planning, predicting prognosis
Comparison	Expert opinions, reference standards
Outcome	Measurable or predictive outcomes such as accuracy, sensitivity, specificity, ROC = Receiver Operating Characteristic curve, AUC = Area Under the Curve, ICC = Intraclass Correlation Coefficient

deep learning, machine learning, artificial neural networks, convolutional neural networks, and computer-aided orthodontic diagnosis. This search was based on the PICO (problem/patient/population, intervention/indicator, comparison, and outcome) elements (Table 1).

Abstracts and full length articles were retrieved. Along with electronic searching other non-electronic source such as hand searching of the journals was also carried out. The required data for this review was selected in two stages. In the first stage the articles were selected based on the title and abstracts related to the research topic. This preliminary search yielded 628 articles that were suitable for the aim of this paper. 80 articles were eliminated due to duplication of the data. Thus a total of 548 articles were retrieved at the second stage of data selection. After the elimination of the duplicate articles, the following inclusion and the exclusion criteria were applied to the remaining articles.

### Criteria for considering studies for this review

#### Inclusion criteria

1. The article must be based on AI technology.
2. There should be a mention of some measurable or predictive outcomes that can be quantified.
3. There should be a clear mention regarding the data sets used for the assessment of the model.

#### Exclusion criteria

1. The articles that focused on areas other than AI technology.
2. Unpublished articles that were uploaded, like conference versions
3. Articles that had only abstracts without full text articles
4. Articles in other than English language

After applying these criteria's the number of articles were further reduced to 18. The name of the authors and the

journal were masked and further circulated among the authors. These articles were critically assessed by all the authors after referring the guidelines of QUADAS-2 (Quality Assessment and Diagnostic Accuracy Tool), a tool for quality assessment of the studies on diagnostic accuracy.<sup>9</sup> Following which the authors had disagreement on 2 articles for inclusion, so these articles were further excluded. Finally 16 articles were included for qualitative synthesis in this systematic review (Fig. 1).

Each of these articles were read in full and quantified respective of the year of publication, so that we could develop the trends that had occurred in the recent years in the area of artificial intelligence in the field of dentistry.

## Results

This systematic review included 16 research articles that were analyzed for quantitative data. The analysis of the literature revealed that most of the studies were conducted in the past 12 years (Fig. 2). The trends show that there is a gradual increase in the research related to artificial intelligence in dentistry.

### Qualitative synthesis of the included studies

The studies that were included in this systematic review were mainly on the application of AI for identifying cephalometric landmarks,<sup>10–15</sup> determining need for orthodontic extractions,<sup>16–18</sup> determining the degree of maturation of the cervical vertebra,<sup>6,19</sup> predicting the facial attractiveness after orthognathic surgery,<sup>20–22</sup> predicting the need for orthodontic treatment,<sup>23</sup> and orthodontic treatment planning (Fig. 3)<sup>24</sup>.

Most of the studies have used convolutional neural networks (CNNs) and artificial neural networks (ANNs). Some studies also reported of using paraconsistent artificial neural network (PANNs) and bayesian network (BN). These neural networks were designed to assess panoramic radiographs (OPG), facial photos, cephalometric radiographs, lateral cephalometric radiographs (Table 2).

### Risk of bias assessment and applicability concerns

All the included studies were analyzed for the risk of bias assessment using QUADAS-2 assessment tool (Supplementary Table 1). There were methodological concerns that likely resulted in a high degree of selection bias in 2/16 (12.5%) of the studies.<sup>6,24</sup> The index test results interpreted without knowledge of the results of the reference standard in the majority of the studies except one.<sup>24</sup> The threshold score was pre-specified in all the studies included in the present analysis. The majority of studies, 8/16 (50%) had low potential for bias with regards to the use and performance of the reference standard.<sup>13,14,19–22,24</sup>

The flow and timing had a high risk of bias in 5/16 (31.25%) of the studies, was high in 5/10 (30%). As depicted in (Supplementary Table 2), comparable results were obtained in the applicability arm of the QUADAS-2 (Figs. 4 and 5).

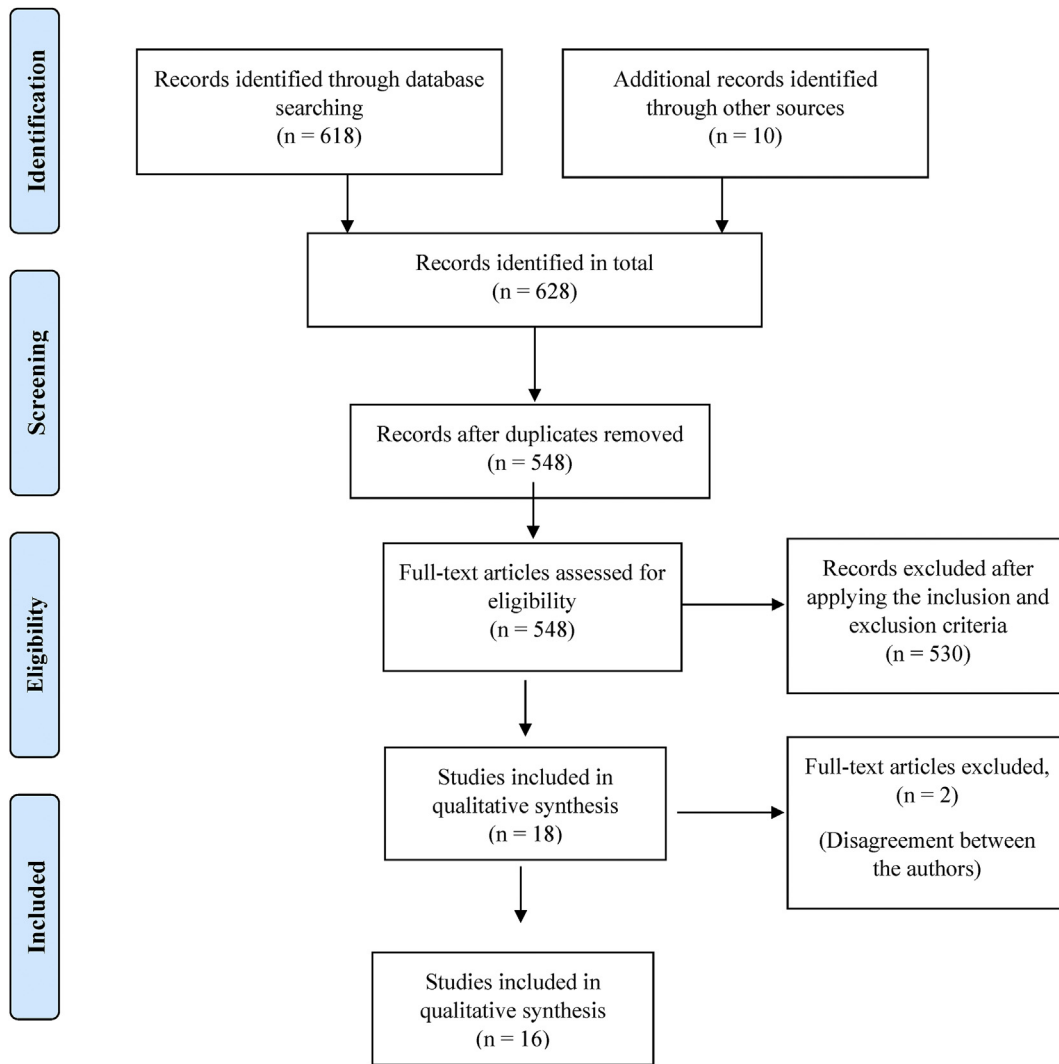


Figure 1 Flow chart for screening and selection of articles.

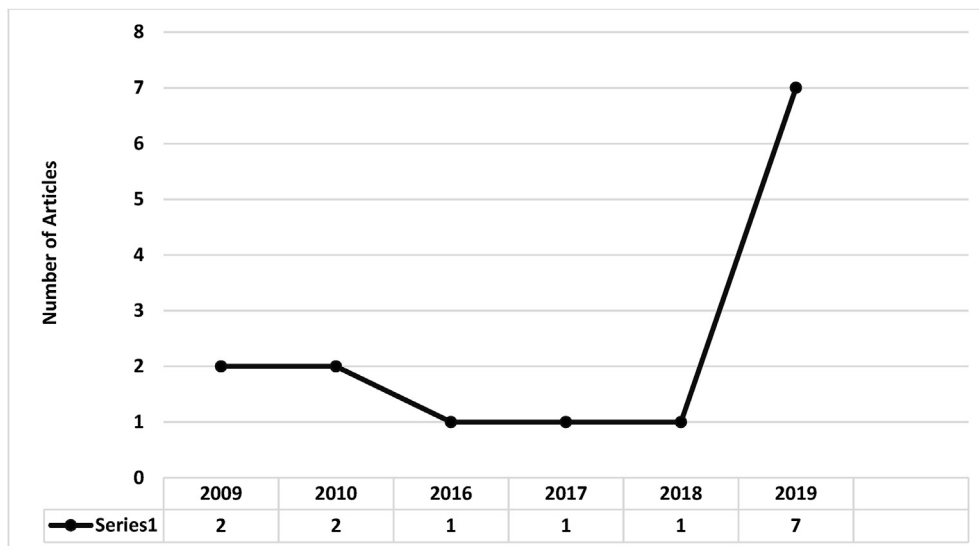
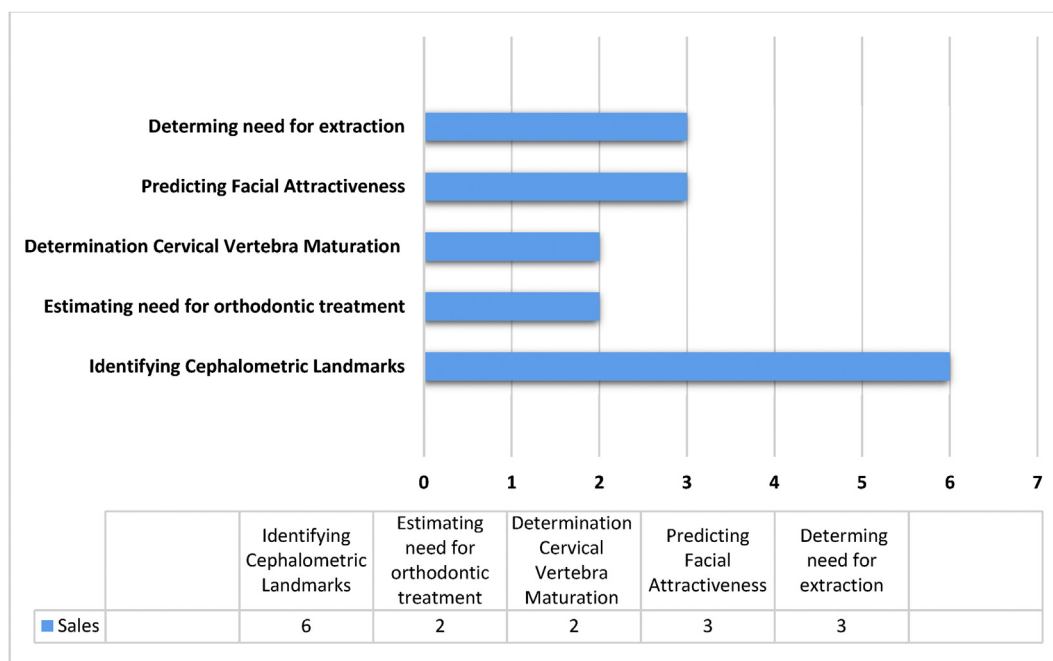


Figure 2 Trends of research on AI in orthodontics.



**Figure 3** Application of AI technology in orthodontics.

## Discussion

The specialty of orthodontics mainly deals with the diagnosis of malocclusion and planning an organized treatment. Malocclusion usually impairs the occlusal function causing psychological discomfort which will eventually result in the reduced quality of life.<sup>25</sup>

The goal of orthodontic treatment plan is to address the problem, by maximizing the benefits to the patient and minimizing the risks associated with it. The treatment plan is based on the patient's clinical findings and results of the diagnostic tests. It is a known fact that the orthodontist's treatment plan can differ for a specific case.<sup>26,27</sup> Application of computers has revolutionized in the field of health sciences and now with the introduction of artificial intelligence the impact is still higher. The AI based systems are dealing with the computational based automated models that can think and act rationally.<sup>4</sup> The AI based models are of auxiliary support to the health care professionals in improving the patient care. They can assist the health care professionals in working more efficiently by saving time.<sup>7</sup>

This paper intends to discuss the scope and performance of these AI based models that have been applied in various aspects of orthodontic diagnosis, treatment planning, clinical decision making, and predicting the prognosis.

### Application of AI for identifying cephalometric landmarks

Cephalometric analysis is considered as an important tool that has been applied for diagnosis and treatment planning.<sup>7</sup> In this paper we reported 6 articles that have applied AI based automated models for cephalometric analysis. A study based on the cellular neural networks was aimed to

evaluate the accuracy in locating the cephalometric landmarks on cephalometric radiographs, the results of this study were encouraging and the model demonstrated good results.<sup>10</sup> These results were similar to the results of the another study that used paraconsistent artificial neural network (PANN) for analyzing the cephalometric variables for orthodontic diagnosis, the results of this study were quite encouraging and the performance of the model was equivalent to the performance of the specialist's.<sup>11</sup>

Another study used AI based deep (CNNs) for automated quantitative cephalometry for identifying the cephalometric landmarks, the system demonstrated higher performance when compared to the top benchmarks reported in the literature with 76% of accuracy,<sup>12</sup> these results were similar to the results of another study that used CNNs based models which performed similar to that of the human experts with promising results.<sup>13–15</sup> The results of these studies suggest that these AI based automated systems can be used as an auxiliary support in orthodontic decision making and they are of viable option when repeated identification is required.

### Application of AI for determining need for orthodontic extractions

Making a decision on orthodontic extraction is one of the major and crucial decision which has a major impact on the prognosis of the treatment. It is considered crucial as the extraction process is irreversible. A clinician's decision is based on his clinical knowledge, expertise and based on the results of the diagnostic tests.<sup>28</sup> There is often a difference in the clinical decision making and variability in the treatment planning among the clinicians,<sup>29</sup> decision making is also dependent on the clinical experience of the practitioners.<sup>26</sup> In the recent years AI technology have been used

**Table 2** Details of the studies that have used AI based models for orthodontic diagnosis, treatment planning, and predicting the prognosis.

Serial no	Authors	Year of publication	Algorithm Architecture	Objective of the study	No. of images/ photographs for testing	Study factor	Modality	Comparison if any	Evaluation accuracy/ average accuracy	Results (+) effective, (-)non effective (N) neutral	Outcomes	Authors suggestions/ conclusions
1	Leonardi et al. <sup>10</sup>	2009	CNNs	CCNs-based AI system for automatic location of cephalometric landmarks	41	Landmarks	Lateral cephalometric radiographs	5 Experienced orthodontists	Not clear	(+) Effective	An acceptable level of accuracy was obtained by the CCNs based system designed for automatic landmark detection	Using soft copies of the digital x-rays is effective
2	Mario et al. <sup>11</sup>	2010	PANNs	A paraconsistent artificial neural network (PANN) for analyzing the cephalometric variables for orthodontic diagnosis	120	Landmarks	Cephalometric radiographs	3 Experienced orthodontists	Not clear,	(+) Effective	The performance of the model was equivalent to that of the specialist's	Can be used as auxiliary support for orthodontic decision making
3	Arik et al. <sup>12</sup>	2017	CNNs	AI based deep (CNNs) for automated quantitative cephalometry	250	Landmarks	Cephalometric radiographs	2 Trained experts	Accuracy of 76%	(+) Effective	This system demonstrated higher performance when compared with the top benchmarks in the literature	None
4	Park et al. <sup>13</sup>	2019	CNNs	Comparing latest deep-CNN based systems for identifying cephalometric landmarks	283	Landmarks	Cephalometric radiographs	Single Shot Multibox Detector (SSD)	5% higher accuracy with (YOLOv3) than Single (SSD)	(+) Effective	You-Only-Look-Once model outperformed in accuracy and computational time than the Shot Multibox Detector	This model can be used in clinical practice for identifying the cephalometric landmarks
5	Kunz et al. <sup>14</sup>	2020	CNNs	An automated cephalometric X-ray analysis using a specialized (AI) algorithm	50	Landmarks	Cephalometric radiographs	12 experienced examiners	Not clear	(+) Effective	AI algorithm was able to analyze unknown cephalometric X-rays similar to the quality level of the experienced human examiners	None
6	Hwang et al. <sup>15</sup>	2020	CNNs	Deep -learning based automated system for detecting the patterns of 80 cephalometric landmarks	283	Landmarks	Cephalometric radiographs	Human examiners	Detection error <0.9 mm	(+) Effective	This system accuracy in identifying of cephalometric landmarks similar to the human examiners	This system might be a viable option when repeated identification of multiple cephalometric landmarks
7	Xie et al. <sup>16</sup>	2010	ANNs	ANN based AI model for deciding if extractions are necessary prior to orthodontic treatment	20	Tooth malocclusion	Lateral cephalometric radiographs	Not mentioned	Accuracy of 80%	(+) Effective	ANN was effective in determining whether extraction or non-extraction treatment was best for malocclusion patients	None

*(continued on next page)*

Table 2 (continued)

Serial no	Authors	Year of publication	Algorithm Architecture	Objective of the study	No. of images/ photographs for testing	Study factor	Modality	Comparison if any	Evaluation accuracy/ average accuracy	Results (+) effective, (-)non effective (N) neutral	Outcomes	Authors suggestions/ conclusions
8	Jung et al. <sup>17</sup>	2016	ANNs	Artificial Intelligence expert system for orthodontic decision-making of required permanent tooth extraction	156	Tooth malocclusion	Lateral cephalometric radiographs	1 Experienced orthodontists	Accuracy of 92%	(+) Effective	The success rates of the models were 92% for the system's recommendations for extraction vs non-extraction	AI expert systems with neural network machine learning could be useful in orthodontics
9	Choi et al. <sup>18</sup>	2019	ANNs	ANN based model for deciding on surgery/non-surgery and determining extractions	316	Landmarks	Lateral cephalometric radiographs	1 Experienced orthodontists	ICC value ranged from 0.97 to 0.99	(+) Effective	This ANN based model demonstrated higher success rate in deciding on surgery/ non-surgery and was also successful in deciding on the extractions.	This ANN based model will be useful in diagnosing of orthognathic surgery cases.
10	Kök et al. <sup>19</sup>	2019	ANNs	AI algorithms for determining the stages of the growth and development by cervical vertebrae	300	Cervical vertebrae	Cephalometric radiographs	1 orthodontists	Mean Accuracy of 77.02%	(+) Effective	ANN could be the preferred method for determining cervical vertebrae stages	None
11	Makaremi et al. <sup>6</sup>	2019	CNNs	CCNs-based AI system for determining of the degree of maturation of the cervical vertebra	300	Cervical vertebrae	Lateral cephalometric radiographs	Not mentioned	Mean Accuracy lesser than 90%	(+) Effective	This proposed model is validated by cross validation and is of use for orthodontists	This is a validated software and can be readily used by orthodontists
12	Lu et al. <sup>20</sup>	2009	ANNs	ANN based model for predicting post-orthognathic surgery image	30	Face	Profile images	1 orthodontists	>80% accuracy in prediction	(+) Effective	The ANN based system demonstrated an improved accuracy and reliability in prediction	Can be used for clinical and treatment planning
13	Patcas et al. <sup>21</sup>	2019	CNNs	AI system for describing the impact of orthognathic treatments on facial attractiveness and age appearance	2164	Facial landmarks	Facial photographs	Not mentioned	Not Clear	(+) Effective	This CNN based AI system can be used for scoring facial attractiveness and apparent age in patients under orthognathic treatments.	None
14	Patcas et al. <sup>22</sup>	2019	CNNs	AI system for evaluating the facial attractiveness of patients who have undergone treatment for clefts and the facial	30	Face	Frontal and profile images	15 laypeople, 14 orthodontists, 10 oral	Cleft cases (all Ps $\geq$ 0.19), For Control	(-)Non Effective	AI system scores were comparable with the scores of the other groups for the cleft	There is a need for further refinement in this AI based

15	Thanathornwong <sup>23</sup> 2018	Bayesian network (BNs)	attractiveness of controls and to compare these results with panel ratings performed by laypeople, orthodontists, and oral surgeons	1000	Tooth malocclusion	Data sets	2 Experienced orthodontists	group (all Ps ≤ 0.02)	Effective (+)	patients, but the scores were lower for the controls	system
16	Li et al. <sup>24</sup> 2019	ANNs	ANN based model for orthodontic treatment planning	302	Landmarks	Extraoral and intraoral photos, lateral cephalometric radiographs	2 Experienced orthodontists	Accuracy of prediction of extraction-non-extraction, (AUC) of 0.982	Effective (+)	This BN based system and demonstrating promising results with high degree of accuracy in the need for orthodontic treatment.	Can be useful for guiding less-experienced Orthodontists for predicting orthodontic treatment.

ANNs = Artificial Neural Networks, CNNs = Convolutional Neural Networks, DCNNs = Deep Convolutional Neural Networks, BN = Bayesian Network, BN = Bayesian Network  
PANN = Paraconsistent Artificial Neural Network, ROC = Receiver Operating Characteristic curve, AUC = Area Under the Curve, ICC = Intraclass Correlation Coefficient.

on deciding the need for orthodontic extraction. A study used an ANN based AI model for deciding if extractions are necessary prior to orthodontic treatment. The model demonstrated remarkable results with 80% accuracy and proved to be an effective tool for decision making,<sup>16</sup> these results were similar to the results of another study based on AI technology which demonstrated even higher accuracy of 92% and this also can be considered as an effective model.<sup>17</sup> The results of these studies suggest that these AI based automated systems can be of great use for clinical decision making, and can be used as an auxiliary support for especially those who are having a lesser clinical experience.

### Application of AI for determining the degree of maturation of the cervical vertebra

Determining the biological maturity level is very much important for assessing the developmental stage of an individual, since the chronological age is not proved to be a reliable method for this.<sup>30</sup> In the recent years change in the shape and level of the development of the cervical vertebra are considered as the most suitable method for determining the biological maturity of an individual.<sup>31,32</sup>

AI based technology has been applied for determining the stages of the growth and development by cervical vertebrae, a study reported that the ANNs based model demonstrated a mean accuracy of 77.02% in determining the stages of the growth and development of cervical vertebrae.<sup>19</sup> These results similar to the results of another study where the AI based model performed even better.<sup>6</sup>

Based on the results of these studies, AI based automated systems can be considered safe for determining the stages of the growth and development of cervical vertebrae and can be of greater value for the orthodontists.

### Application of AI for predicting the facial attractiveness after orthognathic surgery

The surgical modes of treatment especially for the closure of the clefts, orthodontic and orthognathic surgeries are mainly expected to improvise the facial appearance along with functional improvements. Unfortunately these treatments does not always result in appreciable results eventually affecting the psychosocial wellbeing of the individual.<sup>33</sup> So assessing the patients facial appearance is a crucial factor for measuring the treatment outcome. AI based technology has been applied for the same, a study used an ANN based model for predicting post-orthognathic surgery image, the model demonstrated promising results with greater than 80% accuracy in prediction,<sup>20</sup> these results were similar to the results of another AI based study for describing the impact of orthognathic treatments on facial attractiveness.<sup>21</sup> The results of these AI based automated systems can be used for clinical decision making and treatment planning and it has also been suggested by the authors that these systems need further refinement to be more precise in prediction.



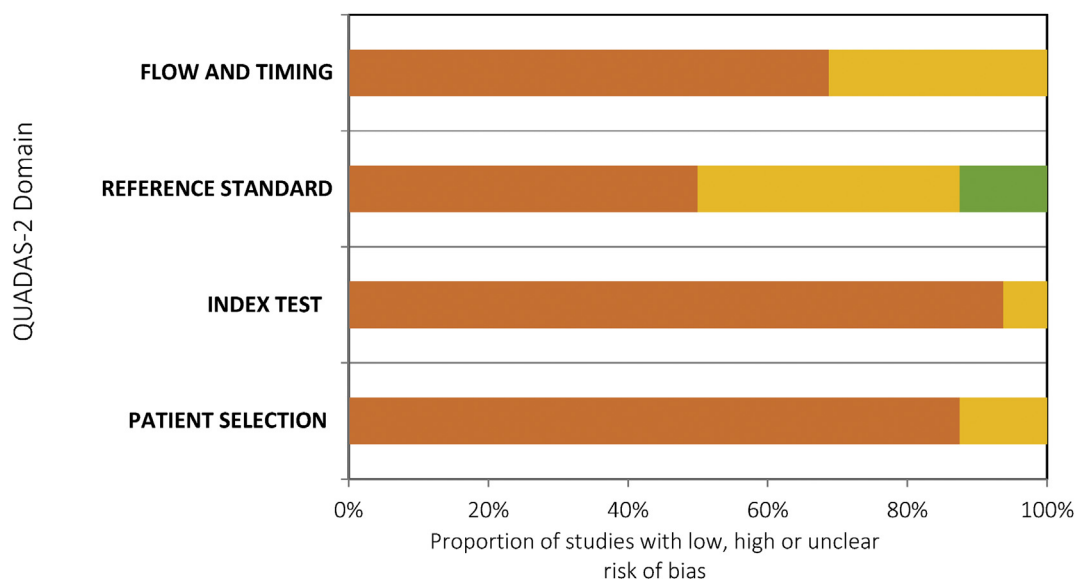


Figure 4 Assessment of individual risk of bias domains.

■ Low ■ High ■ Unclear

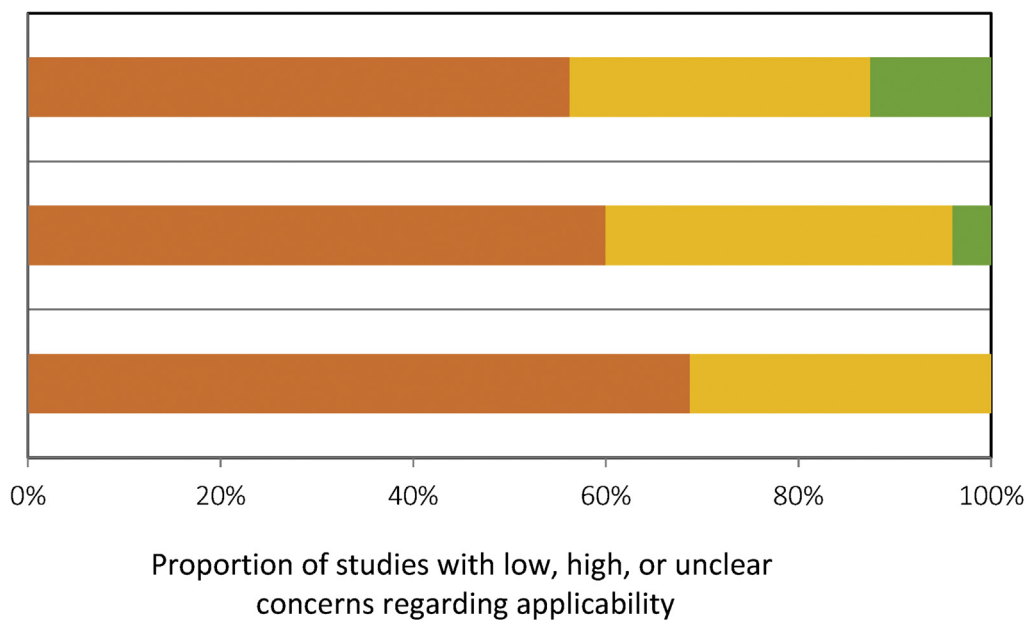


Figure 5 Applicability concerns.

**Application of AI for predicting the need for orthodontic treatment and treatment planning**

Over the past few decades computer applications have been developed to aid the health professionals in clinical decision making. These advancements have been made to overcome the use of indices that were imprecise as their clinical judgments regarding orthodontic treatments were known to vary. In the recent times AI based technology has been used as a clinical decision support systems, to help the

clinicians in decision making. A study based on the AI technology was designed for predicting the need for orthodontic treatment, this model proved to be effective and demonstrated promising results with high degree of accuracy in predicting the need for orthodontic treatment.<sup>23</sup> Another study used an ANN based model for orthodontic treatment planning, the results showed that the performance of the model was highly effective, the model demonstrated excellent accuracy levels in predicting for extraction-non-extraction, and also the anchorage patterns.<sup>24</sup> The results of these studies suggest that these

models can be used as auxiliary guide for lesser experienced orthodontists for predicting the need for the treatment and treatment planning and can be a useful tool for providing secondary opinion.

## Conclusion

Application of artificial intelligence in the field of health care has revolutionized the accuracy in the diagnosis and treatment planning. These systems have proven to be very efficient in performing the tasks for which they have been designed. Orthodontics is a specialty in which the clinician relies mainly on the diagnostic tools for clinical decision making. AI application has proven to be efficient and helpful for the dentist to be more precise in diagnosis and clinical decision making. Results from the various studies reported in this systematic review are suggestive that the accuracy of the AI based systems are quite promising and reliable. These systems can simplify the tasks and provide results in quick time which can save the dentist time and help the dentist to perform his duties more efficiently. The results of these reported studies are valuable for considering these systems in clinical practice. These systems can be of greater aid and can be used as auxiliary support for dentists with lesser experience.

## Conflicts of interest

The authors have no conflicts of interest relevant to this article.

## Acknowledgements

Not applicable.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jds.2020.05.022>.

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