

# Developing and validating a machine learning system for Orthodontic treatment planning- A descriptive study

Hemanth Madaiah<sup>1</sup> | Afshan Saman Waremani<sup>2</sup> | Aravind Marikenchannavar<sup>3</sup> | Shivaprasad Gaonkar<sup>4</sup> | Prajwal Prabhu<sup>5</sup> | Dipasha K Rao<sup>6</sup> | Sanjana Shaji<sup>7</sup>

<sup>1</sup>Professor and Head of Department, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>2</sup>Reader, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>3</sup>Professor, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>4</sup>Reader, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>5</sup>Senior Lecturer, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>6</sup>Senior Lecturer, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

<sup>7</sup>Postgraduate Student, Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India

## Correspondence

Afshan Saman Waremani, Department of Orthodontics and Dentofacial Orthopedics, Dayananda Sagar College of Dental Sciences, Karnataka, India. 560011  
Email: afshansw@dscds.edu.in

## Abstract

**Background:** The success of any orthodontic treatment involves a robust clinical examination along with a comprehensive treatment planning that involves a combination of various essential factors. Orthodontic treatment is a long-term procedure and accurate diagnosis and treatment planning forms the essence of successful orthodontic treatment. The advent of AI (artificial intelligence) has revolutionized dentistry and can prove to be a valuable tool in orthodontic treatment planning. Hence the objective of this study was to construct a machine learning predictive model for orthodontic treatment planning and correlate the treatment plan prediction of the model to treatment plan decided by expert Orthodontists. **Methodology:** The sample consisted of 650 case records of orthodontically treated patients satisfying inclusion criteria. The data was split into a training and a test set. The input layer of variables consisted of parameters that most commonly determine the diagnosis and treatment planning of the patient. The output layer comprised of various modes of treatment. The test set was used to check for the efficacy of the ML predicted treatment plan and compared to that of the decision made by the expert Orthodontists. **Results:** The ML models were trained and the accuracy for Treatment predictive models was deduced. The algorithm Random Forest provided the best results and was used as the predictive model for Treatment planning. This model showed an accuracy of 94.53% and an F1 score of 96.75% for treatment objectives. **Conclusion:** The use of an automated machine learning system allows the generation of orthodontic treatment predictive models.

## KEYWORDS

Treatment planning, Machine learning system, Training and test dataset, Reliability

## 1 | INTRODUCTION

Orthodontic treatment planning is an integral part of orthodontic management and is the second most important part following the patient examination. The prevalence of malocclusion in Indian population is around 20-30%.<sup>1</sup> Orthodontic treatment is a long-term procedure and accurate diagnosis and treatment planning forms the essence of successful orthodontic treatment. Comprehensive deliberate evaluation of numerous factors makes diagnosis and treatment planning a complex

process without any objective patterns, and vigorously relies on the subjective judgement of the orthodontists. Currently, we use patient data which includes many parameters each of which contributes in increasing the accuracy of treatment planning. Expertise knowledge and experience are required to make such an evaluation and correlate clinical features to diagnosis and subsequent treatment planning. Any lapses in treatment planning can lead to irreversible changes and may even be difficult to rectify in future. Orthodontic treatment requires cautious decision-making processes that are the cornerstone of a satisfactory treatment outcome, such as tooth extraction plan and the possibility of surgical interventions<sup>2</sup>. AI is expected to assist orthodontists especially

those inexperienced in making correct decisions. An automated treatment planning which uses objective data than subjective judgement is expected to reduce variability among treatment plans generated. This can also give insight into correlation of successful treatment plans and clinical features which conventionally might be overlooked. In the last few decades, the field of dentistry has widely revolutionized newer technologies mainly based on machine learning technologies that have made a significant contribution and can be used as reliable tools in assisting the clinicians in accurate treatment planning. These machine-learning 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. The specialist can apply this technology for better clinical decision making for orthodontic treatment. Several expert systems have been developed for orthodontic treatment.

## 2 | MATERIALS AND METHODOLOGY

### Source of Data

The data required for the study was collected from the case records of patients undergoing treatment at the Department of Orthodontics and Dentofacial Orthopaedics, Dayananda Sagar College of Dental Sciences, Bengaluru.

**Sample size:** 600 for training, 50 for testing.

**Sampling Method:** Criteria-based sequential sampling.

**Study Design:** Descriptive study.

**Inclusion Criteria:** Patients with complete case records including clinical examination, cephalometric data, and expert treatment plans.

**Exclusion Criteria:** Syndromic patients, previous orthodontic treatment history, or incomplete records.

**Materials:** Case records, ML software (Python, Jupyter, Spyder), Intel-64 processor (4-16 core), 8GB RAM, 500GB-1TB disk space.

**Procedure:** 650 case records were procured. Variables were quantified per the Data Dictionary. Data entry was performed in Microsoft Excel.

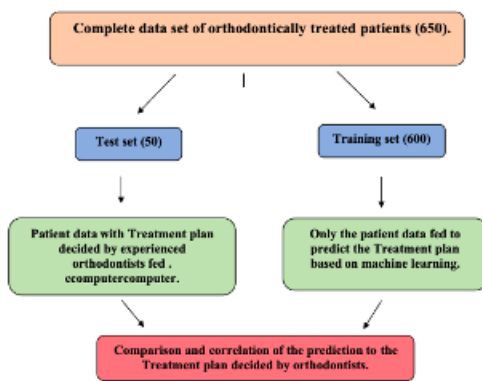


FIGURE 1 Methodology

**Variables and parameters:** The input layer mainly consisted of parameters that is most important in determining the treatment planning of the patient.

The dataset consisted of 25 parameters. The output layer consisted of the mode of treatment. These input variables were processed to ensure all of them were quantified by converting them into numerical values (Data Dictionary) before being used for the model training. The data entry was done in four Microsoft Excel spreadsheets.

**Training set and test set:** The curated dataset was divided into two subsets: a training set and a test set. The division was stratified to maintain proportional representation of different categories within each subset. Approximately 80% of the data was allocated to the training set, while the remaining 20% was reserved for testing the trained models' performance. The machine learning models were developed using the training data: Treatment Objectives Model: This model aimed at predicting the treatment objectives for orthodontic cases. These objectives were categorized into nine different categories, encompassing aspects such as alignment, bite correction, and aesthetic enhancement. This model utilized supervised learning to learn from historical treatment plans and outcomes. The five most suitable algorithms were used to construct the ML model and the data was run with all the algorithms.

Once the model was trained, the test set with only the input parameters without the output was fed. Based on the treatment objectives given by the predictive model was trained and tested to be able to give the accurate output for the same test set of cases. Thus, the accuracy and efficiency of the model was determined.

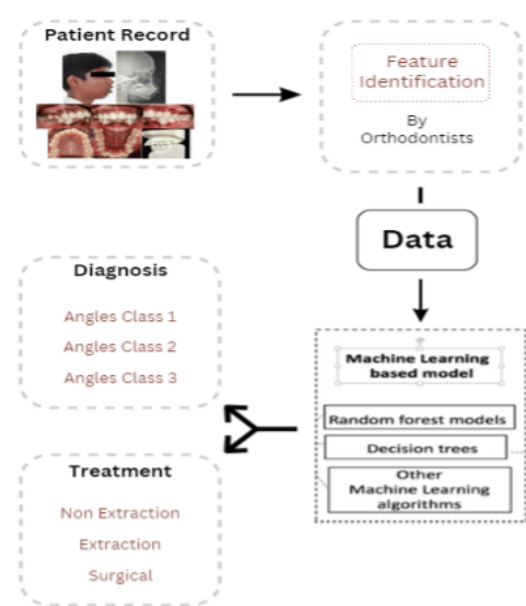


FIGURE 2 Integrative Machine Learning Framework for Enhanced Orthodontic Treatment planning

Machine Learning based AI predictive models require enormous and detailed data for successful operation. Considering the records

**TABLE 1** Input parameters

SI No.	Parameter	SI No.	Parameter	SI No	Parameter
1	Patient Name	13	Lower Incisor to Mandibular Plane	25	Treatment Objectives
2	Age	14	Basal Plane Angle		
3	Gender	15	Y-axis		
4	Clinical FMPA	16	U1 to SN		
5	Naso-Labial Sulcus	17	SNA		
6	Habits	18	SNB		
7	Incisors	19	ANB		
8	Canine	20	UI to NA(mm)		
9	Molars	21	UI to NA(angle)		
10	Overbite	22	LI to NB(mm)		
11	Overjet	23	LI to NB(angle)		
12	Mandibular Plane Angle	24	Max:Mand -2:3		

**TABLE 2** Data Dictionary

SI No.	Numerical data	Categorical data
	Patient ID	Gender: Male, Female
	Age	Clinical FMPA: High, Average, Low
	Overbite	Nasolabial Sulcus: Acute, Obtuse, Average
	Overjet	Incisors: Class 1, Class 2, Class 3, Open bite
	Mandibular plane angle	Canine: Class 1, Class 1 bilaterally, Class 2, Class 2 bilaterally, Class 3, Class 3 bilaterally
	Lower incisors to mandibular plane	Molars: Class 1, Class 1 bilaterally, Class 2, Class 2 bilaterally, Class 3, Class 3 bilaterally
	Basal plane angle	Habits: NRH, Tongue thrusting, Thumb sucking, Mouth breathing, Bruxism
	Y axis	Treatment: Extraction, Non-Extraction, Fixed functional appliance, Twin block, Orthopedic appliance, Surgical
	U1 - SN	
	SNA	
	SNB	
	ANB	
	UI to NA(mm)	
	UI to NA(angle)	
	LI to NB(mm)	
	LI to NB(angle)	
	Max:mand -2:3	

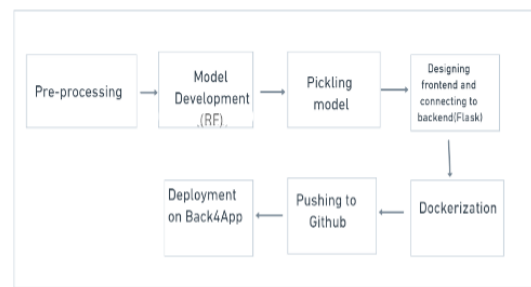
**TABLE 3** Algorithms used

SI No.	Algorithm
1	Logistic Regression
2	Support Vector Classifier
3	Naive Bayes
4	Decision Tree
5	Random Forest

and data available of orthodontically treated patients, generalized and normalized data was obtained and purposive and stratified sampling techniques were used to obtain maximum and proportionate data for each of the layers. 650 was the sample size which was proportionally divided into a training and test set in the ratio 80:20 for enhanced accuracy of the model.

### 3 | RESULTS

The study consisted of 650 samples that were divided into a training set with treatment plan entered in the data and a test set without the treatment plan. The ML models were then trained and the accuracy for Treatment predictive models was deduced. The algorithm providing the



**FIGURE 3** End-to-End Machine Learning Model Development and Deployment Pipeline

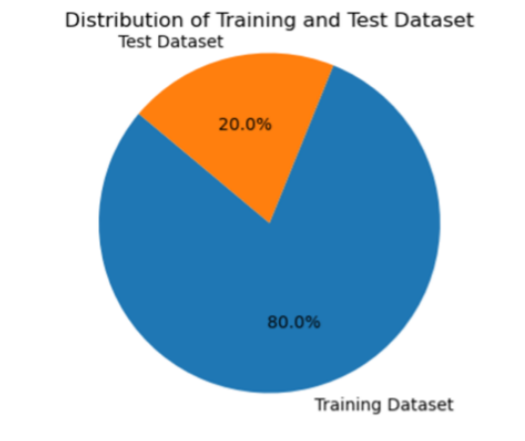
best results was then considered. According to the results, Random Forest provided the best results hence it was used as a predictive model for treatment. This model showed an accuracy of 94.53% and an F1 score of 96.75% for Treatment objectives.

The correlation between the input parameters were also determined with a heat map of the correlation matrix.

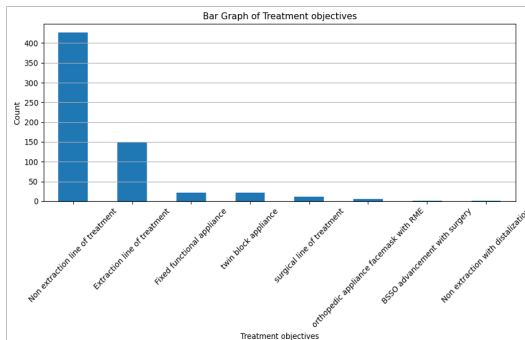
Furthermore, in this study, the relative contribution of the individual parameters or factors to the treatment plan was determined and the top ten parameters were ranked according to their importance.

**TABLE 4** Treatment – Accuracy

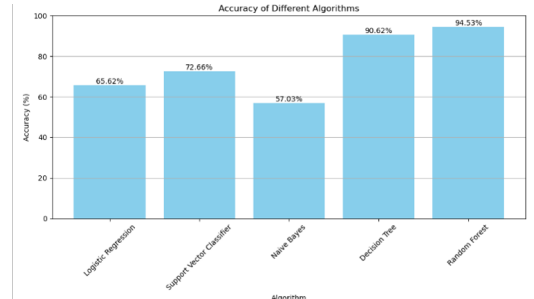
	Algorithm	Accuracy	Precision	Recall	F1 Score
0	Logistic Regression	0.656250	0.688058	0.765625	0.715326
1	Support Vector Classifier	0.726562	0.668896	0.750000	0.674039
2	Naive Bayes	0.570312	0.672764	0.515625	0.553869
3	Decision Tree	0.906250	0.948614	0.945312	0.946292
4	Random Forest	0.945312	0.970052	0.968750	0.967594



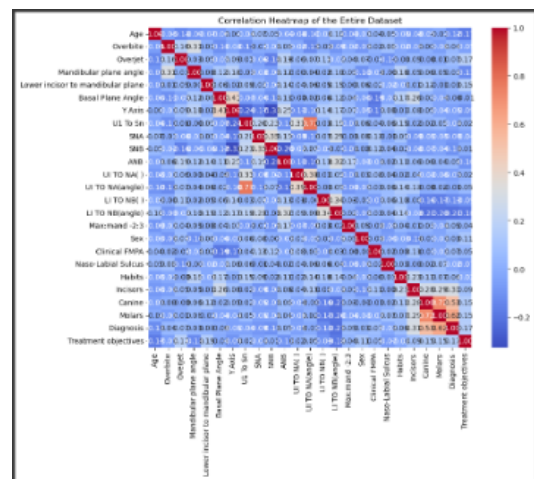
**FIGURE 4** distribution of test and train dataset



**FIGURE 5** Bar Graph of Treatment Objectives



**FIGURE 6** Accuracy of Treatment model

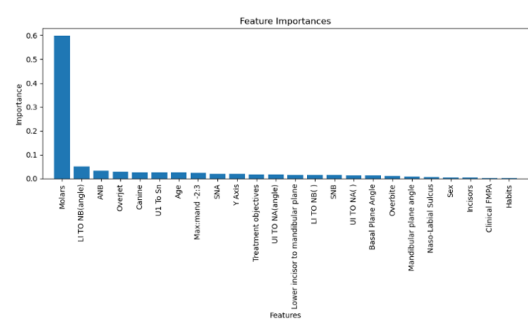


**FIGURE 7** Heat map of correlation matrix for Treatment. The colour gradient indicates the strength of the correlation with blue being the least and red being the highest correlated parameters

## 4 | DISCUSSION

Orthodontic treatment requires cautious decision-making processes that are the cornerstone of a satisfactory treatment outcome, such as tooth extraction plan and the possibility of growth modulation or even surgical intervention. AI is expected to assist orthodontists in making correct decisions. Many studies have been carried out in orthodontics that have made use of AI and ML to predict various aspects of treatment planning most of which deals with cephalometric landmark identification<sup>3</sup> and extraction-non extraction decisions.<sup>4</sup> There is a scarcity of studies in predicting a broader outline and the major mode of treatment considered. This has been attempted in our study which seeks to develop a predictive model harnessing the power of AI and ML to aid in determining the most suitable treatment objectives.

Through rigorous training, our ML model was equipped to analyze orthodontic data and provide valuable insights into treatment planning. This innovative approach holds promise for enhancing the precision and efficiency of orthodontic care, thereby potentially revolutionizing the field of orthodontics. A few studies have been conducted to determine the usefulness of AI in orthodontic treatment planning. A study by Park et al.<sup>5</sup> compared two AI machine learning algorithms for automated identification of cephalometric landmarks and concluded that the AI accurately identified the landmarks with approximately 50% accuracy while our study compared 5 different algorithms for finding out the highest accuracy for the input data provided. Real et al<sup>6</sup> developed and



**FIGURE 8** Feature importance graph for Treatment

explored the usefulness of an artificial intelligence system for the prediction of the need for dental extractions during orthodontic treatments based on gender, model variables, and cephalometric records and generated prediction models with an accuracy of 93.9% whereas in this study different treatment modalities like extraction, non-extraction, surgical line of treatment and growth modulation were taken into consideration. A study by Kk et al.<sup>7</sup> showed the application of AI algorithms aimed at determining growth by Cervical Vertebrae Maturation Index (CVMI) stages in orthodontics utilizing cephalometric radiographs showcasing various classifiers, including Random Forest, Logistic Regression, Decision Tree, K-Neighbors, Artificial Neural Networks (ANN), Linear Support Vector Machine (SVM), and Naïve Bayes. Notably, their findings indicated that the Decision Tree Classifier exhibited the highest accuracy among the classifiers employed. In this study, focusing on orthodontic datasets, we conducted a comparative analysis leveraging similar AI algorithms. Contrary to Kk et al.'s findings, the results of this study demonstrated that both the Random Forest and Decision Tree algorithms exhibited superior accuracy in handling orthodontic data. Through meticulous evaluation and experimentation with these classifiers, our study underscores the efficacy of Random Forest and Decision Tree algorithms in achieving heightened accuracy levels when applied to orthodontic datasets. In a study by Suhail et al.<sup>8</sup> he predicted tooth extraction, diagnosis, and extraction patterns with a total of 287 samples using three types of AI softwares namely ANN(Artificial neural network),RF(random forest) and LR(Logistic regression) and concluded that for extraction patterns RF outperformed ANN, while this study compared only extraction line of treatment the algorithm used by Random forest displayed the highest accuracy similar to our study. Yu et al.<sup>9</sup> used a deep learning multimodal CNN model for skeletal classification using cephalometry in orthodontic diagnosis and treatment planning. The model showed high performance in classifying skeletal jaw bases. Although deep learning algorithms have been shown to improve performance when applied to cephalometric analysis, many of these studies focus on detecting cephalometric landmarks only. Compared to the above studies which made use of cephalometric data alone, in this study we used a trained model which included orthodontic clinical data with 25 parameters and patient information like age, gender, etc. to predict treatment objectives. Also, in comparison with study by Kk et al.,<sup>7</sup> two of the algorithms namely Decision Tree and Random Forest

showed high accuracy from 90-95% in treatment plan prediction model. Jung et al.<sup>2</sup> used ANN for diagnosis of extractions and extraction patterns. In addition to cephalometric measurements, 6 indexes—maxillary arch length discrepancy index, mandibular arch length discrepancy index, molar key index, large overjet index, protrusion index, and chief complaint index for protrusion—were included in the input data. The study was done with 156 subjects with 80% accuracy achieved in results. Peilin Li et al.<sup>10</sup> used multilayer perceptron ANN for determination of extraction-non extraction, extraction patterns and anchorage type in 302 subjects with 82% accuracy. Xi et al.<sup>11</sup> constructed a decision-making electronic system using ANN to determine the necessity of orthodontic extractions in patients between 11-15 yrs. The above studies have been conducted majorly to determine the need for extractions and their patterns in orthodontics with approximately 150 – 300 subjects using ANN. Whereas, this study used and compared 5 different algorithms (Table 3) for a much larger sample size of 650 to improve the performance of the model and dealt with orthodontic treatment options such as extraction, non-extraction, surgical line and many other objectives. Comparative to other studies, the ML model used in this study achieved an improved accuracy of 95% in the treatment model. Furthermore, this study determined not only relative contribution of factors but also deduced the inter factor correlation with heat maps and charts. According to the results of this study under the heat map analysis (Figure 7), the highest correlation (varying shades of red indicating the strength) was been found between – UI TO NA(angle)and U1 To Sn; Molar relation and Canine relation; Diagnosis and Molars relation; Diagnosis and Canine relation; Y Axis and Basal Plane Angle. The least correlation (varying shades of blue indicating the strength) as per the results was found between – SNB and Y Axis; ANB and SNB; U1 To Sn and Y Axis; LI TO NB(angle) and Diagnosis; LI TO NB(angle)and Canine relation. The Feature importance graph (Figure 8) revealed for the treatment plan prediction, the highest contribution is of molar relation followed by LI to NB angle, ANB angle, overjet, canine, U1 to SN, age. Diagnosis and treatment planning are especially important in orthodontics. This is because many treatments are irreversible, or cause irreversible adverse effects such as apical root resorption, gingival recession and dental caries. Because of this irreversibility, the recall and F1 scores of the ML model is of more importance for reliability in its prediction. Therefore, the system output showed the highest F1 and accuracy value in treatment prediction (Table 4) for the random forest predictive model for treatment. This supports efficient implementation of the model for clinical practice. To evaluate the model's capacity in classifying treatment plans accurately, we constructed a treatment model tailored to identify treatment objectives (Figure 5). Subsequently, we subjected the model to rigorous testing on various parameters to discern its efficacy in prescribing the appropriate treatment plan according to the patient's condition and needs. This approach not only gauges the model's performance but also ensures that the treatment rendered to each patient is meticulously tailored, optimizing the orthodontic outcomes and enhancing patient care. However due to increased complexity and limited data set for training, various other modes of treatment such as expansion, distalization

etc. were not considered. The predictive models aimed to generate key treatment options crucial for orthodontic care. In terms of treatment options, the models provided a comprehensive array of choices, including extraction and non-extraction methods, surgical interventions, and various other modalities tailored to address specific orthodontic concerns. The diverse treatment options highlighted in Figure 5 underscore the versatility and adaptability of the predictive models in accommodating the multifaceted nature of orthodontic cases, thereby facilitating personalized treatment plans optimized for each patient's unique needs and circumstances.

## 5 | LIMITATIONS OF STUDY

Medical data is often too complex for detailed AI analysis. Thus, despite the high performance of the ML model in the present study, the main limitation was the amount of data (E.g.: skeletal class II cases are more prevalent, class III surgical cases are rare due to patient preferences, crowding cases are more prevalent demanding extractions etc.) and so the model was trained with data that could have been affected by selection bias. Orthodontic diagnosis and treatment planning is highly intricate, subjective, multifactorial with consideration of innumerable factors such as facial appearance, skeletal relation, patient's general dental condition etc. The functional, camouflage and surgical planning requires a thorough careful examination which is not all about measurements and values. The ML model could not include complex orthodontics cases like skeletal deformities, uncommon extraction patterns, soft tissue functions etc. There are various ways to treat a malocclusion. There is no definite answer on how to treat an orthodontic patient. The purpose of this study was not to find the correct answer. It was to assess whether the ML predictive model could provide a reference or assistance to less experienced practitioners by emulating the dynamics of experienced orthodontists.

## 6 | FUTURE SCOPE OF STUDY

The ML model constructed in this study can be further improvised with detailed and more amount of data which are of complex nature using various theories and philosophies of orthodontic diagnosis and treatment planning. It can be integrated with already existing orthodontic softwares<sup>12</sup> and programmed to naturally gauge the information for a comprehensive structured and customized treatment plan for every individual. There is a need to undertake more studies and researches in the field of orthodontics to analyze the applicability and efficacy of AI and ML. The wide variety of clinical data collected from different clinicians is of great help in model training to improve performance. From an epidemiological point of view, this model is a useful tool for analyzing large amounts of existing data for an elementary classification of the treatment options in order to create large datasets for future retrospective studies. Machine Learning models may not have the subtle

expert decision-making ability due to the limited quality of technological expertise and training data but with rapidly advancing AI innovations and continuous improvement of the diagnostic system by improving the quality and quantity of data, Machine Learning Predictive model can be an effective Clinical Decision Support System for orthodontists in the near future.

## 7 | CONCLUSION

In this study, a pioneer elementary attempt was made to predict the treatment plan using an Artificial Intelligence-Machine Learning model for patients requiring orthodontic treatment and the reliability was compared to that of expert orthodontic decisions. It was concluded that the Machine Learning predictive models can be trained and the accuracy for Treatment predictive models were deduced. The algorithm providing the best results was then considered. According to the results, Random Forest provided the best results hence it was used as a predictive model for treatment planning. This model showed an accuracy of 94.53% and an F1 score of 96.75% for Treatment objectives. Thus, the Machine Learning Predictive model can become a valuable Clinical Decision Support System in the field of Orthodontics in the near future and provide orthodontists a diagnostic framework, flexibility and feasibility of different treatment options.

## REFERENCES

1. Proffit WR, Fields HW, Sarver DM. Contemporary orthodontics. 5th ed. St Louis: Mosby; 2013.
2. Jung SK, Kim TW. New approach for the diagnosis of extractions with neural network machine learning. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2016 Jan 1;149(1):127-33.54.
3. Lindner C, Wang CW, Huang CT, Li CH, Chang SW, Cootes TF. Fully automatic system for accurate localisation and analysis of cephalometric landmarks in lateral cephalograms. *Scientific reports*. 2016 Sep 20;6(1):1-0.
4. Martina R, Teti R, D'Addona D, Iodice G. Neural network-based system for decision making support in orthodontic extractions. In *Intelligent Production Machines and Systems 2006* Jan 1 (pp. 235-240). Elsevier Science Ltd.
5. Park JH, Hwang HW, Moon JH, Yu Y, Kim H, Her SB, Srinivasan G, Aljanabi MN, Donatelli RE, Lee SJ. Automated identification of cephalometric landmarks: Part 1— Comparisons between the latest deep-learning methods YOLOV3 and SSD. *The Angle Orthodontist*. 2019 Nov;89(6):903-9.
6. Real AD, Real OD, Sardina S, Oyonarte R. Use of automated artificial intelligence to predict the need for orthodontic extractions. *Korean J Orthod*. 2022Mar 25;52(2):102-111.

7. Kök, H., Acilar, A.M. & İzgi, M.S. Usage and comparison of artificial intelligence algorithms for determination of growth and development by cervical vertebrae stages in orthodontics. *Prog Orthod.* 20, 41 (2019).
8. Suhail Y, Upadhyay M, Chhibber A, Kshitiz. Machine Learning for the Diagnosis of Orthodontic Extractions: A Computational Analysis Using Ensemble Learning. *Bioengineering (Basel).* 2020 Jun 12;7(2):55.
9. Yu HJ, Cho SR, Kim MJ, Kim WH, Kim JW, Choi J. Automated skeletal classification with lateral cephalometry based on artificial intelligence. *Journal of dental research.* 2020 Mar;99(3):249-56.
10. 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 Feb 14;9(1):2037.
11. Xie X, Wang L, Wang A. Artificial neural network modelling for deciding if extractions are necessary prior to orthodontic treatment. *The Angle Orthodontist.* 2010 Mar;80(2):262-6.
12. Noroozi H. Orthodontic treatment planning software. *American journal of orthodontics and dentofacial orthopedics.* 2006 Jun 1;129(6):834-7.

**How to cite this article:**

Madaiah H, Waremani S A, Marikenchannavar A, Gaonkar S, Prabhu P, Rao DK, Shaji S. Developing and validating a machine learning system for Orthodontic treatment planning- A descriptive study. *World J Dent Excell.* 2025;1(2):4-10.