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Original Research Article

Artificial intelligence-based automated model for prediction of extraction using neural network machine learning: A scope and performance analysis

Mridula Trehan[1]*, Deeksha Bhanotia[1], Tarannum Alam Shaikh[1], Shivangi Sharma[1], Sunil Sharma[1]

[1] *Dept. of Orthodontics, NIMS Dental College & Hospital, Rajasthan, India*

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ABSTRACT

Objective: To compare the Artificial Intelligence based model & conventional technique for prediction of extraction in orthodontic treatment plan.

Materials and Methods: A comparative study was conducted on total 700 patients, who were divided into training set and testing set based on simple random sampling by means of computer generated random numbers. The photographs of the 630 patients [training set] along with the treatment plan finalized for them based on Arch Perimeter & Carey's Analysis, was fed in the AI model [convolutional neural network (ResNet-50)] in order to train it for the stipulated function of eventually predicting the treatment plan in the testing set [70 patients], based on the input of the right profile photographs. The accuracy of measurement of the parameters of these seventy test set patients by the machine learning model relative to the manual method was compared eventually. Using the Statistical Package for Social Sciences, the acquired data was statistically analyzed, and $p < 0.05$ was deemed statistically significant. The normality of the data was examined using the Shapiro-Wilks test and the Kolmogorov-Smirnov test. Depending on the collected data and normality assessed, appropriate reliability was estimated.

Result: The analysis of 70 test patients showed that 65.12% of the total extraction cases and 62.96% of the total non-extraction cases (as predicted by the AI model) were in agreement with the results of the model analysis.

Conclusion: It is suggested that the present AI model can further be developed in order to improve the accuracy of prediction.

1. Introduction

The use of computers and other technologies to simulate human behavior and mental processes is known as artificial intelligence, or AI. John McCarthy first described the term AI in 1956 as the science and engineering of making intelligent machines.[1] The goal of AI is to produce a machine that is able to learn through data and can solve problems by itself.[2]

In recent years, orthodontics has made extensive use of artificial intelligence to improve the efficiency and accuracy of the diagnosis process. Since healthcare professionals are ultimately responsible for diagnosing patients and determining the best course of therapy, the advent of AI-based models cannot completely replace them.[3] AI may be a helpful tool for making precise healthcare judgments in a short amount of time. AI apps can help doctors make better judgments and hence perform better since the results produced by AI are often quite accurate and can thus be utilized, in certain situations, to prevent human errors.[4] They are dependable, faster, and have the potential

* *Corresponding author*.
E-mail address: anonymous72000@gmail.com (M. Trehan).

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to automatically complete tasks with the competence of experienced clinicians.[2–5]

Plaster study models are an integral element of the orthodontic patient record. They provide a progressive record of care, which the practitioner uses as a diagnostic tool. Plaster model technique has better repeatability for many of the parameters.[6] Plaster models may not be an accurate replica of the real tooth dimensions due to dimensional changes in the impression materials and stone during preparation, even if they have been utilized for the construction of appliances that fit precisely in the mouth.[7] However, plaster models have been authenticated since many years, but their use is associated with several problems, mainly storage, mutilation and loss.[8]

A comprehensive diagnosis and treatment planning leads to a successful orthodontic treatment. The degree of obliquity and the mismatch between the arch form and tooth dimensions is assessed using orthodontic model analysis as one of the diagnostic and treatment planning tools.[9] This eases the three-dimensional (3D) documentation of the dental arches in pre-treatment, progress and post-treatment records.[10] Important components of an orthodontic treatment planning include tooth size- arch length discrepancies, maxillomandibular relationship, facial profile, skeletal maturation, dental asymmetries, and patient cooperation.[11] Tooth crowding and protrusions demand rigorous attention during orthodontic planning and may require the extraction of first or second premolars.[12]

Strict observation and indications are necessary for application of extraction modality.[13] It involves thorough knowledge of the laws governing the movement of teeth post extraction, the normal development of the orofacial system and the eruption of teeth. Inconsiderate extractions performed without thorough prior analysis lead to irreparable damage rather than improvement of the situation.[14] For most cases, extractions must precede fixed mechanotherapy to achieve controlled closure of the spaces, alignment of teeth in the dental arch and restoration of proper occlusion.[15]

The choice between extraction and non-extraction treatment modality is an endless debate in orthodontics that has seen many phases throughout the journey of time. The model analysis of permanent dentition should be performed meticulously so that different treatment possibilities can be explored.[16]

Due to the shortcomings of performing model analysis(es) manually, attempts have been made to utilize technology in order to minimize human errors and thereby aid in the enhancement of diagnostic accuracy.[17] Artificial Intelligence is certainly expected to present a lucrative deal in this regard. This study was performed in order to compare the judgement for the need for extraction in orthodontic treatment planning between the conventional technique based on Arch Perimeter and Carey's Analysis performed on plaster study models and artificial intelligence-based automated model.

2. Materials and Methods

A comparative study was conducted in National Institute of Medical Sciences University to predict the need for extraction in orthodontic treatment planning using Artificial Neural Network modelling and conventional technique. Data of seven hundred patients reporting to the Department of Orthodontics and Dentofacial Orthopaedics at the institution who met the inclusion criteria were considered for the study.

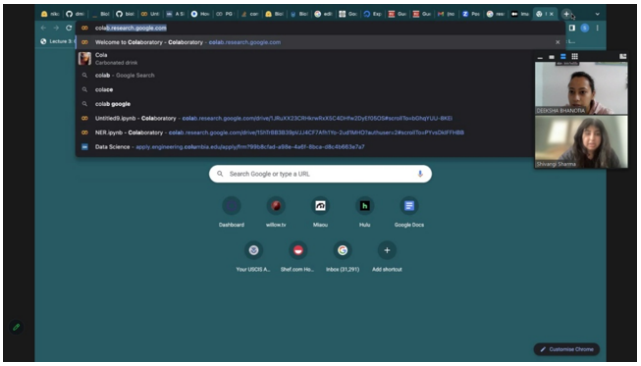


Figure 1: Artificial neural network model

Figure 2: The extra-oral right profile photograph of the patients

Table 1: Distribution of patients advised for extraction or non-extraction treatment modality based on model analysis, constituting the TRAINING SET for the AI model

Treatment plan	No. of patients (% of the total training set data)
Indicated for extraction	284 (45.07%)
Not indicated for extraction	346 (54.92%)
Total	630(100%)

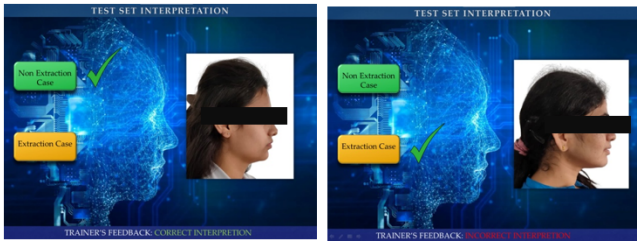
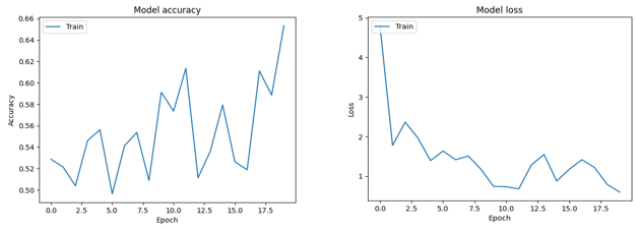
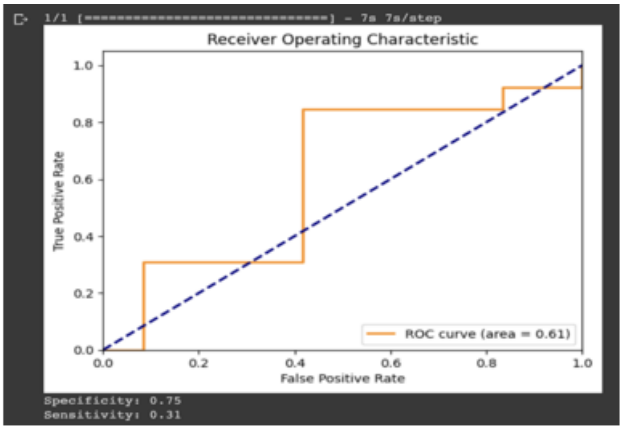


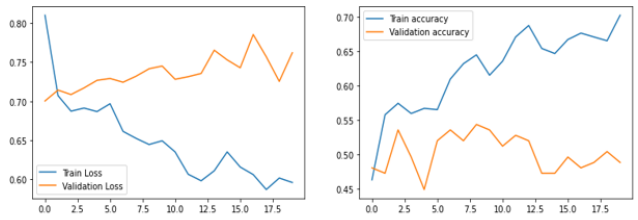
Figure 3: Interpretation of diagnosis using software based on right profile photograph



Graph 1: Graph depicting model accuracy and model loss in training set



Graph 2: The ROC graph for the ANN model



Graph 3: Graphs depicting the validation accuracy of the algorithm of the model

Table 2: Treatment plan derived using model analysis for patients in Test Set

Treatment plan	No. of patients (% of the total test set data)
Employing extraction	38 (54.28%)
Not employing extraction	32 (45.72%)
Total	70(100%)

Table 3: Treatment plan predicted by the AI based model for the patients comprising the Test Set.

Treatment plan	No. of patients (% of the total test set data)
Employing extraction	43 (61.42%)
Not employing extraction	27 (38.57%)

Table 4: Interpretation of treatment decision in test group

Treatment decision predicted by AI model	In agreement with conventional method	Not in agreement with conventional method
Extraction	28 (65.12%)	15 (34.88%)
Non extraction	17 (62.96%)	10 (37.04%)

Before the commencement of this study, approval was obtained from the Institutional Ethics Committee, NIMS University Rajasthan, Jaipur. Patients with normal occlusion, patients with malocclusions except Angle's Class II div 2, Angle's Class I type 1 M/O, individuals without a prior history of extraction, orthodontic treatment, or partial eruption of the permanent dentition up to the second molars, as well as individuals without any dental abnormalities up to the second molars, were included. And the exclusion criteria led to elimination of the patients with skeletal asymmetry and maxillofacial deformities, patients with dental crowding, but normal soft tissue profile, patients with Angle's Class II div 2, Angle's Class I type 1 M/O, patients with missing teeth except congenitally missing third molars, patients with impacted or unerupted teeth except third molars & the patients with retained deciduous teeth.

A particular method was used to estimate the sample size based on information from a prior study, and a sample size of 700 was determined to be the appropriate number.

The conventional method comprises the assessment of the need for extraction based on Arch Perimeter Analysis for the maxillary arch and Carey's Analysis for the mandibular arch of the patient. The afore-mentioned model analysis(es) were performed by measuring the mesio-distal diameters of the teeth present in the upper and lower arches respectively, on the plaster study models and recording the same on a graph paper. The arch form was outlined from this graph and the linear arch dimension was recorded. The available linear arch dimension was then measured by adapting a 0.020 brass wire on the cast from the mesial marginal ridge of the first molar on one side to the other, passing over the

premolars through their greatest diameter and around and over the anterior ridge where the incisal edges of the teeth were intended to relocate.[11] Arch- length- tooth material discrepancy was then determined. The inferences for the above analysis(es) being: If the arch discrepancy is lesser than 2.5 mm, there is no need for extraction; the second and first premolars, respectively, should be extracted if the difference is 2.5 to 5 mm and higher than 5 mm.[18]

The dataset, for input feedback of the artificial intelligence based automated model utilized the extra-oral right profile photographs of the patients under study to determine the requirement for extraction in orthodontic treatment planning. A convolutional neural network (ResNet-50), which is a type of ANN, was used to predict the need for extraction. The images were preprocessed as required using horizontal and vertical flipping and rescaling. They were re-sized to sixty-four by sixty-four size images and a batch-size of thirty-two was used to ingest images into the model. The model was specifically designed to be a categorical classification model with two predictive classes and was trained for twenty epochs.

The model consists of two dense layers with one thousand and twenty-four and five hundred and twelve nodes respectively, the ReLu activation function was applied to add non-linearity to the model and a dropout of zero point two was applied to prevent overfitting. With a learning rate of 0.0001, the Adam optimizer was utilized together with category cross entropy loss. The model's test accuracy ended up being around 65%. The data collected was entered into the artificial neural network (ANN) model and was checked for metrics including accuracy, precision, recall, true positive rate, and false positive rate. An ROC curve was also made to analyse the accuracy.

The total data set (700) was divided into training set and test set based on simple random sampling. 90% (630) of the total data constituted the training set.These 630 patients were selected to establish the training set based on simple random sampling by means of computer generated random numbers. Data of the remaining 10% (70) patients was aggregated to constitute the testing set.

The photographs of the 630 patients along with the treatment plan finalised for them based on Arch Perimeter & Carey's Analysis, was fed in the AI model in order to train it for the stipulated function of eventually predicting the treatment plan in the testing set, based on the input of the right profile photographs. The accuracy of measurement of the parameters of these seventy test set patients by the machine learning model relative to the manual method was compared eventually.

The Statistical Package for Social Sciences (SPSS, IBM version 20.0) was used to conduct statistical analysis on the acquired data once it had been imported into Microsoft Excel. Statistical significance was defined as p 0.05, with the threshold of significance maintained at 5%. The normality of the data was examined using the Shapiro-Wilks test and the Kolmogorov-Smirnov test. A suitable estimate of dependability was made based on the data that had been gathered and the normalcy test results.

3. Result

Out of the 630 patients in the training group, 284 patients (i.e. 45.07% of the total training set data) were accepted for extraction treatment and 346 patients (i.e. 54.92% of the total training set data) were chosen for non-extraction treatment based on Arch Perimeter & Carey's Analysis. (Table 1)

Out of the 70 test set patients, 38 patients (i.e. 54.28% of the total test set data) were indicated for extraction and 32 patients (i.e. 45.72% of the total test set data) were not indicated for extraction based on conventional method. (Table 2)

The right profile photographs of the 70 test set patients were uploaded on the AI model and the ANN model was made to predict the treatment plan for the patients based on the profile photographs. 43 patients (61.42% of the total test set data) were predicted to undergo extraction line of treatment and 27 patients (38.57% of the total test set data) were indicated for non-extraction line of treatment. (Table 3)

The treatment decision predicted by the AI based model for the 70 test set patients was eventually compared with the results found in the model analysis for the same, to test the ANN model for accuracy, as rightly suggested by the title of the set.

Out of the 43 patients predicted as extraction cases by the ANN model, the treatment plans for 28 cases (i.e. 65.12% of the total extraction cases as predicted by the AI model) were in agreement with the results of the model analysis, whereas the treatment plan for 15 patients (i.e. 34.88% of the total cases predicted for extraction) did not conform with the findings of the model analysis. Out of the 27 cases predicted for non-extraction treatment modality, 17 patients (i.e. 62.96% of the total non-extraction cases as predicted by the AI model) were presented with a treatment decision which was in agreement with the model analysis, however, for 10 patients (i.e. 37.04% of the total cases predicted for non-extraction treatment modality) the treatment decision was in disagreement with the decision based on model analysis.(Table 4) The sensitivity for the prediction of treatment plan (either indicating or contraindicating the need for extraction) of the AI based automated model was calculated as 64.04%.

4. Discussion

In a variety of clinical situations, artificial intelligence approaches including Bayesian networks, artificial neural

networks, fuzzy expert systems, and hybrid intelligent systems have been applied.[19]

The tremendous increase in the awareness and expectations towards dental health in recent times is encouraging health care professionals to provide better standards of care.[20] Application of AI in orthodontics has the potential to revolutionalize the current system of practice.[21] These automated models simplify tasks and provide results in no time, enabling the orthodontists to become more efficient.[22] The present Artificial Neural Network based model utilizes a profile view of the patient's face to predict if there is need for extraction or not, in order to correct the malocclusion presented by the patient.[23] This valuable clinical aid will not only save time for the orthodontists but can be used as an auxiliary support for less experienced practitioners.[16,24] To determine whether extractions are required before receiving orthodontic treatment, a decision-making expert system based on an artificial neural network (ANN) might be helpful.[25]

In the présent study, out of the six hundred and thirty patients in the training group, cases selected for non-extraction treatment modality were greater in number and the différence in distribution was not statistically significant.[26]

The prediction of accuracy of ANN model was 65.12% for extraction cases and 62.96% for non-extraction cases and the AI model used in the present study had a sensitivity of 64.04%**,** whereas *Xie et al.* (2010) used an ANN system to determine whether an extraction or non- extraction treatment was good for juvenile patients presenting malocclusion, and found the ANN worked with eighty percent accuracy.[27]

Study by *Jung et al.* (2016) suggested the success rates were ninety two percent in the training set and ninety three percent in the test set. The learning set was divided into training set and validation set to minimize overfitting and to verify the fitness of the model.[28]

In the study by *Xie et al.*[7] the age group of patients taken under study was limited to eleven to fifteen years old, unlike our study in which age is no bar. So, our present model ponders to a greater population than the above. At the same time, the procedure in the ANN model developed by *Xie et al.*[27] requires multiple inputs including cast measurements, hard tissue cephalometrics and soft tissue cephalometrics, whereas our present model gives the decision based on the input of just a single and not so difficult to retrieve parameter, the right profile photograph. We are utilizing an essential diagnostic aid for planning the treatment compared to the above study which utilizes a supplementary diagnostic aid, i.e. lateral ceph for diagnosis, which makes our study superior.[28–35]

Advantages of the present study are that the present AI model can assess the treatment plan purely based on single parameter i.e., right profile pic and has no boundations of age limit.

The main limitation of the present study is that the sensitivity is confined to 64.04%. Another limitation is that in the training group, the decision for extraction is purely based on Carey's and Arch Perimeter Analysis without any consideration of soft tissue. Additionally, the AI model was unable to take into account patients with soft tissue anomalies, unusual extraction patterns & missing teeth.[29,30]

5. Conclusions

A comparative study was conducted to predict the need for extraction in orthodontic treatment planning using Artificial Neural Network modelling and conventional technique to conclude that the ANN model presented a sensitivity of 64.04% relative to the conventional method. The prediction accuracy was 65.12% for the extraction cases and 62.96% for the non-extraction cases relative to the conventional method.

It is suggested that the present AI model can be developed so as to cover all the cases. In the future, increasing the sample size of the dataset further, would give even better results because Deep Learning models generally perform better given a large sample size.

6. Source of Funding

None.

7. Conflict of Interest

None.

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Author biography

Mridula Trehan, Dean and Principal, Professor and Head https://orcid.org/0000-0001-7329-3818

Deeksha Bhanotia, PG Student https://orcid.org/0009-0000-2969-8041

Tarannum Alam Shaikh, PG Student

Shivangi Sharma, Master of Science

Sunil Sharma, Professor Vice Chancellor, Professor

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