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Prediction of Apical Extent Using Ensemble Machine Learning Technique in the Root Canal through Biomechanical Preparation: In-vitro Study

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This work aims to evaluate the dimensions of the apical extent after preflaring with the primary treatment and retreatment on human extracted teeth during endodontic treatment with the help of an ensemble machine learning model. The endodontic file ensures this procedure. It is a medical instrument utilized to eliminate the debris and smear layer as a pulp from the root canal during root canal treatment (RCT). Inadequate biomechanical RCT preparation frequently leads to post-operative apical periodontitis. This results in severe gum inflammation that harms the soft tissues, if left untreated, may harm the bones of the root canals supporting teeth. Therefore, to obtain the proper RCT instrumentation and endodontic treatment, the dimension of the apical extent has been analyzed using a machine learning model in this work. For this study, digital intraoral radiographic images have been recorded with the help of the Kodak Carestream Dental RVG sensor (RVG 5200). The RVG sensor is directly coupled with the CS imaging software (Carestream Dental LLC, NY) to acquire radiographs. Furthermore, the recorded images have been used to measure the dimensions of apical length. The machine learning ensemble classifiers are used in this study to classify the apical condition, such as apical extent, beyond the apical, and up to apical or perfectly RCT. The ensemble bagged, boosted, and RUSboosted trees classifiers are used in this analysis. The maximum accuracy obtained through the ensemble bagged trees model is 94.2 %, the highest among the models. The machine learning approaches can improve the treatment practice, improve RCT results, and provide a suitable decision support system.

Keywords: Root canal treatment; Endodontics; Radiographic analysis; Apical extent; Machine learning.

1 Introduction

A root canal treatment (RCT) can be performed on an infected or inflamed tooth to relieve the toothache from the tooth[1]. The RCT is recommended when a bacterial infection has harmed the pulp[2]. When the pulp has a bacterial infection, the inflammation may cause the germs to grow and propagate. Through the propagation of infection, the canal of the root is caused by bacteria[2]. These bacteria enter the tooth through the mouth and damage the entire canal of the tooth and neighbouring tooth. The germs must be eliminated to cure the endodontic treatment inflammation through the RCT[3,4]. Few indications and symptoms may appear for the pulp infection, such as pain while biting, eating, and chewing, jaw and gums may be swell, *etc*. It has been deemed essential to estimate the apical dimension using an endodontic instrument to manage the RCT to provide an adequate root canal[5–7]. Therefore, the measurement of the apical extension has been investigated in this work to achieve the appropriate endodontic instrumentation.

The technology has been employed in earlier studies in several areas of endodontics and dentistry research to evaluate the strategies for assessing dimensions of the epical extent. Few works dealt with the apical size, and some of the work discussed the dimensions of a root canal. Ibelli *et al.*[8] determine the apical dimension of the effects of cervical preflaring in maxillary lateral incisors. Anatomically significant differences were observed in the apical dimension. Further concluded that they got an accurate association between anatomical and file dimensions. Gesi *et al.*[9]

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investigated the apical extent dimension following the preflaring. The dimensions of the apical were established electronically using the largest instrument. The Mann-Whitney U test was employed to observe the distinction between the treatment group. When there is periapical radiolucency, the apical region of the root canal has a greater dimension. It includes checking each attribute to ensure that such tools are of appropriate sizes for successful canal operation. Kumar *et al.*[10] examined the influence of the apical dimension on vertical root failure. The authors used the lateral compaction technique to prepare the root canal using the rotary nitinol alloy instrument. The radiographic apex was used to acquire the apical root filling. Hung *et al.*[11] worked on root caries for diagnostic prediction using machine learning. The authors developed the support vector machine model to observe the best performance. Performance of AI Applications Developed for Diagnosis of treatment, Decision-Making, and Prediction[12].

The approach of dimension analysis of apical extension has been established in this manuscript. This work used the digital radiographic sensor for image scanning, whereas CS imaging software is used for image acquisition and dimensional measurement. The ensemble machine learning technique has been employed to classify the apical condition of the root canal. This work helps to analyze the apical extent measurement after preflaring the root canal through endodontic treatment. The manuscript is organized in the following manner: The methodology and materials are explained in section 2, which includes the sample preparation, biomechanical preparation, and root canal treatment. Section 3 defined the principle and procedure of the digital radiograph through the RVG sensor. This section also discussed the perfectly filled, underfilled, and overfilled classes of the endodontic treated teeth, which have examined for the research. The ensemble learning model, such as bagged, boosted, and RUSboosted trees, are discussed in the same section. Section 4 discussed the results of the current study before and after analyzing the apical dimensions. Observation of the study is also discussed in the same section. In section 5, a summary of the work is discussed and compared the observation between the three conditions. The conclusion is conveyed in the following section, where the maximum accuracy and performance are obtained in the ensemble bagged trees classifier.

2 Material and methodology

2.1 Sample preparation

Three hundred human extracted teeth were obtained from the College of Dental Science and Hospital Rau, Indore, India. Out of these, one hundred seventy-one human extracted teeth have been chosen for the biomechanical preparation. The hospital provided the extracted teeth contaminated with bacteria and germs. In this stage, extracted teeth require a cleaning process. Thus, before sample preparation,kept these teeth in hydrogen peroxide for a week to properly eliminate the bacteria from the surface. After that, the manual sample preparation method is used, as mentioned by Thakur *et al*. and shown in Fig. 1[13]. After being kept for a week, again clean each tooth individually. After that, use the cold setting powder and liquid material to make the cold mounting. Once dried, remove the mould and get the final produced tooth sample.

2.2 Biomechanical preparation (BMP)

Following the preparation of the tooth sample, the biomechanical preparation to locate the root canal begins. An airotor is used to commence the canal preparation. The airotor gives the initial ditch to the tooth's enamel rotating at a very high speed. Since the enamel is the very hard part of the body, it requires the

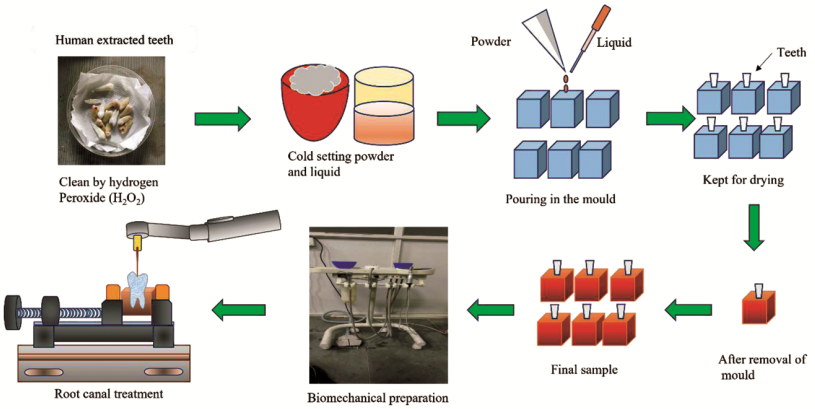

Fig. 1 — Methodology for the sample selection and preparation

optimum ditching speed using pneumatic pressure. Preliminary, the round diamond burr and the straight diamond burr (Prime Dental Product Pvt. Ltd.) are used to open the access. After that, water injection was given continuously throughout the root canal preparation[14]. The biomechanical preparation process includes irrigation, which aids in eliminating necrotic tissue when finding and cleaning the root canal[14–16]. The hand-driven endodontic file system and micromotor were employed to observe the root canal in the teeth sample. To make the canals lengthen and more uniformly shaped and enlarge them using a series of small endodontic files. The proposed approach predicts the apical extent during endodontic treatment using a machine learning technique, as shown in Fig. 2.

2.3 Root canal treatment

Once the root canal has been found from the mounted sample, the RCT process can begin after biomechanical preparation is done. Through RCT, the infected and inflamed pulp is removed with the help of an endodontic instrument. The flat top of the tooth, known as the crown, is opened using an endodontic file to gain access to the soft tissue inside (*i.e.*, pulp) and eliminate any leftover infected debris[17.] The X-smart plus endo-motor (Dentsply, Maillefer, Switzerland) and the motor-driven endodontic file are used for shaping and cleaning during the RCT. Following the removal of the pulp, clean and lengthen the root canal because the root canal is typically relatively small, filling it might be challenging. The duration of the procedure increases with the number of tooth roots possesses.

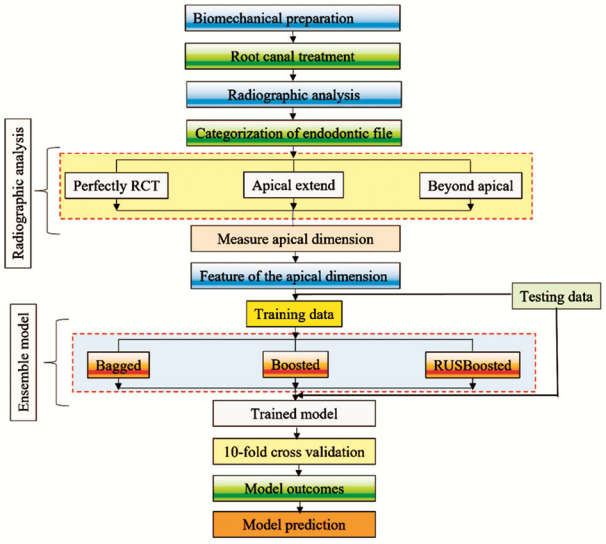

Fig. 2 —The proposed methodology of analysis of apical extent dimension

Root canal therapy is an effective treatment for preserving the tooth and curing the infection.

3 Digital Radiographic Analysis

The digital radiograph has been taken from the Kodak Carestream Dental RVG 5200 Sensor, which is very sophisticated, sensitive, and reliable. This sensor is used for medical imaging and dentistry for digital radiographs, as shown in Fig. 3. In 1987, the French dentist Dr. Francis Mayen invented digital radiography for medical imaging. Various adjustments are made, and current concepts are being established for its application due to this digital technology's effectiveness. Radio Visio Graphy is another name for digital radiography, and this procedure employs an RVG sensor[18,19]. In dentistry, this technology is utilized in place of x-ray radiography[18]. The sensor provides higher photos attributable to the cooperation of a high-sensitivity scintillator, fiber optics, and high-resolution rugged CMOS (complementary metal-oxide semiconductor) sensor. The Kodak Carestream Dental provides two sides of the RVG sensor, one side provides the sensor, and another gives the cable connector. The X-ray radiation is used to expose the endodontic treated sample for examination, and then the sensor records the light that has been refracted. The recorded photograph is immediately processed and transformed into digital data through the Analog-to-Digital converters using CS imaging software (Carestream Dental). The dedicated laptop receives that digital data, enablesto review the images immediately.

3.1 Perfectly RCT or perfectly filled

Analyzethe obtained digital radiograph in this step, where the endodontic instrument successfully carries out the RCT during the procedure. In a perfectly RCT or

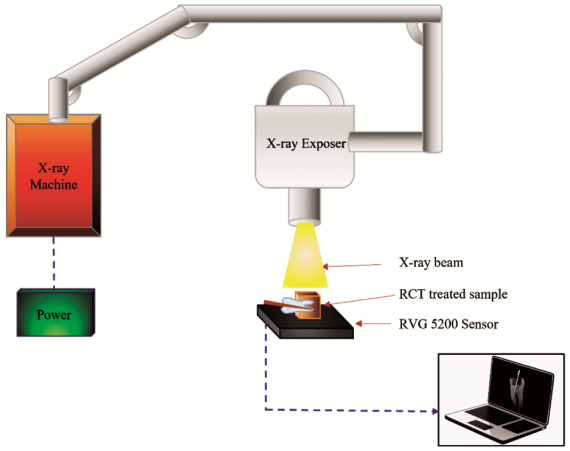

Fig. 3 — Schematic diagram of digital radiographic analysis

perfectly filled category, the apical region of the endodontic file is filled to the apical portion. The endodontic procedure is completed without any inaccuracies.

3.2 Apical extent

The effects of the post-RCT process appear to be most significant at the apical level. In this condition, the endodontic file suffered too short of the radiographic apex, and the file did not reach out to the root canal apical section. The underfilling happens due to the canal blockages inside the root canal, which is visible as an outcome.

3.3 Beyond apical

The endodontic instrument reaches beyond the apical portion of the apical canal root; this situation is overfilled or beyond the apical. Sometimes due to access force during the endodontic treatment, the endodontic file proceeds beyond the root canal. The treatment becomes overfilled.

4 Results

4.1 Apical dimension measurement

The dimensional analysis of apical extent has been carried out following the endodontic treatment and retreatment. The radiographs have been acquired from the RCT-treated mounted tooth using the Kodak Carestream Dental RVG 5200 digital sensor, as shown in Fig. 3. Through the RVG sensor, images have proceeded with the help of CS Imaging software (Carestream Dental LLC, NY). During the radiograph acquisition, there is a time limit for the x-ray exposing the treated sample. Depending on the objects and scanning equipment, the optimum exposure times for digital scanning ranged from 0.02 to 0.13 seconds[20,21]. In this anal ysis, utilized the 0.09 seconds as an x-ray expose time for exposing and scanning the tooth. This is the optimal exposure time for object observations and sensing equipment. Achieved the sharpness and high-resolution radiograph through the optimal parameter, as shown in Figs. 4 & 5. To maximize the visibility of measurement areas, the digital images must be adjusted by altering the contrast and brightness through the CS Imaging software.

4.1.1 Radiographic Images before the Dimensional Measurement

Subsequently, the acquisition of the digital images through the RVG sensor and the image visualization has been carried out in the CS Imaging Software. The digital images are categorized into three categories: perfectly RCT images, apical extension images, and beyond the apical images, respectively, as shown in

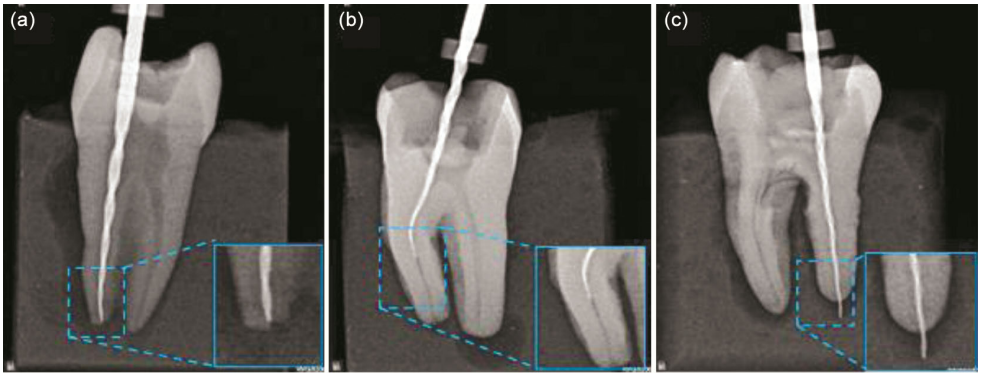

Fig. 4 — Radiographic images analysis before the dimensional measurement (a) perfectly RCT, (b) apical extent, and (c) beyond apical

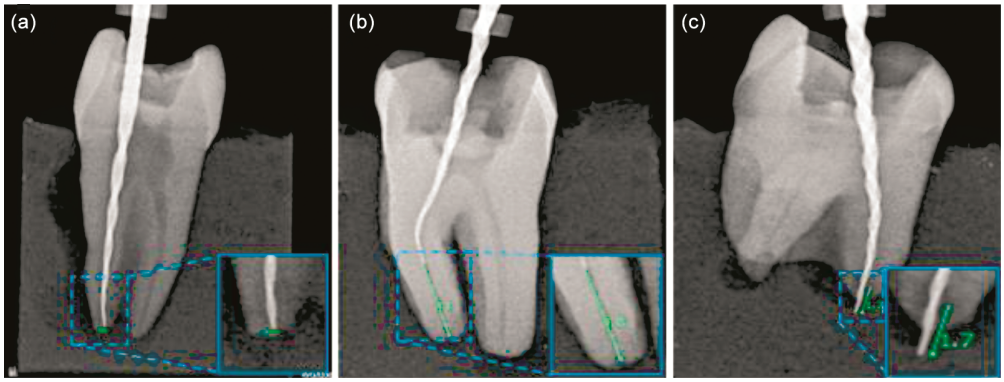

Fig. 5 — Radiographic images analysis after the dimensional measurement (a) perfectly RCT, (b) apical extent, and (c) beyond apical

Fig. 4. From the total of one hundred sixty-four endodontic RCT-treated teeth sample images, each category is analysed, such as perfectly RCT images (n=50), apical extension images (n=88), and beyond the apical (n=26), respectively. In perfect RCT images, most endodontic files are penetrated up to the apex and do not make any errors, as shown in Fig. 4 (a). However, Fig. 4 (b) shows the apical extension, where the endodontic file could not reach the apex position. In another case, the endodontic file penetrated beyond the apical length during the endodontic treatment, as shown in Fig. 4 (c).

4.1.2 Radiographic Images after the Dimensional Measurement

After measuring the dimension of apical extension from the endodontic-treated root canals, digital radiographs are analyzed for all three categories: perfectly RCT, apical extension, and beyond the apical. These three conditions are shown in Fig. 5. The blue colour box denoted the zoomed images of the root canal after the cleaning and shaping, as shown In Fig. 5 (a-c). The green colour line represents the measured dimension of the canal in Fig. 5 (b-c), whereas Fig. 5 (a) shows only the apex position of the endodontic file. The perfect RCT has been observed in Fig. 5 (a) because the root canal is entirely clean and shaped. The apical length is perfectly observed when performing RCT in a straight root canal. In Fig. 5 (b), the RCT-treated image demonstrated the apical extent. It happened because of the chance of canal blockage in the presence of debris, dead tissue, the complexity of the root canal and complex canal anatomy, etc. Beyond the apical or overfilled endodontic treated radiographic image is shown in Fig. 5 (c). The endodontic tool penetrated beyond the apical length due to the improperly executed RCT or perhaps the access load applied to the instrument during the RCT Measurement of the apical dimension has been calculated during RCT with the following condition such as perfectly RCT, apical extent, and beyond the apical, as shown in Fig. 6.

4.2 Performance of the Ensemble Models

The ensemble machine learning technique has been implemented in this study to classify the apical extension of the root canal during the RCT.A machine learning approach called ensemble techniques, that technique combines multiple base models to create a single, optimum predictive model. The strengths of several ideal base models are combined through ensemble learning. When using this learning technique, many different models are considered and averaged to create a final model. Analyze the optimum model accuracy with their performance through these ML approaches. This approach uses ensemble machine learning such as ensemble bagged trees, boosted trees, and RUS boosted trees.

4.2.1 Ensemble Bagged Trees

Bootstrap Aggregation, often recognized as Bagging, is also commonly referred to as ensemble learning because it establishes a model by combining Bootstrapping and Aggregation. Bagged trees are a well-known machine learning approach that significantly boosts the prediction power of a single decision tree[22]. A key concept behind bagged trees is that they rely on various decision trees instead of one, which enables them to take advantage of the expertise of multiple models.

4.2.2 Ensemble Boosted Trees

Similar to the bagged trees, a collection of decision trees is combined with the boosting ensemble approach to produce boosted trees. Boosted trees correct mistakes made by earlier decision trees. The errors of trees from earlier rounds are considered while creating new trees. Consequently, new trees are produced following one another. Every tree depends on the one before it. Sequential learning is the name given to this sort of learning approach.

4.2.3 Ensemble RUS Boosted Trees

Random under Sampling is referred to as RUS. The RUS boosted is adept at recognizing unbalanced data and indicating that a training data class contains fewer entries than another. In contrast to individual trees, distributed training data are integrated into a robust classifier and repeatedly run-on base learners.

The confusion matrix shows that the training accuracy of the ensemble machine learning models is exceptionally good than the testing dataset, as shown

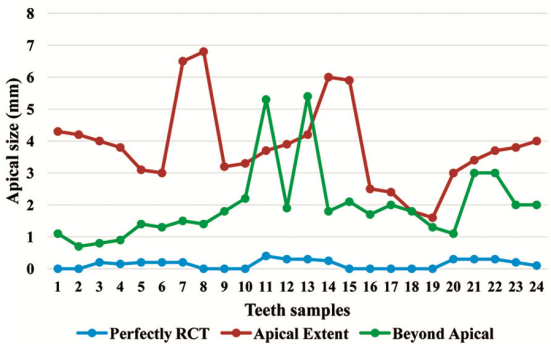

Fig. 6 — Apical dimensional measurement during RCT with the following condition: perfectly RCT, apical extent, and beyond the apical (displayed only 24 samples of each category)

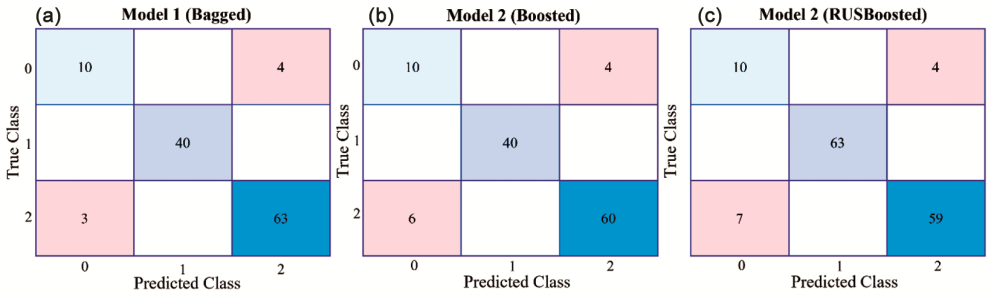

Fig. 7 — Confusion matrix of Training data with their ensemble learning models

Table1 — Performance evaluations of the ensemble machine learning models

Performance	Bagged tree		Boosted tree		RUS boosted	
	Train	Test	Train	Test	Train	Test
Precision (%)	90.32	86.11	85.41	88.24	84.15	87.73
Sensitivity (%)	88.96	83.63	87.44	86.97	86.94	88.78
Specificity (%)	96.85	93.77	95.64	94.92	95.33	95.26
Accuracy (%)	94.16	88.23	91.66	90.19	90.83	90.19
F1 score (%)	89.6	84.54	86.32	87.52	85.33	85.19

in Figs 6 & 7. The classifier successfully detects the model's positive class and true positive rate. The observed accuracy of the training model, such as ensemble bagged trees, boosted trees, and RUSboosted trees, are 94.2%, 91.7%, and 90.8%, respectively. Whereas the testing accuracies of the models are 88.2%, 90.2%, and 90.2%, respectively, as shown in Table 1. The performance of the models includes the precision, sensitivity, specificity, accuracy, and F1 score, respectively.

5 Discussions

In dentistry, machine learning (ML) may anticipate periapical illnesses, root canal failure, apical dimension, endodontic treatment, and retreatment procedures[11–13,23–25]. The present research work involves the dimensional prediction of the apical extension during the biomechanical preparation of the root canal using the ensemble machine learning approach. This approach includes the ensemble bagged, boosted, and RUS boosted trees to predict and classify the dimensional class. Furthermore, analyze the performance of the ensemble learning model and compare the accuracies, precision, sensitivity, and specificity between them.

The RCT accuracy essentially depends on the biomechanical preparation of the root canal. The carelessness of this preparation makes the root canal treatment unsuccessful. The RCT process involves three steps: access opening, shaping and cleaning, and obturation. The access opening step help to open the crown of the teeth, and it uses pneumatic pressure to rotate the high-speed diamond burr. This diamond burr is used to initiate the ditching in the tooth surface. The next step included cleaning and shaping, in which the endodontic file is used to clean the root canal and makes the shape for the endodontic treatment. Shaping and cleaning are the significant steps of biomechanical preparation. Because this study is an in-vitro study with limitations, the third phase, obturation, is not utilized.

Several dental professionals believe that the primary intention of RCT is pulp removal and dentine removal is superfluous[26]. It is a significant misperception that contributes to the high failure rate of RCTs[26]. Even after cleaning and shaping, it is impossible to be sure that all of the infectious dentine is removed. Consequently, removing the affected and inflammatory debris from the root canal is crucial. Otherwise, the endodontic file does not penetrate properly inside the root canal. Thereafter, the overfilled and underfilled endodontic treatments are observed. The adequately filled, underfilled, and overfilled apical length dimensions are studied through the current work.

The Carestream Dental RVG 5200 sensor is used to acquire the radiographic images for the extent of apical dimensional analysis. The image post-processing is carried out using the CS imaging software, where the endodontic-treated root canals' apical lengths are measured, as shown in Figs 4 & 5. The measurement data is post-processed through MATLAB software (Math Works, U.S.). Using MATLAB, the feature has been evaluated through the

measured data, as shown in Fig. 8. All three conditions of the treated canal have been analyzed through features. The observed maximum value is highest compared to the perfectly RCT and beyond the apical. The lowest minimum value is observed in the perfect RCT or adequately filled endodontic-treated canal. The result of the ensemble bagged, boosted, and RUS boosted trees are classified in this work. The maximum accuracy observed from the training data is 94.2 %, obtained from the ensemble bagged tree classifier. In contrast, the minimum accuracy observed from the RUS boosted tree classifier is 90.8%. Figs 9 & 10 represent the area under the curve (AUC) and receiver operating characteristic (ROC). This curve is used to estimate the accuracy of the model. The maximum and minimum AUC of the training datasets are 0.96 and 0.93, as shown in Fig. 9. The maximum and minimum AUC of the testing datasets are observed as 0.96 and 0.91, as shown in Fig. 10. Table 1

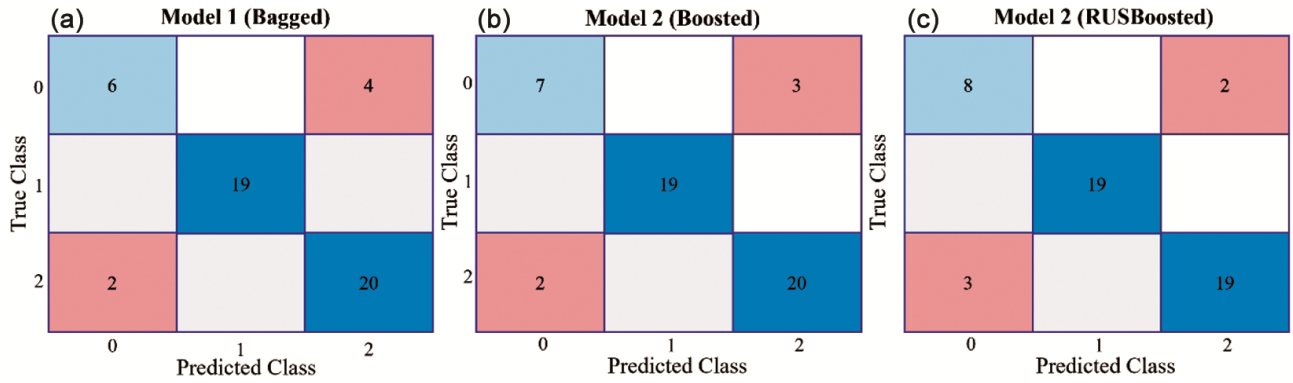

Fig. 8 — Confusion matrix of testing data with their ensemble learning models

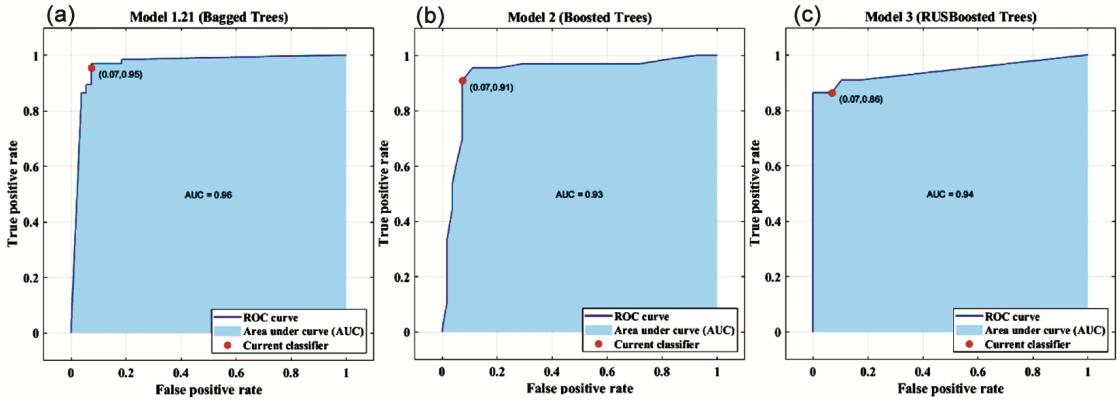

Fig. 9 — The ROC and AUC performance curves of the training datasets.

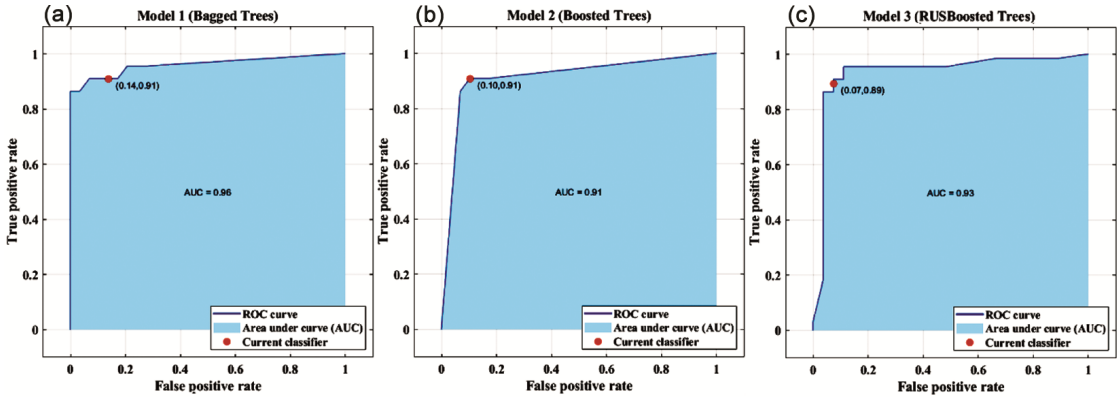

Fig. 10 — The ROC and AUC performance curves of the testing datasets.

demonstrates the performance of the ensemble machine learning model, including the precision, sensitivity, specificity, and F1 score. The ensemble bagged trees model provides excellent results based on their outcomes. The bagged trees noticed the best accurate prediction model when analyzing the apical extension during the biomechanical preparation of the root canal.

Before figuring out the dimension of apical extent, it's advised to preflare the mid and coronal parts of the canal. The margin of error in medical observations of the apical size cannot be eliminated, although it can be minimized[9]. In order to achieve appropriate apical section cleaning, a few literatures have recommended that the root canal's apex section be extended three times higher than the initial files that clinically correlate to the working size[9,17,27].Endodontic instruments are used more than the recommended size in straight root canals. It may be able to decrease the number of debris and germs still present in the section of the canal. Cleaner canals are produced in more significant apical length, which may help to enhance performance. Treatment failure may occur if canals are not cleaned, particularly near the apex[28].The current work uses machine learning techniques to provide practitioners appropriate clinical decision support systems for measuring the apical extent through biomechanical root canal preparation.

6 Conclusions

In the current work, the dimensional analysis of apical extent on the root canal after primary treatment and retreatment on human extracted teeth during endodontic treatment has been studied using the machine learning technique. The apical extension measurement has been analyzed with the help of a radiographic examination. From this research, the following conclusions can be drawn:

1. The approach for analyzing digital radiography images worked incredibly well for determining the apical extent dimensions. Maintaining the post-preflaring using endodontic tools and examining the apical region of the root canals impact the degree of root canal curvature.
2. The apical region of the canal needs to be a specified size, and the root canal must be appropriately shaped and cleaned to prevent over-instrumentation. Due to the root canal's anatomical foramen and anatomical variation, the dimension of the apical extension has been observed in the class of apical extent
3. The maximum feature value is observed in the apical extent class. The minimum feature value is achieved in the perfectly RCT or adequately filled endodontic-treated canal.
4. According to the current investigation, ensemble bagged trees enhance the performance assessment of training and testing datasets compared to boosted trees and RUS boosted trees, with an accuracy of 94.2%.

Conflict of interest

The authors declare that they have no conflict of interest

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References

1 Hulsmann M, Peters O A & Dummer P M H, *Endod Top*, 10 (2005) 30.
2 Peters L B, Wesselink P R, Buijs J F & Winkelhoff A J V, *J Endod*, 27 (2001) 76.
3 Metzger Z, Teperovich E, Cohen R, Zary R, Paqué F & Hülsmann M, *J Endod*, 36 (2010) 697.
4 Thakur V S, Kankar P K, Parey A, Jain A & Jain P K, *Proc Inst Mech Eng Part H J Eng Med*, 236 (2022) 329.
5 McGuigan M B, Louca C & Duncan H F, *Br Dent J*, 214 (2013) 341.
6 Taubman M & Spielman A I, *J Dent Res*, 86 (2007) 922.
7 Nayak A, Kankar P K, Jain P K & Jain N, *Proc Inst Mech Eng Part H J Eng Med*, 233 (2019) 839.
8 Ibelli G S, Barroso J M, Capelli A, Spanó J C E & Pécora J D, *Braz Dent J*, 18 (2007) 102.
9 Gesi A, Mareschi P, Doldo T & Ferrari M, *Int J Dent*, 2014 (2014) 4.
10 Kumar A R P, Shemesh H, Loveren C V, Latha S J, Shireen F, Bharathi R V & Kishen A, *Int Endod J*, 52 (2019) 1283.
11 Hung M, Voss M W, Rosales M N, Li W, Su W, Xu J, Bounsanga J, Ruiz-Negrón B, Lauren E & Licari F W, *Gerodontology*, 36 (2019) 395.
12 Boreak N, *J Contemp Dent Pract*, 21 (2020) 926.
13 Thakur V S, Kankar P K, Parey A, Jain A & Jain P K, *Proc Inst Mech Eng Part H J Eng Med*, 236 (2022) 121.
14 Garg A G N, Textbook of ENDODONTICS 3rd Edn, Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, India, 2014.
15 Molina B, Glickman G, Vandrangi P & Khakpour M, *J Endod*, 41 (2015) 1701.

16 Schäfer E, Irrigation of the root canal, *Endod Pract Today*, 1 (2019) 11.
17 Cohen B R S, Pathways of the Pulp, 6th Edn., Mosby-Year Book, 1987.
18 Harikrishnan P, *J Hand Microsurg*, 8 (2016) 181.
19 Ilić D V & Stojanović L S, *Vojnosanit Pregl*, 69 (2012) 81.
20 Shan J, Tucker A W, Gaalaas L R, Wu G, Platin E, Mol A, Lu J & Zhou O, *Dentomaxillofacial Radiol*, 44 (2015) 1.
21 Yoshiura K, Nakayama E, Shimizu M, Goto T K, Chikui T, Kawazu T, Okamura K, *Dentomaxillofacial Radiol*, 34 (2005) 140.
22 Kumar A, Parey A & Kankar P K, *Indian J Pure Appl Phys*, 60 (2022) 339.
23 Mörch C M, Atsu S, Cai W, Li X, Madathil S A, Liu X, Mai V, Tamimi F, Dilhac M A & Ducret M, *J Dent Res*, 100 (2021) 1452.
24 Qu Y, Lin Z, Yang Z, Lin H, Huang X & Gu L, *J Dent*, 118 (2022) 103947.
25 Nayak A, Kankar P K, Jain N & Jain P K, *J Dent Sci*, 13 (2018) 184.
26 Sharma S, Rajkumar V, Sarin S, Sarin S, Chugh C S & Harmeet K, *HECS Int J Commun Heal Med Res*, 3 (2017) 89.
27 Grossman D D S, *Oral Med Oral Pathol*, 28 (1969) 746.
28 Nair P N R, Sjögren U, Krey G, Kahnberg K E & Sundqvist G, *J Endod*, 16 (1990) 580.