DENTISTRY

Artificial Neural Network for Prediction of Unerupted Premolars and Canines

Saif Mauwafak Ali[1)], Hayder Fadhil Saloom[2)], Mohammed Ali Tawfeeq[3)]

ABSTRACT

Objective: **The purpose of this study was to establish Neural Network for prediction the size of unerupted premolars and canines in Iraqi population.**

Design: **Prospective cohort study**

Subjects and Methods: **for this study, ninety four adult patients (41 males and 53 females) seeking for orthodontic treatment with the age range of 15-20 years were recruited. Data were obtained from intra oral photographs. ANN was developed as new and accurate method for prediction of unerupted teeth using MATLAP program.**

Result: **High degree of correlation was obtained for this Network between the summation of mesiodistal width of premolars, canines of the target and the actual output (r = 90794).**

Conclusions: **This study suggests that artificial intelligence systems with neural network machine learning would be useful as an accurate method in orthodontics for prediction of unerupted teeth and its performance was achieved by components such as proper selection of the input data, preferable generalization and appropriate organization.**

KEY WORDS

digital technology; Artificial Neural Network; MATLAP program.

INTRODUCTION

The nature of malocclusion in orthodontic results from dental, skeletal problems, or a combination of these problems[1)]. A large number of cases of malocclusion develop during the mixed dentition stage as showed by many orthodontic literatures especially during the interval from the 6th to the 12th year of life[2)].

One of the main reasons for patients who seek orthodontic treatment is crowding of teeth since, it is an unaesthetic problems, and furthermore maintenance of oral hygiene also becomes difficult. Intervention can be done to treat or to reduce its severity if it can be diagnosed early during mixed dentition stage[3,4)].

So, the purpose of the analysis during mixed dentition period is to predict as accurately as possible the space required for the alignment of the canines and the premolars[5)].

An important factor in managing the developing occlusion of a growing child is predicting the size of un erupted teeth during the mixed dentition period[6)]. Great importance is given to predict the sizes of un erupted posterior teeth in the mixed dentition especially if a good treatment plan is to be established[7)]. Answering the traditional question of whether the available space in the posterior segments is sufficient depend on accurate prediction to allow the permanent teeth to erupt freely with good alignment in their respective arches[8,9)].

Many reports have indicated attempts to predict the width of un erupted permanent canine and premolars since 1940's[10)]. These methods, namely prediction tables of Moyers (1963) and Tanaka and Johnston equations (1974) are the most largely used because of their simplicity[11,12)]. These methods could be classified into three main categories based on the predictor (independent variable): 1) the evaluation based on the erupted teeth 2) measuring un-erupted teeth on radiographs 3) the combination of the first and second methods is used as a predictor[13)].

An important criteria for a predictive method are accuracy, safety, and simplicity to become a part of the comprehensive case analysis in contemporary orthodontic practice[14)].

However, the accuracy of these methods on other races is doubtful since, they were developed on Caucasian populations only[15)]. Still other methods use regression equations based on the high linear correlation between relevant groups of teeth. The common factor in this category is the possibility of predicting the sizes of unerupted teeth by using the widths of other fully erupted permanent teeth[16-20)].

Globally, digital technology is becoming constantly one of the most important procedures in the clinical activities and, thus, orthodontic digital revolution has been added more and more by orthodontists in their clinical practice[21)].

Currently, many multiple-factor analysis methods are available for medical use and among these Artififcial Neural Network (ANN) model analysis is very commonly used. Recently, there have been many studies about artificial intelligence and bioinformatics[21,22)]. One approach is machine learning using a Neural Network system[23)].

In true sense, ANNs are the simple clustering of the primitive artificial neurons and this clustering occurs by creating layers, which then are connected to one another. As showed in Figure 1, the input layer consists of neurons that receive input from the external environment. The output layer consists of neurons that communicate the output of the sys-

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1) BDS, MSC. PHD student, University of Baghdad, College of dentistry, Orthodontic department
Baghdad, Iraq
2) BDS, MSC, PHD. Orthodontic Professor, University of Baghdad, College of dentistry, Orthodontic department
Baghdad, Iraq
3) MSC, PHD. Computer engineering Asst. Prof, University of Mustansiriyah, College of engineering , computer engineering department
Bagdad, Iraq
Correspondence to: Saif Mauwafak Ali
(e-mail: Saifmowafak777@gmail.com)

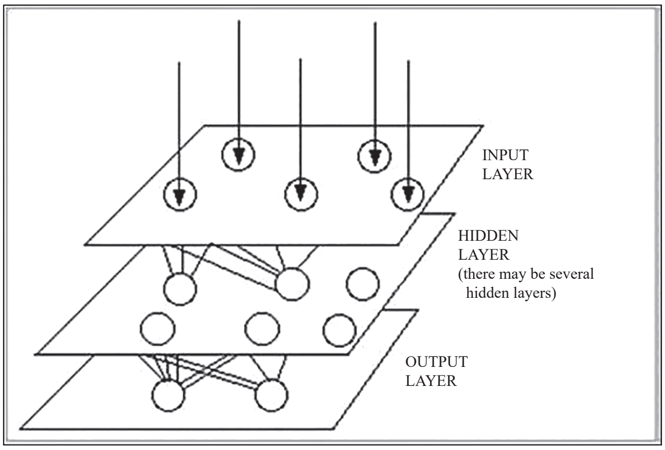

Figure 1: The structure of an Artificial Neural Network.[25)]

tem to the user or external environment. There are usually a number of hidden layers between these input and output layers; however, Figure 1 is just a simple structure with only one hidden layer. When the input layer receives the input, its neurons produce output and this becomes input to the other layers of the system. The process continues until a certain condition is satisfied or until the output layer is invoked and fires their output to the external environment[24)].

Previously, in orthodontics, the use of ANN was restricted for the decision of extraction; the prediction of change in lip curvature; and for the prediction of arch form[25-27)]. The mentioned studies found that, ANN model analyses were more accurate as compared to the conventional ones.

To our knowledge, no studies have employed the ANN for the prediction of un erupted premolars and canines during mixed dentition analysis using intra-oral photographs. Thus this study aimed to make a new artificial intelligence decision-making model for prediction of un erupted teeth through only photographs using neural network machine learning.

MATERIALS AND METHODS

A total of ninety four patients were recruited for this prospective study, with age range of 15-20 years, (41 males and 53 females) seeking for orthodontic treatment. This study was conducted in the Al-Shaab specialist dental center in Baghdad. Inclusion criteria were patients with age range (15-20) years, no previous orthodontic or surgical treatment, all permanent teeth erupted up to second molar included, no craniofacial trauma, and no congenital anomalies Exclusion criteria were patients who were not fit for orthodontic treatment (poor oral hygiene, multiple caries), patients with systemic diseases or pregnant patients, patients were not within the age range. Ninety four dental impressions were taken for both upper and lower arches of patients by using polysiloxane impression material. Maxillary and mandibular occlusal photographs were taken for all the patients using digital camera (Nikon D7500 DSLR Camera, Tokyo, Japan) and Nikon AF-S VR Micro-NIKKOR 105 mm f/2.8 G IF-ED lens. In this technique, a modified intra oral combination mirror was used[28)]. A 35 mm trimmed scale was bonded on the front surface of an occlusal cheek retractor which is used for calibration purposes.

These images were subsequently uploaded into Autodesk Auto-Cad software (21.0). The contact points of lower incisors, upper and lower premolars and canines were marked indirectly.

After that manual space analysis were performed by conventional method using digital Vernier gauge caliper to determine mesiodistal width of lower incisors, mesiodistal width of upper and lower canines and premolars. These dental measurements were validated against the digital dental measurements from intraoral photographs that uploaded into AutoCad software.

Inter and intra examiner calibrations were performed out on a sample of 27 subjects (15 males and 12 females) for assessment of dental factors from intraoral digital photograph and physical plaster dental casts.

In ANN programming, all the data of dental measurements had uploaded into MATLAP program (R2020a v 9.8.0/2020) from the Microsoft Excel. The data was randomly divided into 70% of data for learning (PTrian = 0.7) and 30% for testing. Feedforward backpropogation Network was used. The learning function was Bayesian Regularization Neural Network.

To prevent overfitting, iterative learning was stopped at the minimum error point of the training set. Next, through evaluation of the test set, the adequacy and accuracy were evaluated, and the best-fit model was chosen. The Network was trained by entering the mesiodistal width of the lower incisors in mm values as inputs values for the Network while the outputs values were the mesiodistal width of upper and lower premolars and canines of 94 patients.

After several attempts the best architecture of the network was 1 variable as input values which was the mesiodistal width of lower incisors, 1 hidden layer composed from 5 neurons and 2 variables as output values which was the mesiodistal width of upper and lower premolars and canine.

Statistical Analysis

Data was subjected to statistical analysis using the Statistical Package for the Social Sciences, version 16.0 (SPSS Inc, Chicago, Ill). Descriptive statistics were performed for mesiodistal width of lower incisors and upper and lower premolars and canines. Sexual dimorphism was evaluated by independent sample t-test. Paired t test was used for comparison of side difference and phot-cast difference for the dental measurements. Interclass correlation coefficients (ICCs) were estimated from repeated dental measurements to evaluate the repeatability and reproducibility of the method. Mesiodistal width of lower incisors was compared with mesiodital width of upper and lower premolars and canines to assess Pearson correlation coefficients. Linear regression analyses were made after designing the Networks for real targets of mesiodistal width of premolars and canines (dependent variables) and actual output of mesiodistal width of premolar and canines (independent variables). Levels of $P < 0.05$ were considered statistically significant.

RESULTS

Shapiro-Wilk test was done to check the normality of distribution of data, the findings showed non-significant difference (P-value > 0.05) that means the data were normally distributed.

The intraclass correlation coefficient (ICC) was used to evaluate the test-retest reliabilities of measuring the mesiodistal width of the teeth on casts and on intra oral photos; the values were scored as follows: ICC less than 0.4, poor reliability; ICC between 0.4 and 0.75, moderate reliability; and ICC greater than 0.75, excellent reliability[29)]. The ICC values in this study ranged from 0.97 to 0.99, demonstrating excellent reliability.

Independent sample t-test was used for comparison of gender difference for the dental measurements which showed significant difference only for the mesiodistal width of canines (Tables 1 and 2).

Paired samples T test was done for dental measurements of the intraoral photos and study models. All the results showed non-significance difference between the intra oral photos and study models dental measurements and no significant difference between the mesiodistal width of right and left premolars and canines with strong correlation between these measurements (Table 3).

Since, there were no significant difference and good correlation between intra-oral photo and study model dental measurements. Pearson correlation coefficient was estimated between the summation of mesiodistal width of lower incisors and upper and lower right premolars and canines from the intra oral photo dental measurements. Significant correlations were found ($P \leq .001$) between these measurements (Table 4).

Linear regression analysis was estimated for 70% of the collected data after designing the Neural Network. It showed high coefficients of correlations between the summation of mesiodistal width of right premolars and canines of the targets and the actual output after designing the Neural Network during the training process ($R = 0.831$ during training part, $R = 0.898$ during testing part of training process and $R = 0.840$ as a whole) (Figure 2) with best training performance which was 0.44681 at epoch 6 (Figure 3).

Following testing process linear regression analysis was estimated for the other 30% of the collected data after designing the Neural

Table 1: Gender difference for the Intra-oral photo dental measurements

Measurements of intra-oral photos	Male subjects n = (41)				Female subjects n = (53)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.72	6.40	5.50	0.40	4.82	6.66	5.56	0.42	-0.62	0.53	NS
MD of lower right central incisors	5.51	7.03	6.07	0.39	5.32	6.86	5.99	0.41	0.92	0.36	NS
MD of lower right canines	6.27	8.01	7.03	0.40	5.60	7.37	6.73	0.37	3.64	0.00	S
MD of lower right 1st premolars	5.70	7.80	7.07	0.47	6.00	8.34	7.02	0.53	0.40	0.69	NS
MD of lower right 2nd premolars	6.25	8.22	7.13	0.51	5.97	8.57	6.88	0.47	2.34	0.12	NS
MD of lower left central incisors	4.88	6.71	5.58	0.39	4.89	6.60	5.59	0.42	-0.08	0.94	NS
MD of lower left lateral incisors	5.44	7.33	6.17	0.43	5.16	6.76	6.05	0.39	1.33	0.19	NS
MD of lower left canines	6.43	8.00	7.08	0.40	5.76	7.33	6.67	0.38	5.00	0.00	S
MD of lower left 1st premolars	5.82	7.75	7.12	0.50	6.14	8.21	6.98	0.48	1.29	0.20	NS
MD of lower left 2nd premolars	6.29	8.67	7.21	0.49	5.91	8.44	6.99	0.53	2.02	0.15	NS
MD of upper right canines	6.98	8.90	7.64	0.36	6.64	8.10	7.27	0.29	5.31	0.00	S
MD of upper right 1st premolars	6.10	8.50	6.89	0.46	6.10	7.54	6.78	0.37	1.25	0.21	NS
MD of upper right 2nd premolars	6.00	8.40	6.95	0.51	6.20	7.77	6.81	0.37	1.48	0.14	NS
MD of upper left canines	6.88	8.60	7.60	0.32	6.71	7.98	7.30	0.29	4.53	0.00	S
MD of upper left 1st premolars	6.13	8.21	6.89	0.44	6.00	7.54	6.80	0.35	1.07	0.29	NS
MD of upper left 2nd premolars	6.12	8.33	6.94	0.48	6.27	7.72	6.82	0.36	1.26	0.21	NS

*MD indicates mesiodistal width of teeth; min: minimum; max: maximum; SD: standard deviation.

Table 2: Gender difference for the dental casts measurements.

Measurements of dental casts	Male subjects n = (41)				Female subjects n = (53)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.75	6.60	5.51	0.40	4.85	6.62	5.55	0.41	-0.40	0.69	NS
MD of lower right central incisors	5.50	7.04	6.07	0.39	5.30	6.85	5.98	0.40	1.13	0.26	NS
MD of lower right canines	5.85	7.96	6.98	0.48	5.63	7.37	6.72	0.36	2.97	0.00	S
MD of lower right 1st premolars	5.75	7.91	7.08	0.46	6.03	8.20	7.02	0.51	0.57	0.57	NS
MD of lower right 2nd premolars	6.25	8.22	7.12	0.50	5.95	8.27	6.91	0.46	2.13	0.14	NS
MD of lower left central incisors	4.88	6.63	5.58	0.37	4.90	6.61	5.56	0.41	0.26	0.79	NS
MD of lower left lateral incisors	5.46	7.30	6.17	0.41	5.16	6.73	6.03	0.38	1.60	0.11	NS
MD of lower left canines	6.40	8.00	7.08	0.40	5.76	7.78	6.69	0.40	4.61	0.00	S
MD of lower left 1st premolars	5.80	7.75	7.11	0.50	6.20	8.20	6.97	0.47	1.37	0.17	NS
MD of lower left 2nd premolars	6.30	8.65	7.21	0.49	5.88	8.40	6.96	0.54	0.66	0.13	NS
MD of upper right canines	6.99	8.93	7.63	0.36	6.67	7.99	7.26	0.30	5.34	0.00	S
MD of upper right 1st premolars	6.10	8.55	6.92	0.47	6.11	7.45	6.79	0.35	1.53	0.13	NS
MD of upper right 2nd premolars	6.10	8.41	6.95	0.51	6.23	7.70	6.83	0.37	1.34	0.18	NS
MD of upper left canines	6.87	8.55	7.60	0.32	6.72	7.88	7.29	0.29	4.67	0.00	S
MD of upper left 1st premolars	6.14	8.23	6.91	0.43	6.10	7.43	6.83	0.34	0.92	0.36	NS
MD of upper left 2nd premolars	6.14	8.32	6.94	0.50	6.21	7.70	6.84	0.36	1.15	0.25	NS

*MD indicates mesiodistal width of teeth; min: minimum; max: maximum; SD: standard deviation.

Network. It showed high coefficients of correlations between the summation of mesiodistal width of right premolars and canines of the targets and the actual output R = 0.90794 (Figure 4).

DISCUSSION

One of the most important aspects of odontometric studies is reliability of measurement, which is the ability to obtain the same measurement consistently over sequential measures[30]. In order to improve the reliability of the measurements studied herein, the following steps were employed: using high-quality dental stone for casts fabrication, using of digital calipers to greatly reduce the possibility of reading error and eye fatigue, and assessing intra-examiner variability using inter class correlation coefficient[31].

Therefore, any differences in the mesiodistal tooth widths, if observed, would result from the tooth size variability in the present sample and the prediction methods studied.

In this study, there were no statistically significant differences between the left and right sides. These findings indicate that the right or the left side measurements could be used to represent the mesiodistal tooth widths for this sample. This finding agreed with the usual practice of using teeth on one side of the jaw, or the average of the two, for analyzing the mesiodistal widths of teeth[32,33].

The results showed that there were statistically significant differences in the tooth widths between the male and female subjects. However, the difference was only statistically significant ($p < 0.05$) for the canines. This finding agree with the results of many studies[34-36], who found that only the canines in both the jaws exhibited a significant sexual difference while the other teeth did not. In a continuation of the same studies, they also determined that there was no statistically significant

Table 3: Comparison of photo-cast and side difference for the dental measurements.

Groups		Pair t test	P value	significance	Correlation	Significance
LR centrals p	LR centrals M	-0.04	0.97	NS	0.99	0.00
LR laterals P	LR laterals M	0.86	0.39	NS	1.00	0.00
LR cainines P	LR canines M	1.29	0.20	NS	0.93	0.00
LR 1st premolars P	LR 1st premolars M	-0.19	0.85	NS	1.00	0.00
LR 2nd premolars P	LR 2nd premolars M	-1.06	0.29	NS	0.98	0.00
LL centrals P	LL centrals M	2.12	0.06	NS	0.99	0.00
LL laterals P	LL laterals M	1.16	0.25	NS	0.98	0.00
LL canines P	LL canines M	-0.85	0.40	NS	0.96	0.00
LL 1 st premolars P	LL 1st premolars M	1.96	0.07	NS	0.99	0.00
LL 2nd premolars P	LL 2nd premolars M	1.14	0.26	NS	0.97	0.00
UR canines P	UR canines M	1.58	0.12	NS	0.98	0.00
UR 1st premolars P	UR 1st premolars	-1.70	0.09	NS	0.96	0.00
UR 2nd premolars P	UR 2nd premolars M	-1.87	0.06	NS	0.99	0.00
UL canines P	UL canines M	0.88	0.38	NS	0.99	0.00
UL 1st premolars P	UL 1st premolars M	-2.43	0.06	NS	0.95	0.00
UL 2nd premolars P	UL 2nd premolars M	-1.77	0.08	NS	0.99	0.00
LR canines	LL canines	-0.62	0.53	NS	0.72	0.00
LR 1st premolars	LL 1st premolars	0.45	0.66	NS	0.79	0.00
LR 2nd premolars	LR 2nd premolars	-1.66	0.10	NS	0.73	0.00
UR canines	UL canines	-0.51	0.61	NS	0.93	0.00
UR 1st premolars	UL 1st premolars	-0.92	0.36	NS	0.88	0.00
UR 2nd premolars	UL 2nd premolars	0.15	0.88	NS	0.97	0.00

*LR indicates lower right; LL: lower left; UR: upper right; UL: upper left; P: intraoral photo; M: study model.

Table 4: Correlation coefficients between the summation of mesodistal width of right premolars, canines and mesiodistal width of lower anterior teeth.

Measurements		All subject (n = 94)		Male subjects (n = 41)		female subjects (n = 53)	
		Correlation	Significance	Correlation	Significance	Correlation	Significance
MD of lower incisors	MD of LR premolars and canines	0.84	0.00	0.86	0.00	0.80	0.00
MD of lower incisors	MD of UR premolars and canines	0.83	0.00	0.85	0.00	0.86	0.00

*MD indicates mesiodistal width of teeth; LR: lower right; UR: upper right.

difference between the left and right sides suggesting that measurements of teeth on one side could be truly representative when the corresponding measurements on other side was unobtainable.

In contrast to other studies which showed that there were statistically significant differences in the tooth widths between the male and female subjects for all teeth in both mandibular and maxillary dental arches[37,39]. Moreover, the measurements obtained from the photographs demonstrated a statistically significant high degree of correlation with dental cast measurements with no significant difference between them. So, in this study the measurements were obtained from the intra-oral photos. Although Vernier caliper measurements were regarded as the "gold standard," against which other measurement techniques are compared. Manual tooth-size analysis can be time-consuming in a busy practice, as well as prone to recording and calculation errors[40].

Difficulty in creating a standardized position for the mirror in this area or the angle formed between the lens and mirror when obtaining the occlusal photograph might be the result of slight difference in measurements between dental cast and intra oral photograph[41]. However, this method shows excellent reliability and only minor errors. These data emphasize using this method as a reliable way of obtaining tooth size and dental arch dimensions. The present study is in accordance with many studies[41,24].

Equations developed by data collected from one ethnic group to predict the size of unerupted permanent teeth might not be applicable to another due to racial and ethnic groups present variations in the mesiodistal widths of their permanent teeth[43,44]. Thus, In contrast, the Artificial Neural Network in this study adjusts its structure based on the training samples presented to the system. Therefore, it can be used to predict the size of unerupted teeth in different ethnic groups, provided that an appropriate training data set is presented to the system which have been documented by Moghimi *et al* in 2011[45].

To minimize overfitting and to verify the fitness of the model, the samples were randomly divided into 70% of data for learning (PTrian = 0.7) and 30% for testing from the beginning in our study. In addition, the learning set was divided into the training set and the testing set and all set to make a generalized model. As a result of this, the success rate of the model was better generalized; this has been descripted by jung and kim[46].

An ideal prediction method should result in no difference between the predicted and actual widths of the permanent canines and premolars[45]. In this study figure 6 showed high degree of correlation between the real target and the output (r = 0.90794) with best training performance which was 0.44681 at epoch 6 which make this method very accurate for prediction of un erupted teeth as compared with other conventional methods.

This study has several limitations due to the regional nature, the proposed prediction method was only tested in one ethnic group. More generalized studies in different ethnic groups are needed to validate the feasibility of the proposed method.

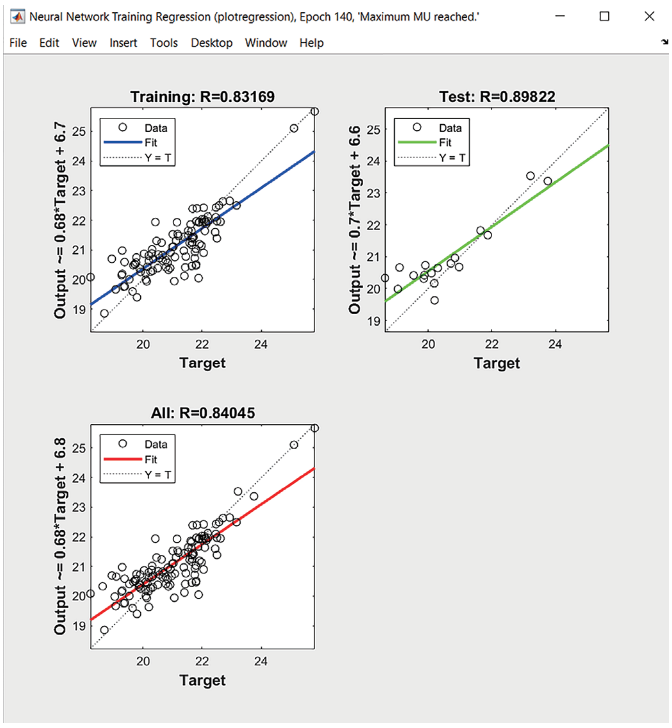

Figure 2: **Scatterplots illustrating linear regression results between the summation of mesiodistal width of right premolars and canines of the targets and the actual output after designing the Neural Network during training process.**

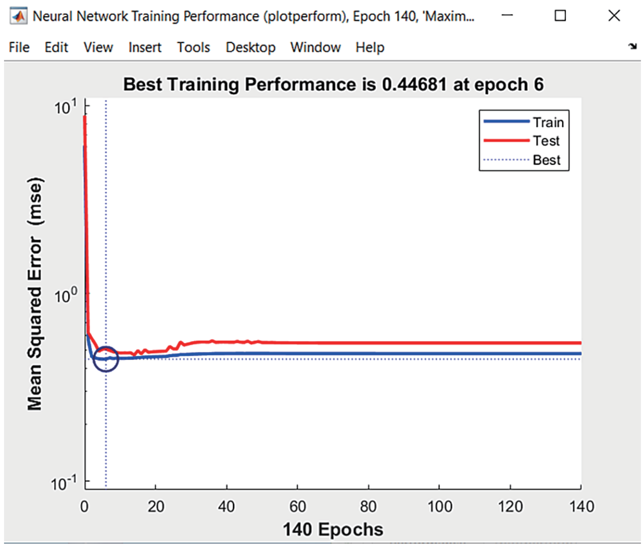

Figure 3: **Best training performance for the Network between the summation of mesiodistal width of right premolars and canines of the targets and the actual output after designing the Neural Network during training process.**

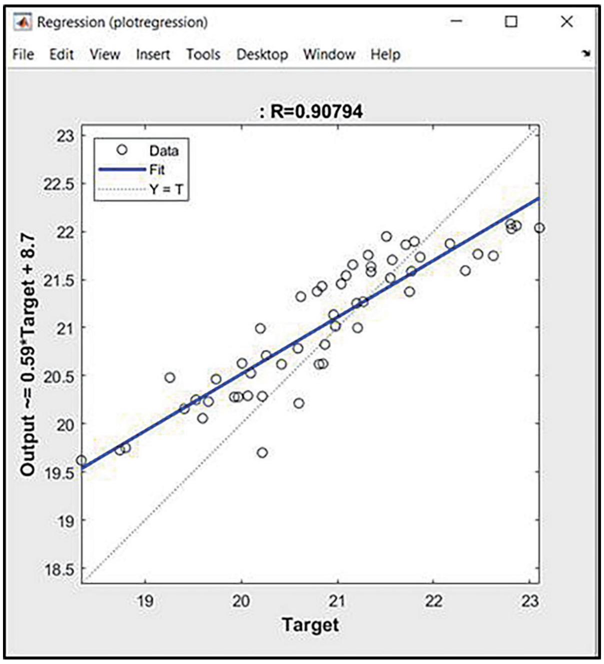

Figure 4: **Scatterplot illustrating linear regression result between the summation of mesiodistal width of premolars and canines of the targets and the actual output after designing the Neural Network during testing process.**

CONCLUSIONS

The proposed method is a promising accurate tool for forecasting the sizes of un erupted premolars and canines, particularly the architecture of this Network can be adjusted based on the data collected from different ethnic groups.

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REFERENCES

1. Martinelli FL, de Lima EM, Rocha R, Tirre-Araujo MS. Prediction of lower permanent canine and premolars width by correlation methods. Angle Orthod 2005;75: 805-8.
2. Proffit WR. Contemporary Orthodontics. 4th ed. St. Louis: Mosby; 2007. p. 462-93.
3. Singh VP, Sharma A. Epidemiology of Malocclusion and Assessment of Orthodontic Treatment Need for Nepalese Children. Int Sch Res Not. 2014; 2014: 1-4.
4. Baral P. Prevalence of Malocclusion in Western Nepal. Orthod J Nepal. 2015; 5(2): 6-8.
5. Alin Boboc , Jos Dibbets. Prediction of the mesiodistal width of unerupted permanent canines and premolars: A statistical approach. Am J Orthod Dentofacial Orthop 2010 Apr; 137(4): 503-7.
6. Galvão MAB, Dominguez GC, Tormin ST, Akamine A, Tortamano A, Fantini SM. Applicability of Moyers analysis in mixed dentition: A systematic review. Dental Press J Orthod. 2013 Nov-Dec; 18(6): 100-5.
7. Shah S, Bhaskar V, Venkataraghvan K, Choudhary P, Mahadevan G, Trivedi K. Applicability of regression equation using widths of mandibular permanent first molars and incisors as a predictor of widths of mandibular canines and premolars in contemporary Indian population. J Indian Soc Pedod Prev Dent 2013; 31: 135-40.
8. Vanjari K, Nuvvula S, Kamatham R. Prediction of canine and premolar size using the widths of various permanent teeth combinations: A cross-sectional study. Contemp Clin Dent. 2015; 6(Suppl 1): S210-S220.
9. Keerthika A., Jeevarathan J. , Ponnudurai Arangannal , Vijayakumar M. , Amudha S. , Aarthi J. Mixed Dentition Analysis Procedure: A Review.Indian Journal of Public Health Research & Development, December 2019, Vol. 10, No. 12.
10. Ballard ML, Wylie WL. Mixed dentition case analysis, estimating size of unerupted permanent teeth. Am J Orthod 1947; 33: 754-9.
11. Moyers RE. Handbook of Orthodontics. 4th ed. Chicago: Year Book Medical Publishers; 1988. p. 235-40.
12. Tanaka MM, Johnston LE. The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. J Am Dent Assoc 1974; 88: 798-801.
13. Buwembo W, Luboga S: Moyer's method of mixed dentition analysis: a meta-analysis. Afri Health Sci 2004; 41: 63-66.
14. Abdul Wahab Nourallah, Dietmar Gesch, Mohammad Nabieh Khordaji, Christian Splieth. New Regression Equations for Predicting the Size of Unerupted Canines and Premolars in a Contemporary Population. Angle Orthod (2002); 72 (3): 216-221.
15. Burhan AS, Nawaya FR. Prediction of un erupted canines and premolars in a Syrian

sample. Prog Orthod. 2014; 15: 4.
16. Seiple CM. Variation of tooth position, a metric study of the adaptation in the deciduous and permanent dentition. Svensk variation Tandlak Tidsker 1946; 26: 39-44
17. Carey CW. Linear arch dimension and tooth size. Am J Orthod. 1946; 35: 762-775.
18. Ballard ML, Wylie WL. Mixed dentition case analysis—estimating size of unerupted permanent teeth. Am J Orthod. 1947; 33: 754-759.
19. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod. 1958; 28: 236-240.
20. Oldfather RH. Estimation of the sum of the widths of unerupted mandible cuspid, first bicuspid, and second bicuspid. Am J Orthod. 1957; 43: 788-789.
21. Su MC, Chang HT. A new model of self-organizing neural networks and its application in data projection. IEEE Trans Neural Netw 2001; 12: 153-8.
22. Halazonetis DJ. Morphometric correlation between facialsoft-tissue profile shape and skeletal pattern in children andadolescents. Am J Orthod Dentofacial Orthop 2007; 132: 450-7.
23. Perfetti R, Ricci E. Analog neural network for support vector machine learning. IEEE Trans Neural Netw 2006; 17: 1085-91.
24. Yaji A., Prasad S., Pai A. Artificial intelligence in dento-maxillofacial radiology. Acta Sci Dent Sci. 2019; 3: 116-121.
25. Nanda SB, Anmol S KalhaAS, Jena AK, Bhatia V, Mishra S. Artificial neural network (ANN) modeling and analysis for the prediction of change in the lip curvature following extraction and non-extraction orthodontic treatment. J Dent Specialities.2015; 3(2): 130-139.
26. Xie X, Wang L, Wang A. Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment. Angle Orthod. 2010; 80: 262-66.
27. Budiman JA. Use of Artificial Neuron Network to Predict Dental Arch Form. Pesq Bras Odontoped Clin Integr 2018; 18(1): e3978.
28. Prakash A, Pulgaonkar R and Chitra P, 2016. A new combination mirror with template for intraoral photography. J Ind Orthod Soc; 50: 61-62.
29. Fleiss JL, Levin B, Paik MC. Statistical methods for rates and proportions. Hoboken, NJ: John Wiley & Sons; 2003 p. 462-93.
30. Oakley C, Brunette DM. The use of diagnostic data in clinical dental practice. Dent Clin North Am. 2002; 46: 87-115.
31. Zilberman O, Huggare JV, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod. 2003; 73: 301-6.
32. Bishara SE, Jakobsen JR. Comparison of two non-radiographic methods of predicting permanent tooth size in the mixed dentition. Am J Orthod Dentofacial Orthop. 1998; 113: 573-6.
33. Al-Gunaid T, Yamaki M, Saito I. Mesiodistal tooth width and tooth size discrepancies of Yemeni Arabians: A pilot study. J Orthod Sci. 2012; 1(2): 40-45. doi:10.4103/2278-0203.99760.
34. Ghose L, Baghdady VS. Analysis of the Iraq dentition: mesio-distal crown diameters of permanent teeth. J Dent Res. 1979; 58: 1047-54.
35. Hashim HA, Murshid ZA. Mesiodistal tooth width- a comparison between Saudi males and females. Egypt Dent J. 1993; 39: 343-6.
36. Syed MA, Selarka B, Tarsariya V. Sexual dimorphism in permanent maxillary and mandibular canines and intermolar arch width: Endemic study. J Indian Acad Oral Med Radiol 2015; 27: 405-11.
37. Van der Merwe SW, Rossouw P, van WykKotze TJ, Trutero H. An adaptation of the Moyers mixed dentition space analysis for Western Cape Caucasian population. J Dent South Afr. 1991; 46: 475-9
38. Uysal T, Basciftci FA, Goyenc Y. New regression equations for mixed-dentition arch analysis in a Turkish sample with no Bolton tooth-size discrepancy. Am J Orthod Dentofacial Orthop. 2009; 135: 343-8.
39. Tome W, Ohyama Y, Yagi M, Takada K. Demonstration of a sex difference in the predictability of widths of unerupted permanent canines and premolars in a Japanese population. Angle Orthod. 2011; 81: 938-44.
40. Ho CT, Freer TJ. A computerized tooth-width analysis. J Clin Orthod 1999; 33: 498-503.
41. Normando D, da Silva PL, Mendes ÁM. A clinical photogrammetric method to measure dental arch dimensions and mesio-distal tooth size. Eur J Orthod 2011; 33: 721-6.
42. Gholston LR. Reliability of an intraoral camera: Utility for clinical dentistry and research. Am J Orthod 1984; 85: 89-93.
43. Al-Kabab F A, Ghoname N A, Banabilh S M. Proposed regression equations for prediction of the size of unerupted permanent canines and premolars in Yemeni sample. J Orthodont Sci 2014; 3: 68-73.
44. Togoo RA, Alqahtani WA, Abdullah EK, A Alqahtani AS, AlShahrani I, Zakirulla M, et al. Comparison of mesiodistal tooth width in individuals from three ethnic groups in Southern Saudi Arabia. Niger J Clin Pract 2019; 22: 553-7
45. S. Moghimi , M. Talebi and I. Parisay . Design and implementation of ahybrid genetic algorithm and artificial neural network system for predicting the sizes of un erupted canines and premolars. Eur. J. Orthod.2012; 34: 480-486.
46. Seok-Ki Jung and Tae-Woo Kim. New approach for the diagnosis of extractions with neural network machine learning. Am J Orthod Dentofacial Orthop 2016; 149: 127-33.