Artificial Neural Network for Prediction of Un-erupted Premolars and Canines in Different Malocclusions

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ABSTRACT

Objective: The purpose of this study was to determine the accuracy Neural Networks models for prediction the size of un-erupted premolars and canines in Iraqi population in skeletal class I, II, III malocclusions.

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. They were allocated into three groups, thirty with skeletal class I (14 males and 16 females); thirty four with skeletal class II (14 males and 20 females); and thirty with skeletal class III malocclusion (13 males and 17 females). Data were obtained from intra oral photographs. Artificial Neural network (ANN) was developed as new and accurate method for prediction of un-erupted teeth using MATLAB program.

Result: High degree of correlation was obtained for the Neural Networks for each malocclusion between the summation of mesiodistal width of premolars, canines of the targets and the actual outputs (R=0.93058, R=0.88889, 0.92489 for class I, II and III Networks models subsequently)

Conclusions: This study suggests that Artificial Neural Networks models would be useful as an accurate method in orthodontics for prediction of un-erupted teeth with different malocclusion and there performance was achieved by components such as proper selection of the input data, preferable generalization and appropriate organization.

Keywords: Artificial Neural Network; MATLAB 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 between the 6th and the 12th year of life 2.

One of the main reasons for patients who seek orthodontic treatment is crowding of teeth since, it isan unaesthetic problem, 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. Thus, 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; and 3) The combination of the first and second methods is used as a predictor 13.

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. Other methods still 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 un-erupted 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 analyses methods are available for medical use and among these Artificial 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 a Neural Network system 23.

ANNs are 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 system 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.

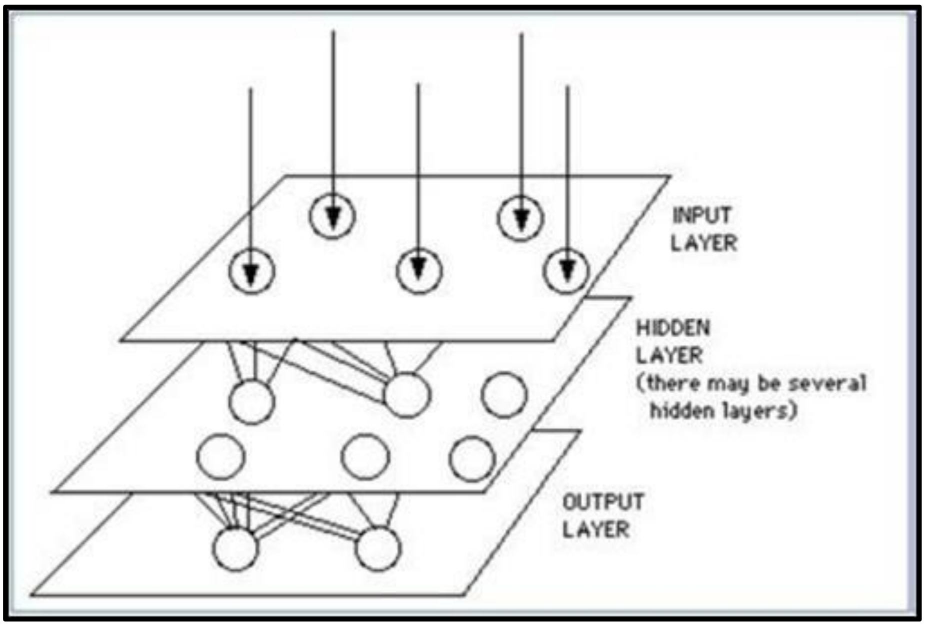

Figure (1) The structure of an Artificial Neural Network 25.

Previously, in orthodontics, the use of ANN was recommended for the decision of extraction; the prediction of change in lip curvature; and for the prediction of arch form 25-27. These studies found that, ANNs models analyses were more accurate as compared to the conventional ones.

To our knowledge, no studies have employed the ANNs for the prediction of un-erupted premolars and canines during mixed dentition analysis using intra-oral photographs in different types of malocclusion. Thus this study aimed to design a new Artificial Neural decision-making model for prediction of un-erupted teeth through only photographs in skeletal class I, II, and III malocclusions.

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. They were allocated into three groups. Thirty with skeletal class I (14 males and 16 females), thirty four with skeletal class II (14 males and 20 females) and thirty with skeletal class III malocclusion (13 males and 17 females). This study was conducted at Al-Shaab specialist dental center in Baghdad, Iraq. 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 subsequentlyuploaded 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 copied into MATLAB 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. Feedforwardbackpropogation 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 millimeters as inputs values for the Network while the outputs values were the mesiodistal width of upper and lower premolars and canines of 94 patients for each malocclusion separately.

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

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 no significance difference (P > 0.05) between the intra oral photos and study models dental measurements and no significant difference (P > 0.05) 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 summations 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).

Table (1) Gender difference for the Intra-oral photo dental measurements for each malocclusion.

Measurements of intra-oral photos class I	Male subjects n=(14)				Female subjects n=(16)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.91	6.60	5.62	0.53	4.90	6.18	5.50	0.36	0.71	0.48	NS
MD of lower right lateral incisors	4.91	6.63	5.60	0.49	4.90	6.20	5.48	0.37	0.91	0.38	NS
MD of lower right cainines	5.70	6.92	6.08	0.35	5.30	6.25	5.86	0.27	**3.43**	**0.00**	**S**
MD of lower right 1st premolars	5.46	7.30	6.25	0.53	5.42	6.58	5.92	0.31	0.44	0.67	NS
MD of lower right 2nd premolars	6.60	8.90	7.15	0.62	5.63	7.31	6.49	0.39	0.48	0.63	NS
MD of lower left central incisors	6.62	8.20	7.23	0.43	6.10	7.45	6.77	0.39	0.77	0.45	NS
MD of lower left lateral incisors	6.50	8.22	7.32	0.55	6.04	7.38	6.82	0.40	1.00	0.34	NS
MD of lower left canines	6.66	8.80	7.31	0.60	6.13	7.30	6.54	0.33	**4.35**	**0.00**	**S**
MD of lower left 1st premolars	6.65	8.10	7.32	0.41	6.20	7.35	6.77	0.33	0.41	0.69	NS
MD of lower left 2nd premolars	6.55	8.65	7.37	0.58	5.93	8.14	6.88	0.62	0.41	0.68	NS
MD of upper right canines	7.20	8.90	7.74	0.44	6.64	7.83	7.20	0.28	**3.98**	**0.00**	**S**
MD of upper right 1st premolars	6.21	8.50	7.03	0.56	6.12	7.11	6.67	0.34	2.01	0.07	NS
MD of upper right 2nd premolars	6.33	8.40	7.15	0.62	6.20	7.19	6.66	0.31	2.00	0.08	NS
MD of upper left canines	7.12	8.60	7.63	0.39	6.71	7.80	7.22	0.27	**3.28**	**0.00**	**S**
MD of upper left 1st premolars	6.13	8.21	7.03	0.54	6.16	7.10	6.70	0.31	2.03	0.06	NS
MD of upper left 2nd premolars	6.37	8.33	7.12	0.58	6.27	7.23	6.68	0.31	2.02	0.06	NS
Measurements of intra-oral photos class II	Male subjects n=(14)				Female subjects n=(20)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.75	6.12	5.47	0.33	4.90	6.28	5.50	0.35	-0.24	0.81	NS
MD of lower right lateral incisors	5.58	6.80	6.04	0.34	5.40	6.73	5.97	0.41	0.49	0.62	NS
MD of lower right cainines	5.85	7.50	6.89	0.53	5.97	7.30	6.73	0.35	**2.14**	**0.04**	**S**
MD of lower right 1st premolars	6.80	7.91	7.28	0.28	6.20	7.87	6.99	0.45	1.17	0.25	NS
MD of lower right 2nd premolars	6.60	7.90	7.06	0.40	5.94	7.71	6.87	0.48	1.30	0.20	NS
MD of lower left central incisors	4.88	6.22	5.55	0.32	4.98	6.50	5.53	0.37	0.16	0.88	NS
MD of lower left lateral incisors	5.68	6.60	6.07	0.25	5.45	6.73	6.06	0.38	0.09	0.93	NS
MD of lower left canines	6.40	7.60	6.92	0.36	5.98	7.78	6.77	0.43	**2.13**	**0.04**	**S**
MD of lower left 1st premolars	6.20	7.70	7.07	0.51	6.26	8.04	6.94	0.42	0.85	0.40	NS
MD of lower left 2nd premolars	6.55	7.72	7.18	0.42	6.20	8.35	6.88	0.46	1.16	0.25	NS
MD of upper right canines	7.15	8.10	7.59	0.24	6.78	7.89	7.28	0.26	**3.55**	**0.00**	**S**
MD of upper right 1st premolars	6.32	7.56	6.88	0.31	6.23	7.32	6.77	0.32	1.06	0.29	NS
MD of upper right 2nd premolars	6.13	7.41	6.91	0.38	6.34	7.26	6.79	0.28	1.15	0.26	NS
MD of upper left canines	7.20	8.15	7.57	0.22	6.74	7.89	7.31	0.30	**2.75**	**0.01**	**S**
MD of upper left 1st premolars	6.36	7.51	6.90	0.29	6.29	7.35	6.80	0.31	0.90	0.37	NS
MD of upper left 2nd premolars	6.20	7.44	6.90	0.39	6.30	7.29	6.80	0.30	0.87	0.39	NS
Measurements of intra-oral photos class III	Male subjects n=(13)				Female subjects n=(17)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.80	5.80	5.36	0.31	4.85	6.62	5.70	0.51	-0.63	0.53	NS
MD of lower right lateral incisors	5.50	7.04	5.99	0.45	5.30	6.85	6.20	0.50	-1.11	0.28	NS
MD of lower right cainines	6.27	7.50	6.83	0.41	6.25	8.00	6.94	0.42	**-2.15**	**0.04**	**S**
MD of lower right 1st premolars	5.75	7.58	6.71	0.67	6.03	8.20	7.13	0.61	-1.66	0.11	NS
MD of lower right 2nd premolars	6.25	8.20	6.85	0.55	5.95	8.27	7.08	0.72	-0.92	0.37	NS
MD of lower left central incisors	5.18	5.98	5.53	0.31	5.06	6.61	5.72	0.50	-1.21	0.24	NS
MD of lower left lateral incisors	5.50	7.03	6.09	0.42	5.16	6.70	6.16	0.45	-0.37	0.71	NS
MD of lower left canines	6.40	8.00	6.96	0.40	6.25	7.88	6.82	0.43	**-2.47**	**0.02**	**S**
MD of lower left 1st premolars	5.80	7.75	6.82	0.75	6.00	8.00	7.11	0.55	-1.10	0.28	NS
MD of lower left 2nd premolars	6.30	7.75	6.85	0.52	5.88	8.40	7.25	0.68	-1.69	0.10	NS
MD of upper right canines	6.98	8.10	7.45	0.39	6.91	8.10	7.41	0.32	**-2.17**	**0.04**	**S**
MD of upper right 1st premolars	6.10	7.35	6.61	0.45	6.10	7.54	6.94	0.42	-1.93	0.07	NS
MD of upper right 2nd premolars	6.00	7.46	6.62	0.46	6.24	7.77	7.03	0.49	0.28	0.78	NS
MD of upper left canines	6.88	8.00	7.47	0.38	7.00	7.98	7.42	0.27	**-2.37**	**0.03**	**S**
MD of upper left 1st premolars	6.13	7.23	6.59	0.41	6.00	7.54	6.91	0.43	-1.97	0.06	NS
MD of upper left 2nd premolars	6.12	7.40	6.61	0.42	6.34	7.72	7.02	0.47	0.35	0.73	NS

MD: mesiodistal width of teeth; min: minimum; max: maximum; SD: standard deviation; NS: no significant difference ($p > 0.05$); S: significant difference ($p \leq 0.05$).

Table (2) Gender difference for the dental casts measurements for each malocclusion.

Measurements of intra-oral photos class I	Male subjects n=(14)				Female subjects n=(16)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.90	6.40	5.57	0.49	4.83	6.25	5.51	0.39	0.379	0.708	NS
MD of lower right lateral incisors	5.70	6.82	6.06	0.34	5.32	6.23	5.86	0.26	1.791	0.085	NS
MD of lower right canines	6.59	8.01	7.06	0.45	5.60	7.33	6.56	0.40	**3.162**	**0.003**	**S**
MD of lower right 1st premolars	5.70	7.54	6.91	0.51	6.00	7.46	6.82	0.37	0.502	0.620	NS
MD of lower right 2nd premolars	6.50	8.22	7.10	0.52	6.40	7.42	6.85	0.35	1.490	0.149	NS
MD of lower left central incisors	4.90	6.71	5.59	0.50	4.89	6.30	5.48	0.39	0.647	0.524	NS
MD of lower left lateral incisors	5.65	7.33	6.31	0.51	5.40	6.62	5.93	0.32	1.430	0.093	NS
MD of lower left canines	6.63	7.92	7.16	0.44	5.99	7.29	6.54	0.37	**4.003**	**0.000**	**S**
MD of lower left 1st premolars	5.82	7.74	7.18	0.55	6.22	7.38	6.77	0.31	1.460	0.141	NS
MD of lower left 2nd premolars	6.54	8.67	7.30	0.58	6.02	8.15	7.00	0.52	1.449	0.160	NS
MD of upper right canines	7.21	8.93	7.73	0.47	6.67	7.80	7.14	0.32	**3.946**	**0.001**	**S**
MD of upper right 1st premolars	6.18	8.55	7.02	0.60	6.23	7.14	6.70	0.33	1.826	0.080	NS
MD of upper right 2nd premolars	6.30	8.41	7.11	0.65	6.24	7.20	6.68	0.29	1.370	0.126	NS
MD of upper left canines	7.11	8.55	7.61	0.40	6.76	7.76	7.21	0.27	**3.221**	**0.004**	**S**
MD of upper left 1st premolars	6.20	8.23	7.05	0.55	6.21	7.20	6.73	0.33	1.931	0.065	NS
MD of upper left 2nd premolars	6.34	8.32	7.11	0.61	6.21	7.21	6.70	0.33	1.266	0.132	NS
Measurements of intra-oral photos class II	Male subjects n=(14)				Female subjects n=(20)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.72	6.11	5.47	0.34	4.90	4.82	6.27	5.50	0.36	0.787	NS
MD of lower right lateral incisors	5.55	6.84	6.04	0.35	5.40	5.40	6.79	5.98	0.43	0.690	NS
MD of lower right cainines	6.30	7.56	6.92	0.40	5.97	5.93	7.37	6.78	**0.36**	**0.037**	**S**
MD of lower right 1st premolars	6.81	7.80	7.22	0.29	6.20	6.17	8.29	7.05	0.53	0.282	NS
MD of lower right 2nd premolars	6.25	7.97	7.07	0.47	5.94	6.23	7.66	6.83	0.38	0.098	NS
MD of lower left central incisors	4.88	6.23	5.54	0.32	4.98	4.99	6.51	5.56	0.38	0.906	NS
MD of lower left lateral incisors	5.59	6.62	6.09	0.26	5.45	5.46	6.76	6.11	0.38	0.863	NS
MD of lower left canines	6.43	7.62	6.93	0.36	5.98	5.91	7.33	6.74	**0.35**	**0.006**	**S**
MD of lower left 1st premolars	6.20	7.71	6.98	0.48	6.26	6.27	8.07	7.05	0.46	0.669	NS
MD of lower left 2nd premolars	6.52	7.73	7.18	0.42	6.20	6.21	8.38	6.96	0.45	0.126	NS
MD of upper right canines	7.14	8.12	7.57	0.24	6.78	6.77	7.80	7.28	**0.27**	**0.001**	**S**
MD of upper right 1st premolars	6.39	7.52	6.88	0.31	6.23	6.39	7.31	6.79	0.32	0.417	NS
MD of upper right 2nd premolars	6.23	7.42	6.91	0.36	6.34	6.41	7.32	6.82	0.30	0.416	NS
MD of upper left canines	7.13	8.12	7.58	0.23	6.74	6.72	7.88	7.31	**0.30**	**0.007**	**S**
MD of upper left 1st premolars	6.43	7.56	6.93	0.28	6.29	6.40	7.41	6.87	0.30	0.516	NS
MD of upper left 2nd premolars	6.21	7.42	6.89	0.42	6.30	6.32	7.32	6.82	0.30	0.570	NS
Measurements of intra-oral photos class III	Male subjects n=(13)				Female subjects n=(17)				T test	P value	Significance
	Min	Max	Mean	SD	Min	Max	Mean	SD			
MD of lower right central incisors	4.79	5.80	5.36	0.32	4.83	6.66	5.73	0.52	-2.189	0.039	NS
MD of lower right lateral incisors	5.51	7.03	5.99	0.46	5.33	6.86	6.23	0.51	-1.237	0.228	NS
MD of lower right cainines	6.27	7.45	6.84	0.39	6.22	7.30	6.87	0.28	**-2.171**	**0.040**	**S**
MD of lower right 1st premolars	5.70	7.64	6.65	0.66	6.07	8.34	7.19	0.61	-0.205	0.840	NS
MD of lower right 2nd premolars	6.25	8.10	6.84	0.59	5.97	8.57	7.02	0.68	-0.700	0.491	NS
MD of lower left central incisors	5.02	6.00	5.51	0.32	5.06	6.60	5.78	0.51	-1.628	0.116	NS
MD of lower left lateral incisors	5.50	7.00	6.07	0.41	5.16	6.65	6.15	0.45	-0.468	0.644	NS
MD of lower left canines	6.47	8.00	6.98	0.37	6.22	7.30	6.75	0.31	**2.184**	**0.043**	**S**
MD of lower left 1st premolars	5.82	7.75	6.76	0.71	6.37	8.21	7.23	0.52	-1.917	0.067	NS
MD of lower left 2nd premolars	6.29	7.74	6.85	0.51	5.91	8.44	7.21	0.63	-1.608	0.121	NS
MD of upper right canines	6.99	8.10	7.44	0.38	6.92	7.99	7.39	0.30	**-2.147**	**0.042**	**S**
MD of upper right 1st premolars	6.10	7.52	6.72	0.52	6.11	7.45	6.92	0.42	-1.054	0.302	NS
MD of upper right 2nd premolars	6.10	7.45	6.63	0.46	6.23	7.70	7.03	0.49	0.376	0.710	NS
MD of upper left canines	6.87	8.00	7.49	0.37	7.08	7.88	7.42	0.24	**-2.161**	**0.041**	**S**
MD of upper left 1st premolars	6.14	7.21	6.61	0.41	6.10	7.43	6.91	0.40	-1.875	0.073	NS
MD of upper left 2nd premolars	6.14	7.51	6.64	0.44	6.30	7.70	7.02	0.45	0.539	0.595	NS

MD: mesiodistal width of teeth; min: minimum; max: maximum; SD: standard deviation; NS: no significant difference ($p > 0.05$); S: significant difference ($p \leq 0.05$).

Table (3) Comparison of photo-cast and side difference of the dental measurements for each malocclusion.

Measurements of class I malocclusion		Pair t test	P value	significance	Correlation	Significance
LR centrals p	LR centrals M	-0.97	0.34	NS	0.99	0.001
LR laterals P	LR laterals M	-0.81	0.43	NS	0.92	0.001
LR canines P	LR canines M	0.92	0.36	NS	0.92	0.001
LR 1st premolars P	LR 1st premolars M	-0.13	0.90	NS	0.92	0.001
LR 2nd premolars P	LR 2nd premolars m	0.51	0.61	NS	0.99	0.001
LL centrals P	LL centrals M	1.44	0.16	NS	0.91	0.001
LL laterals P	LL laterals M	1.60	0.12	NS	0.94	0.001
LL canines P	LL canines M	0.70	0.49	NS	0.99	0.001
LL 1 st premolars P	LL 1st premolars M	0.25	0.80	NS	0.99	0.001
LL 2nd premolars P	LL 2nd premolars M	1.25	0.22	NS	0.94	0.001
UR canines P	UR canines M	1.48	0.15	NS	0.96	0.001
UR 1st premolars P	UR 1st premolars	-1.45	0.16	NS	0.99	0.001
UR 2nd premolars P	UR 2nd premolars M	-0.68	0.50	NS	0.96	0.001
UL canines P	UL canines M	1.49	0.15	NS	0.99	0.001
UL 1st premolars P	UL 1st premolars M	-2.03	0.05	NS	0.90	0.001
UL 2nd premolars P	UL 2nd premolars M	-1.12	0.27	NS	0.99	0.001
LR canines	LL canines	-0.59	0.56	NS	0.85	0.001
LR 1st premolars	LL 1st premolars	-1.30	0.21	NS	0.74	0.001
LR 2nd premolars	LR 2nd premolars	-2.35	0.03	NS	0.80	0.001
UR canines	UL canines	1.44	0.16	NS	0.97	0.001
UR 1st premolars	UL 1st premolars	-0.71	0.48	NS	0.93	0.001
UR 2nd premolars	UL 2nd premolars	0.18	0.86	NS	0.98	0.001
Measurements of class II malocclusion		**Pair t test**	**P value**	**significance**	**Correlation**	**Significance**
LR centrals p	LR centrals M	0.41	0.68	NS	1.00	0.001
LR laterals P	LR laterals M	1.06	0.30	NS	1.00	0.001
LR canines P	LR canines M	1.37	0.18	NS	0.82	0.001
LR 1st premolars P	LR 1st premolars M	-0.11	0.92	NS	1.00	0.001
LR 2nd premolars P	LR 2nd premolars m	-1.19	0.24	NS	0.95	0.001
LL centrals P	LL centrals M	1.40	0.17	NS	0.99	0.001
LL laterals P	LL laterals M	2.44	0.02	NS	0.97	0.001
LL canines P	LL canines M	-0.83	0.41	NS	0.90	0.001
LL 1 st premolars P	LL 1st premolars M	1.65	0.11	NS	0.99	0.001
LL 2nd premolars P	LL 2nd premolars M	-1.00	0.32	NS	0.99	0.001
UR canines P	UR canines M	1.06	0.29	NS	0.98	0.001
UR 1st premolars P	UR 1st premolars	-1.96	0.06	NS	0.99	0.001
UR 2nd premolars P	UR 2nd premolars M	-1.68	0.10	NS	0.98	0.001
UL canines P	UL canines M	0.12	0.90	NS	0.99	0.001
UL 1st premolars P	UL 1st premolars M	-1.89	0.07	NS	0.83	0.001
UL 2nd premolars P	UL 2nd premolars M	-1.18	0.24	NS	0.98	0.001
LR canines	LL canines	0.65	0.52	NS	0.70	0.001
LR 1st premolars	LL 1st premolars	1.13	0.27	NS	0.71	0.001
LR 2nd premolars	LR 2nd premolars	-2.27	0.03	NS	0.71	0.001
UR canines	UL canines	-0.77	0.45	NS	0.95	0.001
UR 1st premolars	UL 1st premolars	-2.41	0.02	NS	0.98	0.001
UR 2nd premolars	UL 2nd premolars	-0.40	0.69	NS	0.96	0.001
Meaurements of class III malocclusion		**Pair t test**	**P value**	**significance**	**Correlation**	**Significance**
LR centrals p	LR centrals M	0.67	0.51	NS	0.99	0.001
LR laterals P	LR laterals M	0.99	0.33	NS	0.99	0.001
LR canines P	LR canines M	-1.02	0.32	NS	0.99	0.001
LR 1st premolars P	LR 1st premolars M	-0.09	0.93	NS	1.00	0.001
LR 2nd premolars P	LR 2nd premolars m	-0.62	0.54	NS	0.99	0.001
LL centrals P	LL centrals M	0.99	0.33	NS	0.98	0.001
LL laterals P	LL laterals M	-1.09	0.29	NS	0.97	0.001
LL canines P	LL canines M	-1.62	0.12	NS	1.00	0.001
LL 1 st premolars P	LL 1st premolars M	1.46	0.16	NS	1.00	0.001
LL 2nd premolars P	LL 2nd premolars M	1.07	0.30	NS	0.99	0.001
UR canines P	UR canines M	0.60	0.55	NS	0.99	0.001
UR 1st premolars P	UR 1st premolars	-0.94	0.36	NS	0.89	0.001
UR 2nd premolars P	UR 2nd premolars M	-0.62	0.54	NS	0.99	0.001
UL canines P	UL canines M	0.06	0.95	NS	0.98	0.001
UL 1st premolars P	UL 1st premolars M	-1.06	0.30	NS	0.99	0.001
UL 2nd premolars P	UL 2nd premolars M	-0.70	0.49	NS	0.99	0.001
LR canines	LL canines	0.52	0.61	NS	0.77	0.001
LR 1st premolars	LL 1st premolars	0.05	0.96	NS	0.85	0.001
LR 2nd premolars	LR 2nd premolars	0.02	0.98	NS	0.75	0.001
UR canines	UL canines	-0.81	0.43	NS	0.97	0.001
UR 1st premolars	UL 1st premolars	1.87	0.07	NS	0.99	0.001
UR 2nd premolars	UL 2nd premolars	0.60	0.55	NS	0.98	0.001

LR indicates lower right; LL: lower left; UR: upper right; UL: upper left; P: intraoral photo; M: study model; NS: no significant difference ($p > 0.05$).

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

Measurements of class I malocclusion		All subject (n=30)		Male subjects (n=14)		female subjects (n=16)	
		Correlation	Significance	Correlation	Significance	Correlation	Significance
MD of lower incisors	MD of LR premolars and canines	0.74	0.001	0.71	0.001	0.68	0.001
MD of lower incisors	MD of UR premolars and canines	0.86	0.001	0.83	0.001	0.82	0.001
Measurements of class II malocclusion		**All subject (n=34)**		**Male subjects (n=14)**		**female subjects (n=20)**	
		Correlation	Significance	Correlation	Significance	Correlation	Significance
MD of lower incisors	MD of LR premolars and canines	0.89	0.001	0.66	0.001	0.60	0.001
MD of lower incisors	MD of UR premolars and canines	0.80	0.001	0.74	0.001	0.76	0.001
Measurements of class III malocclusion		**All subject (n=30)**		**Male subjects (n=13)**		**female subjects (n=17)**	
		Correlation	Significance	Correlation	Significance	Correlation	Significance
MD of lower incisors	MD of LR premolars and canines	0.77	0.001	0.72	0.001	0.83	0.001
MD of lower incisors	MD of UR premolars and canines	0.87	0.001	0.83	0.001	0.86	0.001

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

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=0.87 R=0.88 R=0.87 for class I, II and III malocclusion subsequently) (Figure 2) with best training performances which were (0.19384 at epoch 8, 0.35391 at epoch 17, 0.381 at epoch 99 for class I, II and III Neural Networks models subsequently (Figure 3). Following testing process linear regression analysis was estimated for the other 30% of the collected data after designing the Neural Networks. It showed high coefficients of correlations between the summation of mesiodistal width of right premolars and canines of the targets and the actual outputs (R=0.93058, R=0.88889, R=0.92489 for class I, II and III malocclusions models subsequently) (Figure 4).

Figure (2) Scatterplots illustrating linear regression results between the summation of mesiodistal width of right premolars and canines of the targets and the actual outputs after designing the Neural Network during training process for each malocclusion.

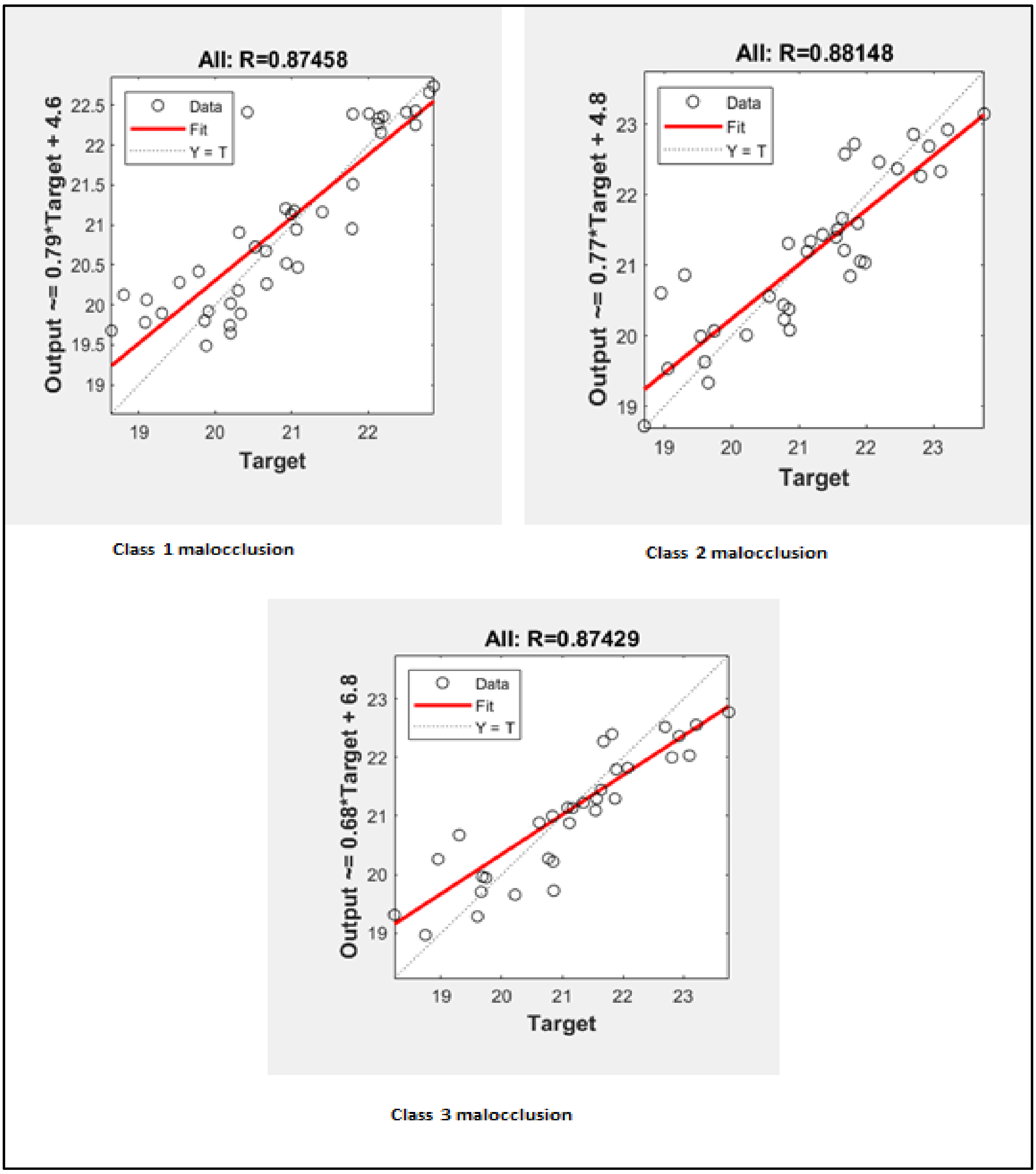

Figure (3) Best training performance for the Network between the summation of mesiodistal width of right premolars and canines of the targets and the actual outputs after designing the Neural Network during training process for each malocclusion.

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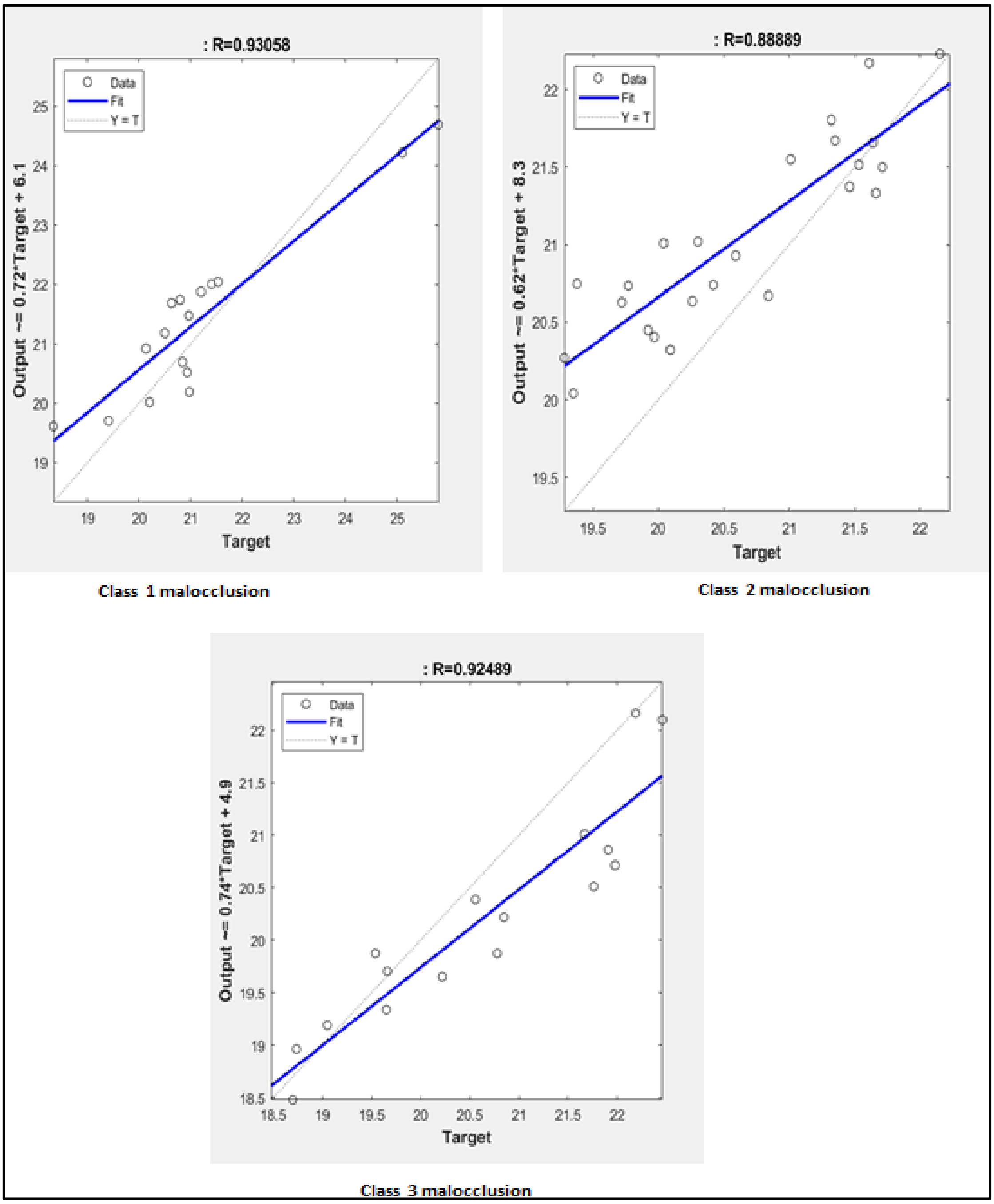

Figure (4) Scatterplot illustrating linear regression result between the summation of mesiodistal width of premolars and canines of the targets and the actual outputs after designing the Neural Network during testing process for each malocclusion.

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 which could be related to the natural symmetrical size of permanent teeth. This finding agreed 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 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. This may be attributed to racial and ethnic nature. Moreover, the measurements obtained from the photographs demonstrated a statisticallysignificant 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 dimensionsin accordance with many studies 41,24.

Equations developed by data collected from one ethnic group to predict the size of un-erupted permanent teeth might not be applicable to another due to racial and ethnic groups present variations in the mesiodistal widths of their permanent teeth43,44. Thus, in contrast, the ANN in this study adjusts its structure based on the training samples presented to the system. Therefore, they can be used to predict the size of un-erupted teeth in different ethnic groups, provided that an appropriate training data set is presented to the system which have been documented by Moghimiet 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. Additionally , 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 kim46.

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 4 showed high degree of correlation between the real target and the output for each malocclusion model which make this method very accurate for prediction of un-erupted teeth as compared with other conventional methods. However, there was slight difference in training performance between Neural Network models for each malocclusion which may be related to the discrepancies in the size of teeth as well as the values of the initial weights and inputs were chosen randomly in each training process.

This study has several limitations due to the regional nature and 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.

CONCLUSIONS

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

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