Artificial neural network (ANN) modeling and analysis for the prediction of change in the lip curvature following extraction and non-extraction orthodontic treatment

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ABSTRACT

Objective: To establish and determine the accuracy of ANN model for the analysis of lip curve change following extraction and non-extraction orthodontic treatment.
Methods: Forty adult subjects who required various combinations of premolars extraction and non-extraction for the correction of their malocclusion were chosen. Based on the extraction pattern, all the subjects (n=40) were divided equally into an extraction and a non-extraction group. The effect of extraction and non-extraction treatment on the depth of upper and lower lip curvature was measured on the lateral cephalograms recorded in natural head position. The data obtained from the cephalometric analysis were used to produce a trained ANN model and then the model was analyzed to determine its accuracy in the prediction of upper and lower lip curvature change.
Results: The mean change in the depth of upper lip curvature following various combinations of premolars extraction and non-extraction treatment was significantly different ($P<0.05$). The predicted values of upper and lower lip curvature change by ANN model were very close to the actual regression analysis values. However, the mean error in predicting the change in the upper and lower lip curvature by ANN model analysis was only 29.6% and 7% respectively which was much less as compared to the routine regression analysis.
Conclusions: The premolars extraction and non-extraction orthodontic treatment had significant effect on the depth of upper lip curve, and the mean error in predicting the change in lip curvature with ANN analysis was much less as compared to computer based statistical analysis.

Key words: Lip curvature changes, Extraction and non-extraction treatment, Artificial neural network analysis.

INTRODUCTION

Evaluation of the human facial profile has always been an essential part of orthodontic diagnosis and treatment planning.[1] Successful evaluation of facial balance and harmony includes a study of the facial soft tissue characteristic. Thus the relationships of nose, lips and chin are important considerations. However, significant consideration has been given to the actual depth of curvature of the lips and the importance of these curves to the overall perception of the lateral facial profile.[2,3] The presence of varying inherent internal soft tissue architecture, however, has complicated the attempts at predicting soft tissue responses to treatment.[3] Consequently, ratios of lip to incisor retraction have gained only limited acceptance because it has been recognized that the interactions that might determine soft tissue changes are complex.[4]

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Currently many multiple-factor analysis methods are available for medical use and among these artificial neural network (ANN) model analysis is very commonly used. ANN is basically an information processing paradigm inspired by biological nervous systems in human brain. The ANN is made up of large number of highly interconnected processing elements called neurons.[5] In true sense artificial neural networks are the simple clustering of the primitive artificial neurons and this clustering occurs by creating layers, which are then connected to one another. As shown in Fig.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, the Fig.1 is 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. The human brain learns from experience. However, neural networks are called machine learning algorithms, because changing of its connection weights (W in Fig.2) causes the network to learn the solution to a problem. The strength of connection between the neurons is stored as a weight-value for the specific connection. The system learns new knowledge by adjusting these connection weights. The learning ability of a neural network is determined by its architecture and by the algorithmic method chosen for training. The ANN models are particularly beneficial when one is searching various problems because of their ability to process complicated problems of uncertainty, nonconfiguration, nonlinearity and multiple factor interactions. As a result, the application of ANN shows great potential as a support system and management system in medical decision making. In orthodontics, ANN models have only been used for human craniofacial growth classification[6], prediction of anterior temporal muscle activity[7] and deciding the need of extractions prior to orthodontic treatment.[8] However, the present study was designed to determine the accuracy of ANN model analysis for the prediction of lip curvature change following extraction and non-extraction orthodontic treatment.

MATERIALS AND METHODS

Total 40 adult subjects who required either all first premolars or upper first and lower second premolars or all second premolars extraction or without any tooth extraction for the correction of their malocclusion were included in the study. Prior to the commencement of the trial, all the participants were informed and a written consent was obtained. The study was also approved by the Ethical Committee. All the 40 subjects were treated by using consistent contemporary biomechanical principles and this study was done over a period of seventeen months. The subjects were divided into 2 main groups of each containing 20 subjects i.e. Group-I [Non-extraction group] and Group-II [Extraction group; all first premolars (n=8), upper first and lower second premolars (n=6), all second premolars (n=6)]. The mean age of the subjects at the beginning of study in the extraction group was 19 year 9 months and in the non-extraction group was 18 year 9 months. Pretreatment and post-treatment lateral cephalograms recorded in the natural head position were analyzed by the same investigator (SBN) to determine the upper and lower lip curvature change. All the cephalograms were recorded in the same machine with similar exposure parameters. In order to provide a consistent reference plane for evaluating horizontal changes in landmarks, both sphenoethmoid (Se) and the inferior pterygomaxillary point (Ptm) on the pterygomaxillary vertical (PMV) line were transferred from the pretreatment tracing to post-treatment tracing, by superimposing on the cranial base landmarks of the pretreatment radiographs as described by Bjork and Skieller.[9] Landmarks chosen for the study were based on the definitions of Nanda et al.[10] Linear measurements were multiplied by a factor of 0.9 to take into account the 9% enlargement factor. In order to access the effect of extraction and non-extraction treatment on soft tissue, the depths of upper and lower lip curves were measured on all pre and post-treatment cephalograms, in relation to skeletally defined PMV line of Enlow et al.[11] The upper lip curvature was calculated as a difference between upper lip thickness at labrale superioris and upper lip thickness at point A in relation to PMV line. Similarly the lower lip curvature was calculated as a difference between lower lip thickness at labrale inferioris and lower lip thickness at point B in relation to PMV line. Various cephalometric landmarks and the linear measurements used for the measurement of depth of upper and lower lip curvatures are shown in Fig.-3.

The ANN model was prepared by utilizing MATLAB software. The model was trained with data of same 40 subjects. The model had two inputs, two outputs, a total of 10 layers with 8 hidden layers, one input layer and one output layer. The input and output layer indices for upper and lower lip curvatures for non-extraction and extraction groups are shown in table-1 and 2. The statistical regression analysis and ANN analysis were done to find out any possible prediction equation where pre-treatment variables can be used to find post-treatment results.

STATISTICS

All the data were analyzed with MINITAB version 13.1 and SPSS version 11 softwares. The data were subjected to the descriptive statistics for the evaluation of mean, standard deviation and range etc. One-way ANOVA was used for multiple group comparison and Man-Whitney test was used for group wise comparison. Stepwise regression analysis was used to identify not only those pre-treatment variables with the most likely influence on lip changes but also to attempt to describe the extent of variability in lip response that might be explained by those variables. The P-value of 0.05 was considered as level of statistical significance.

RESULTS

The change in the curvature of the upper and lower lips following various combinations of premolars extraction and non-extraction treatment is described in table-3. The curvature of the upper lip was changed significantly (P<0.05) following premolars extraction and non-extraction orthodontic treatment as compared to the lower lip. Correlation and regression analysis for the measurement of relationship between various pre-treatment parameters to predict the post-treatment changes in lip-curve is described in table-4**.** When analyzing the results of stepwise regression, it became obvious that only prediction of lower lip curvature change in upper first and lower second premolars extraction group was good enough with 95.3% explained variance (Table-4).

The ANN predicted values for upper and lower lip curvature change were very close to the actual prediction values obtained from conventional regression analysis. The neural network prediction values for upper and lower lips curvature changes are shown in Fig.-4. The results of random data of 10 patients which were considered for testing showed very promising (Fig.-5). The mean error in the prediction of upper and lower lip curvature change was 29.6% and 7% respectively which were very less as compared to the statistical regression analysis (Fig.-6 and 7).

Table 1: The input and output layer indices for upper and lower lip curvatures for non-extraction group.

SN	Input layers for upper lip curvature	Input layers for lower lip curvature	Output layers for upper lip curvature	Output layers for lower lip curvature
1	4.6	7.1	0.8	2.4
2	2.8	4.4	-2.8	-3.3
3	3	5.6	2	-0.2
4	3.3	8.5	0.5	-0.7
5	3.9	5.2	-5.1	-0.7
6	3.5	6.3	2.7	-0.3
7	4	11.7	-1.2	4.3
8	4.5	1	0.2	-5
9	2.5	4.5	-0.2	-1.2
10	5.2	2.6	1.4	-6.4
11	2.7	6.4	0.7	-5.5
12	4.5	5.2	1.7	2.5
13	1.8	6.5	-0.5	0.6
14	1.9	6.5	1	-1.7
15	4	3.9	-0.6	-2.1
16	4.6	8.3	0.9	3.8
17	4.9	8.3	1.1	-1.8
18	3.9	4.4	0.3	-0.3
19	5.1	6.9	1.7	1.3
20	4.2	9.7	1.7	2.6

Table 2: The input and output layer indices for upper and lower lip curvatures for extraction group.

SN	Input layers for upper lip curvature	Input layers for lower lip curvature	Output layers for upper lip curvature	Output layers for lower lip curvature
1	6.2	5.4	0.2	0.9
2	5.1	6.9	1.7	1.3
3	7.3	10.3	-0.1	2.5
4	3.7	8.1	1.9	2.7
5	4.6	8.3	0.9	3.8
6	5.1	9.1	1.3	2.8
7	4.9	8.3	1.1	-1.8
8	3.4	7.6	1.1	-4.6
9	6.9	2.2	5.7	-2.8
10	6.7	2.3	1.6	-2.3
11	6.5	6.8	4.6	2.7
12	4	3.9	-0.6	-2.1
13	6.5	7.5	2	4.7
14	4	7.8	2.1	5.3
15	4.8	6	1.4	3.2
16	5	6.4	1.1	-0.6
17	5	6.8	0.6	0.5
18	6.2	5.4	0.2	0.9
19	3.3	8.5	0.5	-0.7
20	1.8	6.5	-0.5	0.6

Table 3: Changes in the upper and lower lip curvatures following extraction and non-extraction treatment

GROUP		UPPER LIP CURVE				
		PRE	POST	LIP CURVE CHANGE		
				MEAN+/-SD	MIN	MAX
4/4 Extraction		4.85+/-1.26	3.71+/-1.79	1.14+/-0.66	-0.1	1.7
4/5 Extraction		5.56+/-1.41	3.62+/-1.56	1.94+/-1.84	-0.1	5.7
5/5 Extraction		4.25+/-1.69	3.86+/-1.43	0.39+/-0.58	-0.5	1.4
Non Extraction		3.74+/-1.01	3.41+/-1.84	0.33+/-1.77	-5.1	2.7
ANOVA	F			3.14		
	P			0.04*		
GROUP		LOWER LIP CURVE				
		PRE	POST	LIP CURVE CHANGE		
				MEAN+/-SD	MIN	MAX
4/4 Extraction		8.37+/-1.09	7.44+/-2.81	0.93+/-3.03	-4.6	3.8
4/5 Extraction		5.65+/-2.43	3.99+/-1.43	1.66+/-3.66	-2.8	5.3
5/5 Extraction		6.73+/-1.1	6.59+/-1.69	0.14+/-0.71	-0.7	3.2
Non Extraction		6.15+/-2.46	6.74+/-2.16	-0.59+/-2.97	-6.4	4.3
ANOVA		F		0.83		
		P		0.49^{NS}		

F – Variance ratio, * = P< 0.05 NS= Non-significant

Table 4: Stepwise regression predictions of upper and lower lip curvatures following extraction and non-extraction treatment

GROUPS	POST TREATMENT LIP CURVE CHANGES	PREDICTION EQUATION	SE	R^2 %
4/4 Extraction	ULCC	ULCC = 3.13 - 0.42 (ULC)	0.5	60.40%
	LLCC	LLCC = -3.24 + 0.52 (LLC)	2.9	7.30%
4/5 Extraction	ULCC	ULCC = -3.61 + 1.07 (ULC)	1.9	42.70%
	LLCC	LLCC = -6.24 + 1.41 (LLC)	0.9	95.30%
5/5 Extraction	ULCC	ULCC = -0.48 + 0.24 (ULC)	0.06	30%
	LLCC	LLCC = 5.65 - 0.76 (LLC)	1.3	32%
Non-Extraction	ULCC	ULCC = -1.01 + 0.35 (ULC)	1.79	4.10%
	LLCC	LLCC = -5.77 + 0.84 (LLC)	2.2	49%

ULCC=Upper lip curvature change, LLCC= Lower lip curvature change,
SE = Predicted Variation, R^2 = Explained Variance

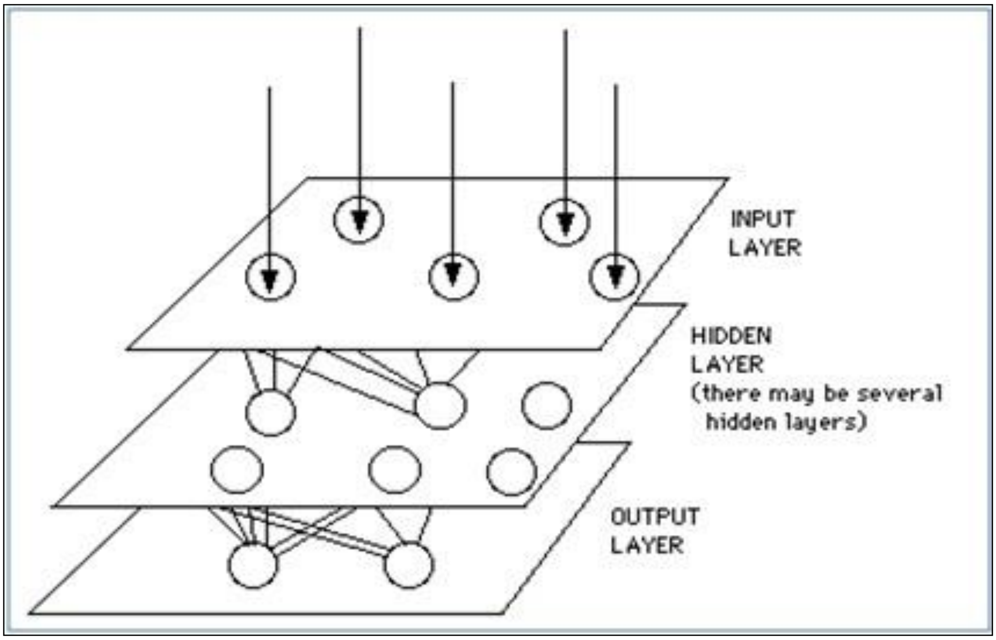

Fig. 1: The structure of an artificial neural network

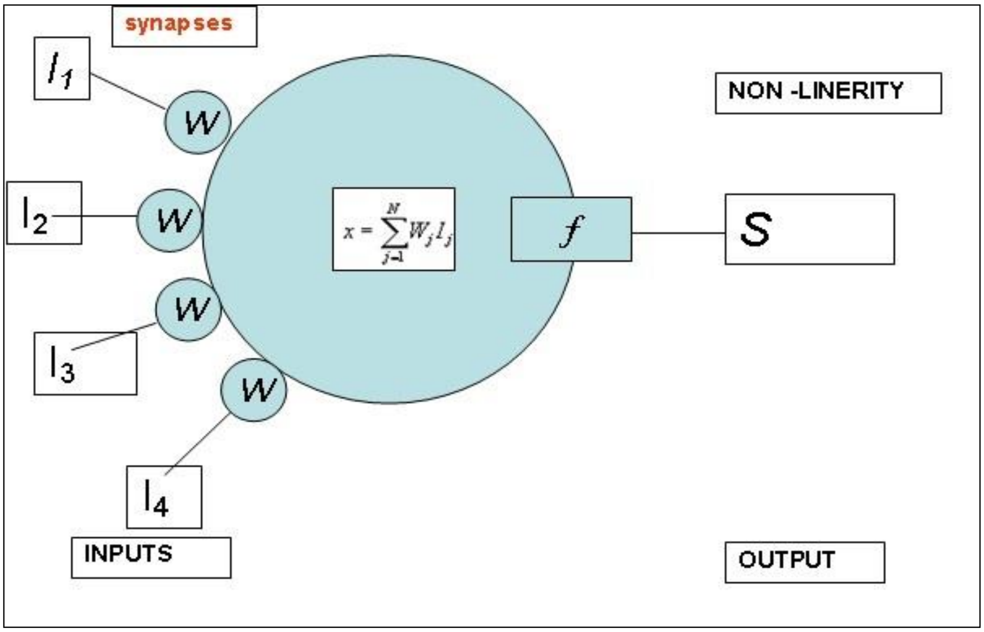

Fig. 2: The basic components of an artificial neuron

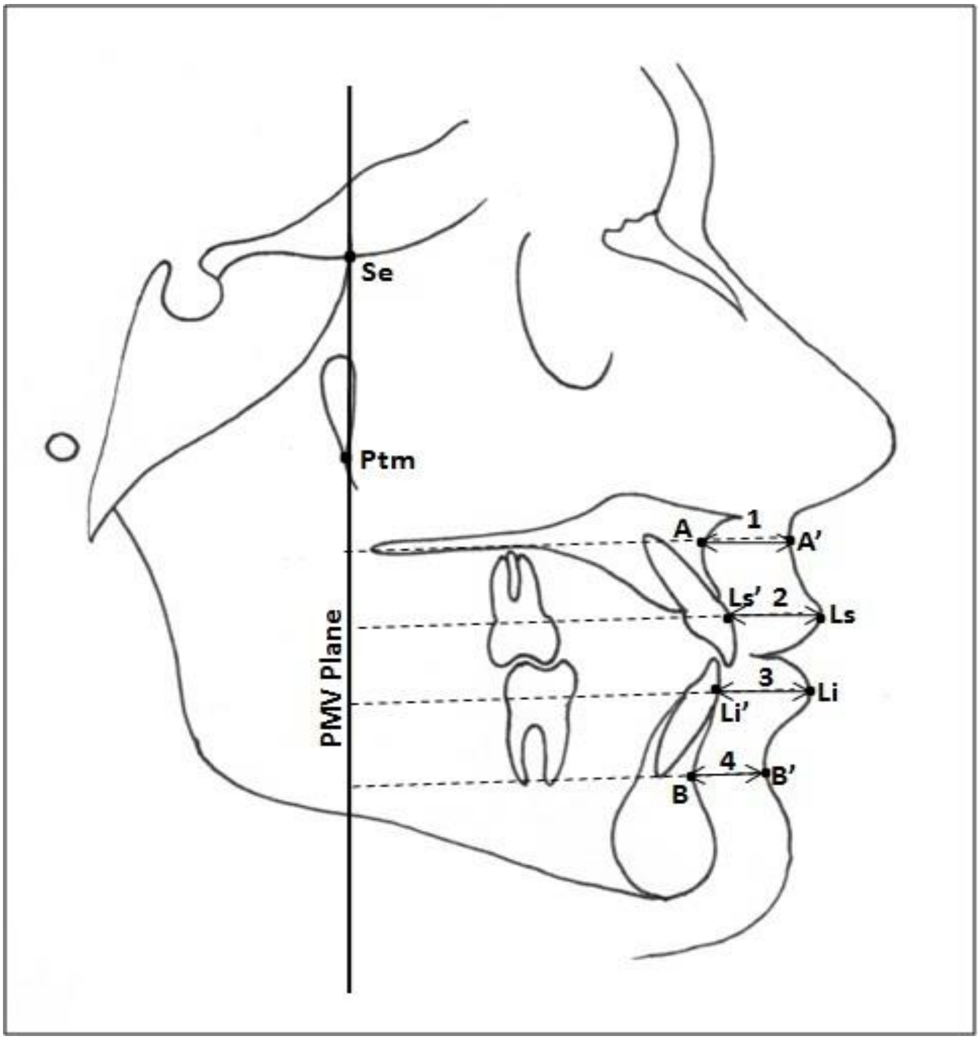

Fig. 3: Various cephalometric landmarks, reference planes and linear parameters used for the evaluation of upper and lower lip curvature changes. *Cephalometric landmarks*: Sphenoethmoidal point (**Se**), the intersection of the

greater wings of the sphenoid with the floor of the anterior cranial fossa; Pterygomaxillary point (**Ptm**), the inferior and most posterior point on the anterior outline of the pterygomaxillary fissure; Point A (**A**); Projected point A (**A'**), point constructed where a line, perpendicular to PMV plane and passing through skeletal A point intersects the soft tissue outline; Labrale superius (**Ls**); Projected labrale superius (**Ls'**), point constructed where a line perpendicular to the PMV plane and passing through labrale superius intersects the hard tissue outline; Labrale inferius (**Li**); Projected labrale inferius (**Li'**), point constructed where a line perpendicular to the MPV plane passing through labrale inferius intersects the hard tissue outline; Supramentale point (**B**); Projected supramentale point (**B'**), the point of intersection of the soft tissue profile with a line drawn perpendicular to PMV plane through supramentale (B point). *Reference plane*: Pterygomaxillary vertical (PMV) plane, plane drawn from the sphenoethmoid point (Se) to the pterygomaxillary (Ptm) point. *Linear parameters*: 1. Upper lip thickness at Point A (A-A'); 2. Upper lip thickness at labrale superius (Ls-Ls'); 3. Lower lip thickness at labrale inferius (Li-Li'); 4. Lower lip thickness at B point (B-B').

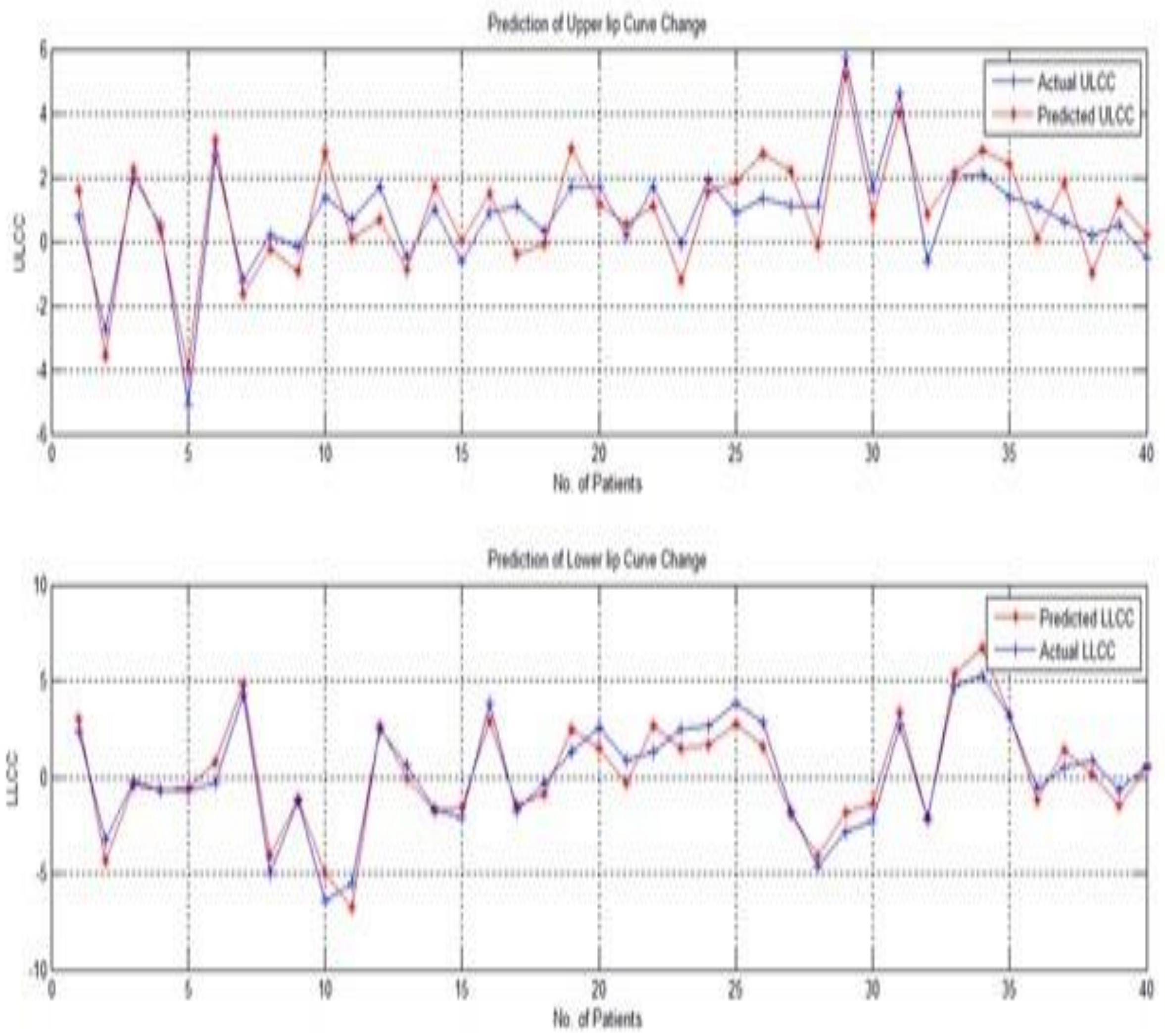

Fig. 4: The neural network prediction values for the upper and lower lips curvature changes.

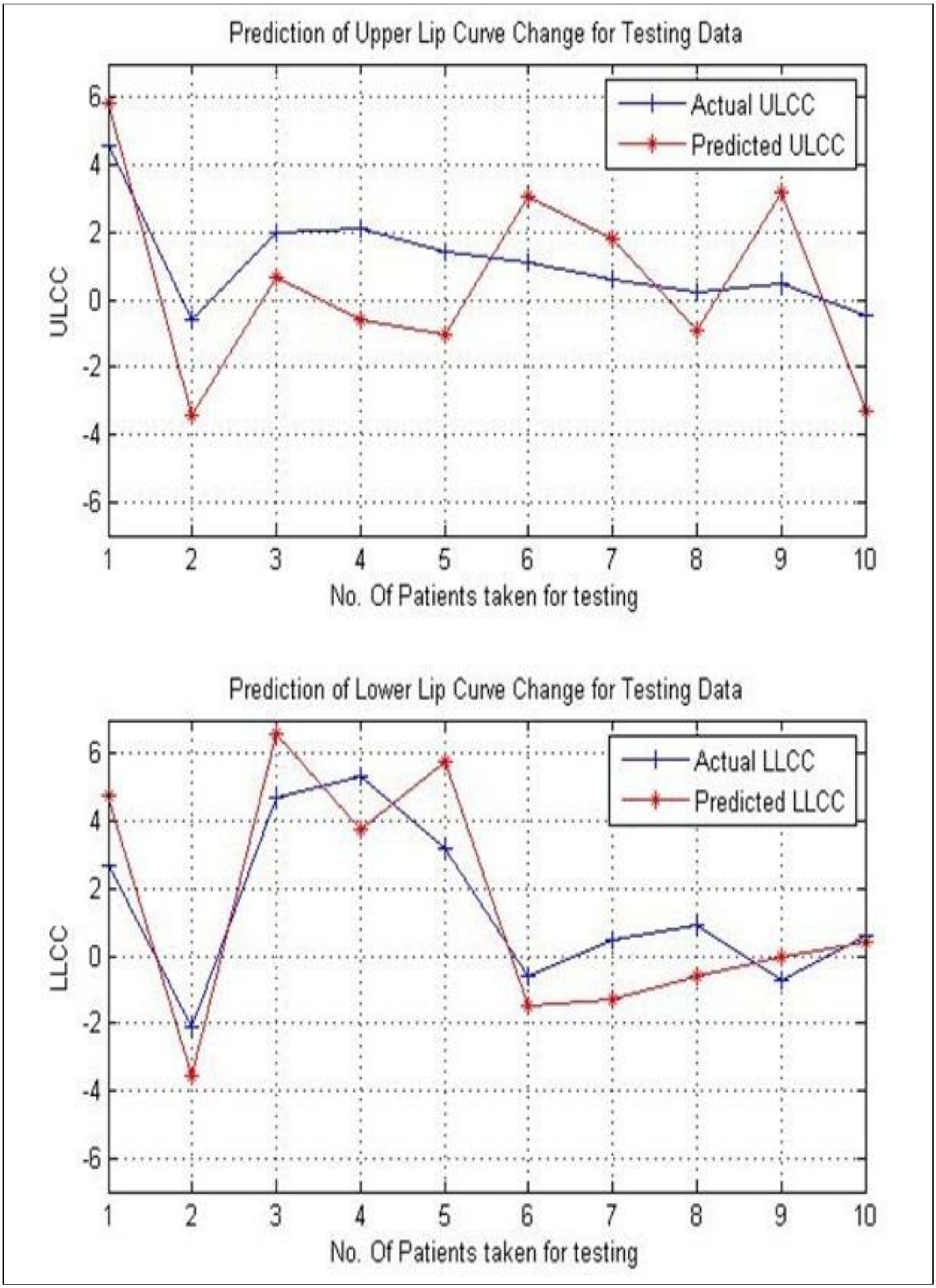

Fig. 5: Prediction of upper and lower lip curve change for the testing data.

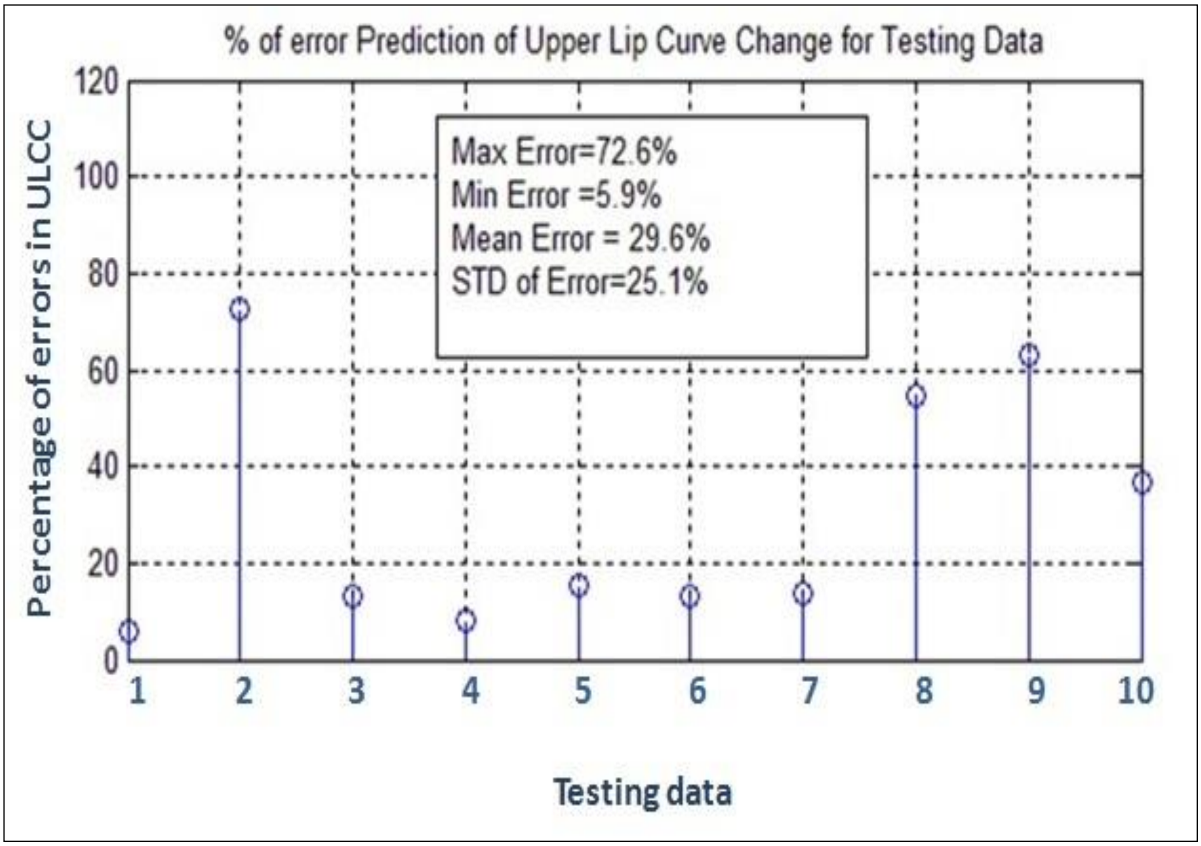

Fig. 6: The comparison of percentage of mean error in the prediction of upper lip curve change for testing data by ANN analysis and regression analysis.

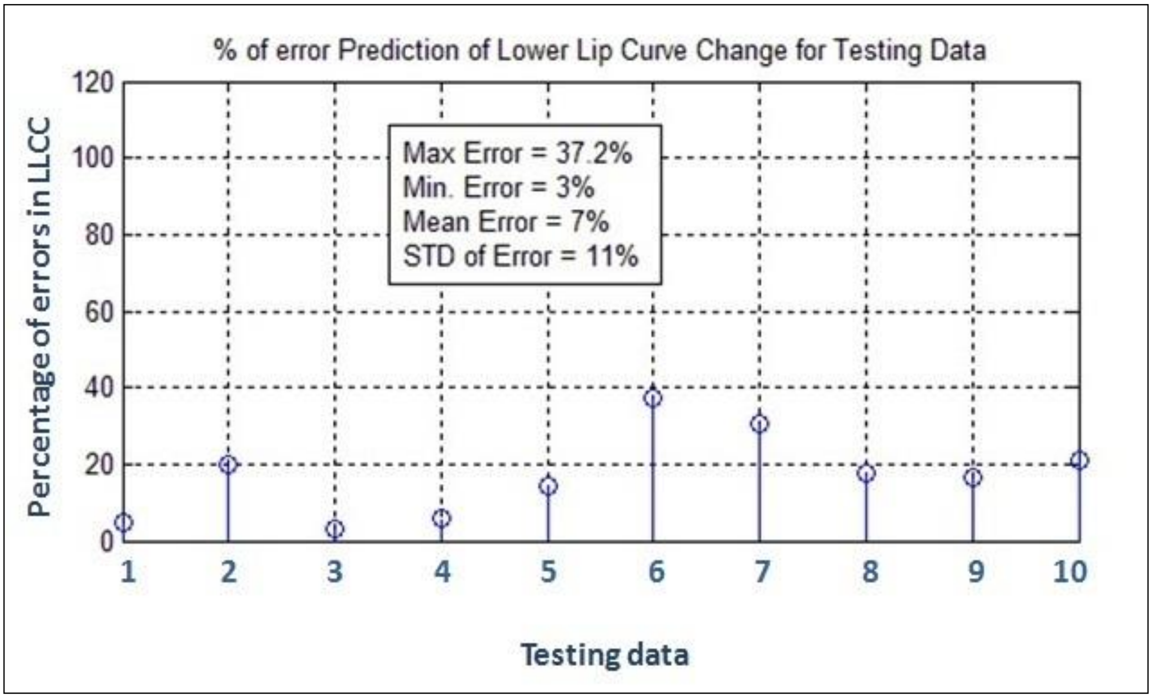

Fig. 7: The comparison of percentage of mean error in the prediction of lower lip curve change for testing data by ANN analysis and regression analysis.

DISCUSSION

Artificial neural network (ANN) models have been used widely in medicine for solving a wide variety of problems.[12-17] However in dentistry, ANN models have been tried occasionally.[6,8,18-20] In orthodontics, ANN models have been used for the analysis and classification of human craniofacial growth,[6] prediction of electromyographic signal values of anterior temporal muscle among children undergoing orthodontic treatment[7] and deciding the need of extractions prior to orthodontic treatment.[8]

From the present study we found that the mean change in the depth of upper lip curvature following premolars extraction treatment was significantly different as compared to the non-extraction treatment. However, there was no change in lower lip curvature following premolars extraction and non-extraction treatment. However in contrast to our observation many previous studies reported no change in the depth of upper and lower lip curvature amongst the various extraction and non-extraction treatment.[21,22] The inherent morphology of the soft tissue appeared to be the greatest determinant of lip curve behavior with extraction and non-extraction treatment.[22] Wholley and Woods also reported that changes in the depths of curvature of both the upper and lower lips were not solely dependent on the selection of a particular premolar extraction sequence.[23] Instead, there were wide ranges of individual variation in the changes in the depths of the lip curves.[23] From the present study it was appear that the change in midface soft tissue was more dependent on changes in the underlying hard tissue as compared to the lower face soft tissue. But previous study done by Moseling and Woods reported that the midface soft tissue was less dependent on changes in the underlying hard tissues than do the lower face soft tissue.[21]

An important observation that we found from the stepwise regression predictions (table-2) was that only prediction of lower lip curve change following upper first and lower second premolars extraction was good enough with 95.3% explained variance. Although the ANN predicted values for upper and lower lip curvature changes were very close to the actual prediction values obtained from statistical regression analysis, but the mean error was only 29.6% for upper lip and 7% for lower lip as compared to the conventional regression analysis. The major drawback of this present study is that the ANN model was trained with data of only 40 subjects. Thus an ANN model from data of very large samples needs to be prepared to establish an accurate decision making system.

Thus the artificial neural network analysis can be the solution to those problems which cannot be easily solved with traditional methods. Neural network expert systems may be trained with only clinical data and as such can be used where 'rule based' decision making may not always be possible. So the artificial neural network analysis is a promising tool to produce clinical decision support systems (CDSS) to provide expert support for health professionals. As information technology applications for dental practice developing rapidly and will hopefully contribute to produce clinical decision support systems (CDSS) of orthodontics and in turn impact patient care.

CONCLUSIONS

The following conclusions were drawn from the present study

1. Extraction and non-extraction treatment had significant effect on the curvature of upper lip change.
2. The ANN model analysis was more accurate for the prediction of lip curvature change following extraction and non-extraction orthodontic treatment as compared to the conventional statistical regression analysis.

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