INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS
ISSN(print): 2643-9840, ISSN(online): 2643-9875
Volume 05 Issue 08 August 2022
DOI: 10.47191/ijmra/v5-i8-39, Impact Factor: 6.261
Page No. 2210-2219

Cephalometric Evaluation of Changes in Tongue Position, Posture and Pharyngeal Airway Dimensions Following Treatment of Angle's Class 1 Bimaxillary Proclination

Pooja Madhavan[1], Shifa Jabar[2], Priya Raj[3]
[1,2,3]College of Dental Sciences & Research Affiliated to Kerala University of Health Sciences (KUHS)

ABSTRACT
Objectives: The aim of the study is to determine and correlate the effects of anterior teeth retraction on tongue position, posture and pharyngeal airway dimensions, in Angle's Class 1 bimaxillary dentoalveolar proclination cases treated with all first premolar extraction.
Materials and Methods: Pre and post treatment lateral cephalogram of fifteen Class I bimaxillary dentoalveolar proclination patients in the age group of 15-25years treated orthodontically as maximum anchorage cases with Preadjusted Edgewise Appliances (MBT prescription) and extraction of all first premolars were compared.
Results: Tongue position analysis showed significant decrease in tg1: 2.2 +/- 1.52 mm (p = 0.001) and TGL: 4.2 +/- 3.877 mm (p = 0.001). Tongue posture analysis showed a significant decrease in Point 1: 1.48 +/- 1.92 mm (p=0.028), Point 2: 1.44 +/- 1.46 mm (p=0.008) and Point 5: 1.92 +/- 2.45 mm (p=0.026).Pharyngeal airway analysis showed significant increase in PNS-Ad1: 1.2 +/- 1.69 mm (p=0.016) while V-LPW: 2.0 +/- 3.047 mm (p=0.023) was decreased. No significant correlation was found between changes in total tongue length and velopharyngeal and glossopharyngeal airway.
Conclusions: A significant reduction in the total tongue length particularly in the posterior region was observed after retraction. Also there was a reduction in the distance between root of the tongue and uvula, dorsum of the tongue and the roof of mouth in the posterior and anterior part of palate respectively. There was an increase in the lower nasopharyngeal airway and a decrease in the hypopharyngeal airway.

KEYWORDS: Bimaxillary dentoalveolar proclination; Tongue position; Tongue posture; Pharyngeal airway; First premolar extraction.

INTRODUCTION

Bimaxillary proclination, diagnosed by the presence of convex profile,upper incisor inclination of 115° and lower incisor inclination of 99 °or more, together with an interincisal angle of 125° or less, often demands the extraction of first four first premolars for its treatment. Most of these extraction spaces will be used for incisor retraction and correction of lip procumbency which in turn will result in reduction of arch dimension and thus could affect tongue position and the upper airway dimension. [1]

Even though the tongue has been reported to move posteriorly after mandibular setback surgery, causing encroachment into the airway [2], very few studies were conducted to evaluate the possible changes in tongue position and posture after extraction treatment and to correlate it with the changes in airway dimensions. Among the various studies conducted regarding the relationship between pharyngeal airway dimensions and extraction orthodontic treatment ,some studies found that the middle and inferior airway dimensions diminished after the extraction treatment [3,4,5] while others [1,6,7] found no difference in the upper airway between pre and post-treatment.

Various clinical and imaging techniques are employed to determine the tongue posture. Clinical examination of tongue posture is limited because of anatomic constrains produced by the surrounding structures and the evaluation is highly subjective. Imaging techniques include lateral cephalograms, computed tomography, radiocinematography, electropalatography, electromagnetic articulography, magnetic resonance and 2-dimensional ultrasonography.

Most previous studies of the pharyngeal airway, have been carried out using a two dimensional (2D) lateral cephalogram. [8] Cephalometry offers considerable advantages over other techniques, including low cost, convenience and minimal exposure to radiation,[9] but superimposition of the left and right images leads to errors, and the left-to-right width of the upper airway is not visible in 2D film. [8] Although numerous studies have been published using CBCT to evaluate airway, few have addressed the accuracy of the measures. [10]

Thus, the current study was done to investigate the effects and correlate the changes in tongue position, posture and upper airway dimensions following treatment of bimaxillary proclination cases treated as maximum anchorage with extraction of four first premolars.

MATERIALS AND METHODS

Fifteen patients between age group of 15 to 25 years (1 male & 14 females patients) who were clinically diagnosed with Angle's Class I bimaxillary dent alveolar proclination and treated as maximum anchorage with extraction of all first premolars were considered for the study. The selected patients were devoid of crowding and extraction space was utilised for retraction of anteriors. Exclusion criteria included history of previous orthodontic treatment, developmental disorders & systemic diseases, cases with missing teeth, patients on medications affecting tooth movement, habits like mouth breathing, tongue thrusting etc., history of tonsillectomy, adenoidectomy, trauma, etc.

The study proceeded with the approval of both the Institutional Scientific committee and Ethical committee (AEC/REV/2016/43).

All patients were strapped-up with 0.022" X 0.028" Preadjusted Edgewise Appliances – (PEA: MBT prescription) after extraction of all four first premolars. Anchorage was reinforced using Nance palatal arch and lingual arch during alignment and incorporating second molars during retraction in maxilla and mandible. Pre and post treatment lateral cephalograms were obtained with good hard and soft tissue outlines; teeth in full occlusion and lips at rest. All the lateral cephalograms were taken with the same machine (Orthophos XG5; Dentsply Sirona, Germany *(linear magnification of the machine = 11% approx.*), by the same operator and were traced manually by the same investigator. To avoid bias these were retraced after 1 week and the two were compared.

The land marks used are given in Table 1. [5, 11, 12]

Table 1. Landmarks

A: Dentofacial Analysis [11]	
S	Sella : Geometric centre of the pituitary fossa
N	Nasion : The most anterior point on the frontonasal suture in the midsagittal plane
PNS	Posterior nasal spine: Posterior spine of the palatine bone constituting the hard palate
Point A	Subspinale: The most posterior midline point in the concavity between the ANS and the prosthion (the most inferior point on the alveolar bone overlying the maxillary incisors)
Point B	Supramentale: The most posterior midline point in the concavity of the mandible between the most superior point on the alveolar bone overlying the lower incisors(infradentale) and pogonion
Ii	Incisal tip of most prominent mandibular incisors
Is	Incisor tip of the most prominent maxillary incisor
Gn	Gnathion: A point located by taking the midpoint between the anterior (pogonion) and the inferior (menton) points on the bony chin
Me	Menton: Lowest point on the symphyseal shadow of the mandible
Go	Gonion: A point on the curvature of the angle
Or	Orbitale :The lowest point on the inferior rim of the orbit
Po	Porion: The most superiorly positioned point of the external auditory meatus
Ba	Basion: Lowest point on the anterior rim of the foramen magnum
Ptm	Pterygomaxillare: The contour of the ptreygomaxillary fissure formed anteriorly by the retromolar tuberosity of the maxilla and posteriorly by the anterior curve of the pterygoid process of the sphenoid bone, the posterio- superior most point on the opening is used

Ptm pr	Ptm perpendicular: Perpendicular from Ptm to Frankfurt Horizontal Plane (FHP: line through Or and Po)
U6	Distal surface of Maxillary first molar
L6	Distal surface of Mandibular first molar
B: Tongue Analysis [12]	
Tg	Tongue point
Mc	Point on the cervical, distal third of the last erupted permanent molar
O	Middle of the linear distance U-Ii on Mc-Ii line
TT	Tip of the tongue
U	Tip of the uvula or its projection on Mc-Ii line
C: Airway Analysis [5]	
Hor	Most inferior point on the spheno-occipital synchondrosis
R	Point of intersection of line from Hor to PNS and posterior pharyngeal wall
Ad1	Point of intersection of posterior pharyngeal wall and line Ptm-Ba
SPPW	Point of intersection of line from soft palate center perpendicular to posterior pharyngeal wall
SPP	Point of intersection of line from soft palate center perpendicular to posterior pharyngeal wall and posterior margin of soft palate
U	The tip of the uvula
MPW	Foot point of perpendicular line from point U to posterior pharyngeal wall
TPPW	Point of intersection of posterior pharyngeal wall and extension of line B-Go
TB	Point of intersection of base of the tongue and extension of line B-Go
V	The most posteroinferior point on the base of the tongue
LPW	Foot point of perpendicular line from point V to posterior pharyngeal wall

Cephalometric analysis for dentofacial parameters is given in Table 2. [13,14]

Table 2. Dentofacial Analysis

Is-NA (linear)	Linear distance from Upper incisor to Nasion – Pt A plane
Is-NA (angular)	Angular measurement from Upper incisor to Nasion – Pt A plane
Ii-NB (linear)	Linear distance from lower incisor to Nasion – Pt B plane
Ii-NB (angular)	Angular measurement from lower incisor to Nasion – Pt B plane
Interincisal Angle	Angular measurement between long axis of upper and lower incisor
Is-SN	Angular measurement from Upper incisor to Sella – Nasion plane
Ii-GoGn	Angular measurement from lower incisor to mandibular plane
SN-GoGn	Mandibular plane angle
U6-Ptm per	Upper molar to pterygoid perpendicular to Frankfort horizontal plane
L6-Ptm per	Lower molar to pterygoid perpendicular to Frankfort horizontal plane

The tongue position and posture were evaluated using Rakosi's analysis based on Rakosi's template (Table 3 and 4).[12,16] It is a transparent plastic template (Figure 1) with an inscribed millimeter scale used to analyse the position of the tongue on the lateral cephalogram. The template is oriented at the point O, which is the centre point of the line through tip of lower incisor and the tip of uvula. A line is drawn through O, perpendicular to the horizontal base and extended to the palate. A further four lines are drawn, 30° to each other, resulting in a total of seven lines. These lines from O metrically evaluates the distance between tongue and various structures like soft palate, roof of mouth, tip of incisors.[15] The template is also used to determine the height of dorsum of the tongue on all seven lines. [16] Representation of the landmarks and lines are given in Figure 2.

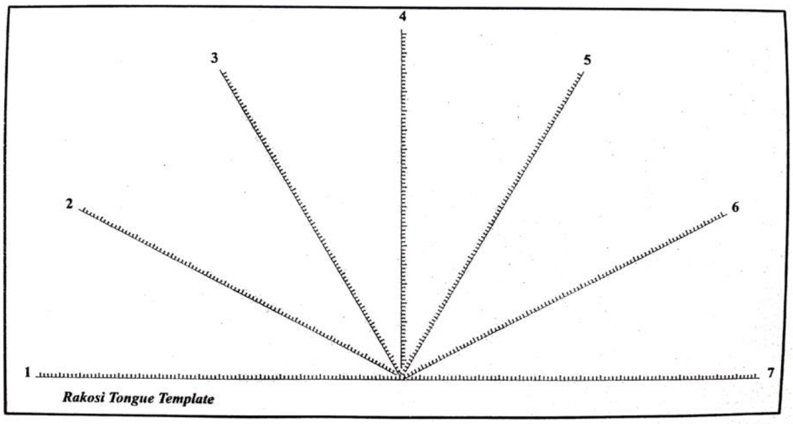

Figure 1. Rakosi's tongue template

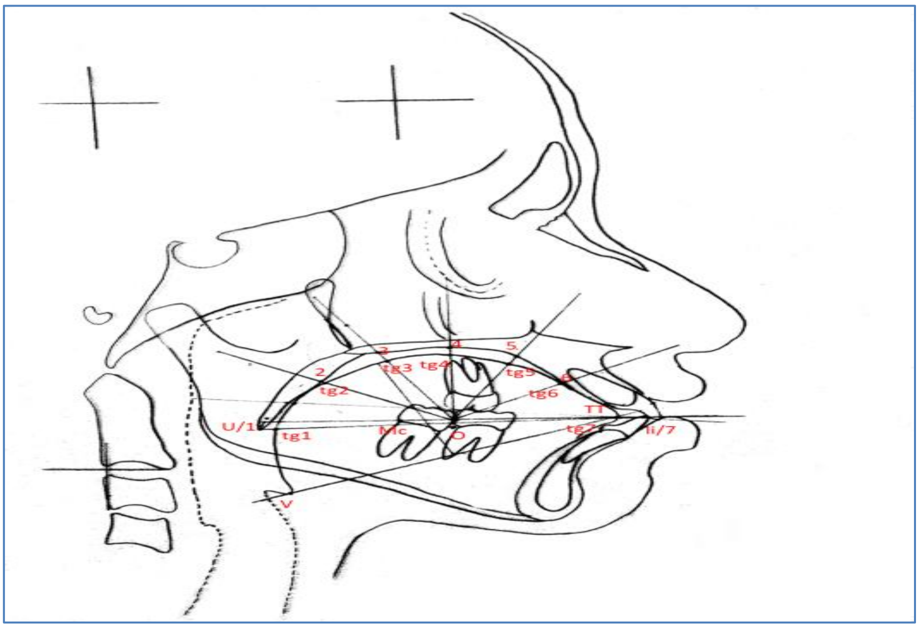

Figure 2. Landmarks and lines for Tongue analysis

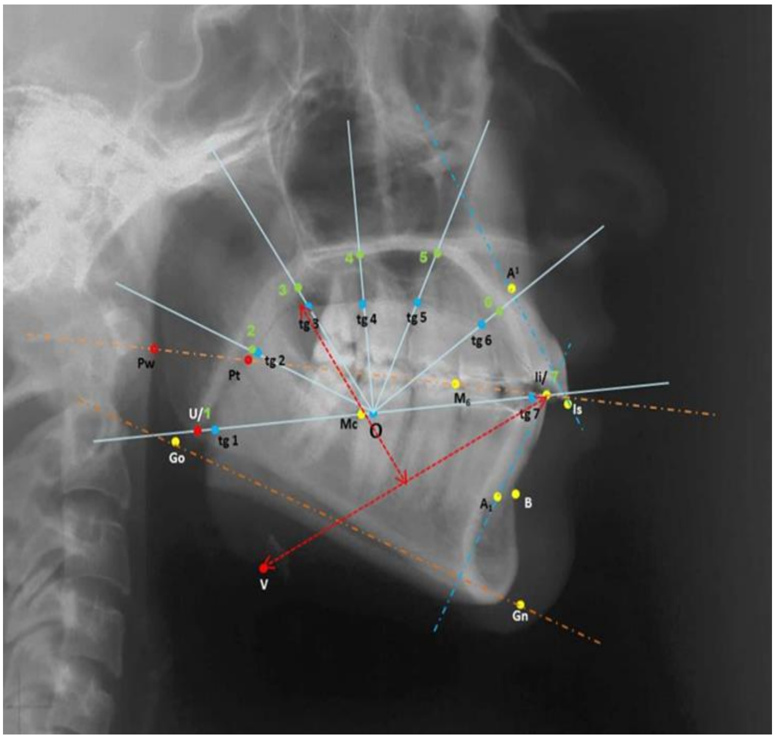

Table 3. Evaluation of Tongue Position

tg1	Line through the O and U or its projection. Measures the length of the tongue in the posterior portion (root) of the tongue.
tg2	Line constructed on O at 30° Mc-Ii line. Indicates the partial length of the tongue in the posterior region of the dorsum.
tg3	Line constructed on O at 60° Mc-Ii line. Indicates the partial length of the middle part of the dorsum of the tongue.
tg4	Line constructed on O at 90° Mc-Ii line. Indicates the partial length of the tongue in the middle of the dorsum of tongue.
tg5	Line constructed on O at 120° Mc-Ii line.
tg6	Line constructed on O at 150° Mc-Ii line. Indicates the partial length of the tongue in the anterior region of the tongue.
tg7	Line constructed on O at 180° Mc-Ii line. Indicates the partial length of the tongue in the tip region.
TGH	Perpendicular to the dorsum of tongue from mid of V-TT line. It measures the height of the tongue.
TGL	Tongue length. This is measured by distance between TT and V point.

Table 4. Evaluation of Tongue Posture

Point 1	Distance between the soft palate and the root of the tongue
Point 2-6	Relationship of the dorsum of the tongue to the roof of the mouth
Point 7	Position of the tip of the tongue relative to lower incisors

Pharyngeal airway changes were evaluated in four different regions: nasopharynx, velopharynx, glossopharynx, and hypopharynx. [5] (Table 5 and Figure 3).

Table 5. Upper Airway Analysis

PNS-R	Distance between PNS and R	Upper nasopharynx
PNS-Ad1	Distance between PNS and Ad1	Lower nasopharynx
SPP-SPPW	Distance between SPP and SPPW	Velopharynx
U-MPW	Distance between U and MPW	
TB-TPPW	Distance between TB and TPPW	Glossopharynx
V-LPW	Distance between V and LPW	Hypopharynx
VAL	Distance between PNS and V	Vertical airway length

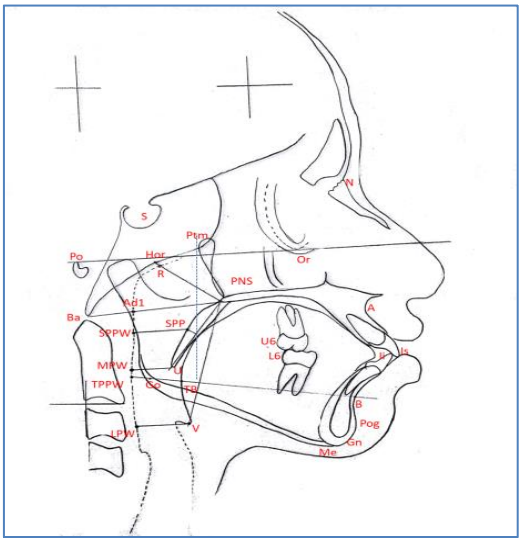

Figure 3. Landmarks and lines for airway and Dentofacial analysis

Statistical analysis

Data was analysed using R software (EZR version 1.32) for Windows.

p value (Probability that the result is true) of <0.05 was considered as statistically significant after assuming all the rules of statistical tests.

Paired t test was done for pre and post treatment dentofacial, tongue position and airway comparison. **Wilcoxon signed rank test** was done for tongue posture analysis as the data was not normally distributed.

The Spearman's rank-order correlation was used for correlation between two variables.

RESULTS

Dentoalveolar changes showed a mean retraction of upper and lower incisors by 4.26 +/- 2.71mm (p = 0.001) and 4.6 +/- 1.99 mm (p = 0.001) respectively which resulted in an Is/NA angle decreased by 11.33 +3/- 4.7 ° (p = 0.001); Ii/NB angle decreased by 15.06 +/- 4.87° (p = 0.001); Interincisal Angle increased by 27 +/-9.08° (p =0.001) (Table 6). The mean distance from the distal surface of maxillary and mandibular first molars to the pterygoid vertical showed a significant decrease post treatment suggesting anchorage has been taxed.

Table 6.Changes in Dentofacial parameters (n=15)

Variable	Pre (Mean +/- SD)	Post (Mean +/- SD)	Pre-Post (Δ) (Mean +/- SD)	t	P
Is-NA (linear) (mm)	7.73 +/- 1.831	3.47 +/- 1.685	4.26 +/- 2.71	5.866	0.001*
Is-NA (angular) (°)	31.53 +/- 3.461	20.20 +/- 3.895	11.33 +/- 4.7	9.162	0.001*
Ii-NB (linear) (mm)	10.27 +/- 2.251	5.67 +/- 1.447	4.6 +/- 1.99	9.740	0.001*
Ii-NB (angular) (°)	42.60 +/- 5.938	27.53 +/- 3.758	15.06 +/- 4.87	11.820	0.001*
Is-SN (°)	117.87 +/- 5.083	107.73 +/- 6.307	10.13 +/- 5.35	7.326	0.001*
Ii-GoGn (°)	108.73 +/- 8.172	93.33 +/- 5.219	15.4 +/- 4.67	12.766	0.001*
Interincisal Angle (°)	101.93 +/- 9.513	129.13 +/- 6.232	27 +/- 9.08	-11.601	0.001*
SN-GoGn (°)	31.33 +/- 7.880	31.47 +/- 8.193	0.133 +/- 1.598	-.323	0.751
U6-Ptm per (mm)	18.07 +/- 3.474	20.33 +/- 3.498	2.26 +/- 1.62	-4.975	0.001*
L6-Ptm per (mm)	18.53 +/- 3.523	20.40 +/-3.158	1.86 +/- 1.56	-5.164	0.001*

*significant at the 0.05 level.

The results displayed in Table 7 shows a significant decrease in tg1 by 2.2 +/- 1.52 mm (p = 0.001), TGL by 4.2 +/- 3.877 mm (p = 0.001), while no significant changes were found in tg2, tg3, tg4, tg5, tg6, tg7 and TGH (p >0.05).

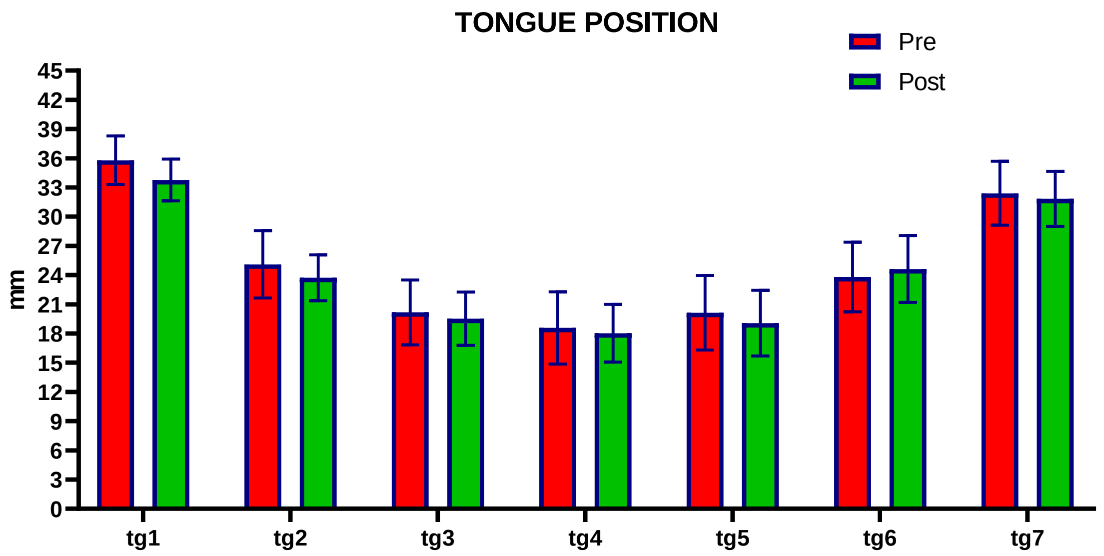

Figure 4. Graphical representation of changes in Tongue position preoperatively and postoperatively

Only tg1 showed statistically significant change. Post treatment values of all parameters except tg6 were decreased.

Table 7. Changes in Tongue position (n=15)

Variable (mm)	Pre (Mean +/- SD)	Post (Mean +/- SD)	Pre-Post (Δ) (Mean +/- SD)	t	P
tg1	36.07 +/- 2.492	33.87 +/- 2.386	2.2 +/- 1.52	5.036	0.001*
tg2	25.27 +/- 3.712	24.27 +/- 2.344	1.00 +/- 3.35	1.222	0.266
tg3	20.20 +/- 3.802	19.40 +/- 2.947	0.80 +/- 4.057	.571	0.456
tg4	18.47 +/- 3.871	18.00 +/- 3.140	0.467 +/- 4.068	.287	0.664
tg5	20.33 +/- 3.848	19.60 +/- 3.521	0.73 +/- 4.69	.574	0.555
tg6	24.73 +/- 3.555	25.20 +/- 3.590	0.467 +/- 3.53	-.614	0.620
tg7	32.87 +/- 3.420	31.93 +/- 3.218	0.933 +/- 3.21	.978	0.280
TGH	32.67 +/- 3.559	32.27 +/- 3.218	4.2 +/- 3.877	.441	0.780
TGL	74.73 +/- 5.800	70.53 +/- 6.854	4.2 +/- 3.877	4.061	0.001*

*significant at the 0.05 level.

Tongue posture after treatment displayed a significant decrease in Point 1 by 1.48 +/- 1.92 mm (p = 0.028), Point 2 by 1.44 +/- 1.46 mm (p = 0.008) and Point 5 by 1.92 +/- 2.45 mm (p=0.026), while no significant changes were found in Point 3,4,6 and 7 (p >0.05).

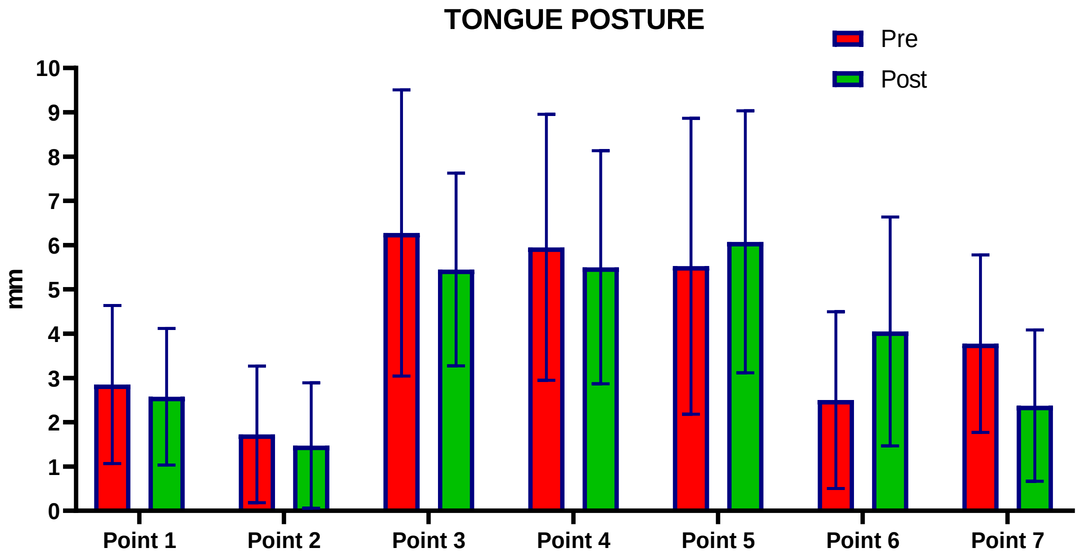

Figure 5. Graphical representation of changes in Tongue posture preoperatively and postoperatively

Point 6 and point 7 showed statistically significant change postoperatively. Post treatment value of point 6 significantly increased, while value of point 7 significantly decreased. Post treatment value of point 5 is increased but the change is statistically insignificant.

Tongue posture after treatment displayed a significant decrease in Point 1 by 1.48 +/- 1.92 mm (p = 0.028), Point 2 by 1.44 +/- 1.46 mm (p = 0.008) and Point 5 by 1.92 +/- 2.45 mm (p=0.026), while no significant changes were found in Point 3,4,6 and 7 (p >0.05). (Table 8)

Table 8. Changes in Tongue posture (n=15)

Variable (mm)	Pre (Mean +/- SD)	Post (Mean +/- SD)	Pre-Post (Δ) (Mean +/- SD)	z	P
Point 1	3.7545+/- 1.55007	2.2727+/- .86959	1.48 +/- 1.92	-2.041	0.028*
Point 2	2.6727+/- 1.43881	1.2273+/- 1.25227	1.44 +/- 1.46	-2.675	0.008*

Point 3	7.1364+/- 3.35478	5.4545+/- 2.62159	1.68 +/- 3.64	-1.379	0.157
Point 4	6.5000+/- 3.26343	4.9545+/- 2.89357	1.54 +/- 2.91	-1.530	0.110
Point 5	7.3364+/- 2.35044	5.4091+/- 3.29255	1.92 +/- 2.45	-2.146	0.026*
Point 6	3.2727+/- 2.04161	3.0909+/- 2.37506	0.19 +/-2.12	.000	0.782
Point 7	4.0909+/- 2.43740	2.4545+/- 1.95518	1.63 +/- 2.84	-1.690	0.086

*significant at the 0.05 level.

Table 9 shows that there was a significant increase in PNS-Ad1 by 1.2 +/- 1.69 mm (p=0.016) and decrease in V-LPW by 2.0 +/- 3.047 mm (p=0.023), whereas PNS-R, SPP-SPPW, U-MPW, TB-TPPW and VAL showed no significant changes (p >0.05).

Table 9. Changes in airway dimensions (n=15)

Variable (mm)	Pre (Mean +/- SD)	Post (Mean +/- SD)	Pre-Post (Δ) (Mean +/- SD)	t	P
PNS-R	19.73 +/- 4.250	20.47 +/- 3.701	0.733 +/- 2.05	-1.684	0.188
PNS-Ad1	24.13 +/- 5.069	25.33 +/- 4.402	1.2 +/- 1.69	-2.837	0.016*
SPP-SPPW	13.93 +/- 3.654	13.47 +/- 3.758	0.467 +/-1 .407	1.284	0.220
U-MPW	11.80 +/- 3.764	13.47 +/- 3.758	1.4 +/- 2.66	1.964	0.061
TB-TPPW	11.80 +/-4.212	11.00 +/- 3.251	0.8 +/- 3.098	1.131	0.334
V-LPW	16.00 +/- 2.777	14.00 +/- 3.780	2.0 +/- 3.047	2.582	0.023*
VAL	53.67 +/- 4.030	53.73 +/- 3.575	0.067 +/- 2.086	-.191	0.903

*significant at the 0.05 level.

A correlation analysis was also done to determine if the decrease in glossopharyngeal and hypopharyngeal airway was related to a decrease in tongue length. (Table 10)

Table 10. Correlation analysis between tongue length with glossopharyngeal and hypopharyngeal airway

			TB-TPPW	V-LPW
Spearman's rho	TGL	Correlation Coefficient	.305	.434
		p-value	.270	.106
		N	15	15

*significant at the 0.05 level.

DISCUSSION

Dentofacial structures

A significant amount of retraction was observed suggested by a decrease in the linear and angular measurements of upper and lower incisor inclination, the inclination of the upper incisor to the cranial base and of the lower incisor to the mandibular plane. (Table 6) Absence of a change in mandibular plane angle suggests that the mechanics used for the correction of bimaxillary dentoalveolar proclination has no significant effect on the vertical dimension. Absolute anchorage devices like temporary anchorage devices, extra oral anchorage devices, etc. were not considered for the present study, thus some amount of anchorage loss was inevitable during retraction. As there was sufficient amount of retraction, anchorage loss was ignored.

Tongue position

The present study used Rakosi's tongue template to assess the tongue position and posture similar to studies by Verma et al., [12] Primozic et al., [17] Subhramanya RM and Gupta S [18] and Tarkar et al. [19] A significant decrease in the overall tongue length (TGL), particularly in the posterior region (tg1) (Table 7) was also observed which is in concurrence by the study conducted by Nagmode et al. [20] .The author concluded that the restriction of the tongue after bimaxillary proclination treatment is considered to be the main cause of relapse and space reopening due to reduction in the tongue length. But the study conducted by Germec –Cakan et al. [4] found that there is no difference in the total tongue length after treatment.

Tongue posture

The present study showed a more retruded tongue posture towards its root as represented by a significant decrease in Point 1 and Point 2 (Table 8) suggesting a reduction in tongue space in the posterior part of the oral cavity after retraction. It also showed a superior positioning of the dorsum of the tongue or an increase in the tongue height at Point 5 region which could be due to incisor retraction. Even though there was a significant retraction of lower anteriors, there was no significant change in the relation between the tip of the tongue and the lower incisors. No similar studies were done in bimaxillary dentoalveolar proclination cases to compare the results obtained from the present study.

Pharyngeal airway

Many studies [21, 22, 23, 24, 25, 26] have proved the reliability of lateral cephalograms in evaluating pharyngeal airway and therefore use of cephalograms in this study is justified. In the present study, the dimension of the nasopharynx was increased and that of hypopharynx were significantly decreased (Table 9). Studies by Germec-Cakan et al.,[4] Wang et al., [5] Chen et al., [3] Bhatia et al., [27], Nuvushetty et al. [28] showed similar results except for an increase in the nasopharynx. Nagmode et al. [20] found a significant increase in upper nasopharyngeal airway measured between PNS-R while in the present study even though an increase was found, it was statistically insignificant but the lower nasopharyngeal airway between PNS-Ad1 showed a significant increase in dimension (possibly attributed to growth and regression of the adenoid tissues). Wang et al., [5] Bhatia et al., [27] Nuvushetty et al., [28] observed a significant decrease in glossopharyngeal and velopharyngeal airway dimensions contradictory to the results in the present study. The varying results could be attributed to the anchorage methods used.

Vertical airway length was not affected similar to results by Bhatia et al. [27] and Nagmode et al. [20], implying that the effect was observed more in horizontal dimensions rather than in vertical dimensions of pharyngeal airway. But, Wang et al. [5] and Nuvushetty et al. [28] found a decrease in the same. Valiathan et al., [7] Al Maaitah et al., [1] Stefanovic et al., [6] Pliska et al., [29] revealed that there was no significant changes in the airway dimensions following maximal retraction in bimaxillary dentoalveolar proclination cases probably due to mandibular growth and the high variability of oropharyngeal volume.

Correlation analysis (Table 10) suggested that there is no significant relation between a decrease in tongue length with the decrease in dimensions of glossopharyngeal and hypopharyngeal airway.

These results should be viewed in the light of the fact that not only anteroposterior dimensions, but the vertical and transverse dimensions of these complex anatomical structures need to be further evaluated using newer three-dimensional imaging technique for more comprehensive results. Thus, the treatment plan must be modified depending on the risk-benefit analysis as per the patient's needs.

CONCLUSIONS

- The tongue occupied a more retruded and an anterosuperior posture after retraction.
- There was a significant decrease in the total length of the tongue after retraction.
- There was an increase in the lower nasopharyngeal airway and a narrowing of the hypopharyngeal airway after retraction.
- There is no significant relation between changes in tongue length and lower airway dimensions.

CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest

REFERENCES

1) Al Maaitah E, El Said N, Abu Alhaija ES. First premolar extraction effects on upper airway dimension in bimaxillary proclination patients. Angle Orthod. 2012;82:853-9.
2) Bills DA, Handelman CS, BeGole EA. Bimaxillary Dentoalveolar Protrusion: Traits and Orthodontic Correction Angle Orthod. 2005;75:333–9.
3) Chen Y, Hong L, Wang CL, Zhang SJ, Cao C, Wei F, Lv T, Zhang F, Liu DX.. Effect of large incisor retraction on upper airway morphology in adult bimaxillary protrusion patients: Three-dimensional multislice computed tomography registration evaluation. Angle Orthod. 2012;82:964–70.
4) Germec-Cakan D, Taner T, Akan S. Uvulo-glossopharyngeal dimensions in non- extraction, extraction with minimum anchorage, and extraction with maximum anchorage cases. Eur J Orthod. 2010 Nov 30.[Epub ahead of print]
5) Qingzhu Wang, Peizeng Jia, Nina K. Anderson, Lin Wang, Jiuxiang Lin. Changes of pharyngeal airway size and hyoid bone position following orthodontic treatment of Class I bimaxillary protrusion. Angle Orthod.2012;82:115-21.

6) N. Stefanovic,H. El,D. L. Chenin,B. Glisic,J. M. Palomo. Three-dimensional pharyngeal airway changes in orthodontic patients treated with and without Extractions. Orthod Craniofac Res. 2013;16: 87–96.
7) Valiathan M, El H, Hans MG, Palomo MJ. Effects of extraction versus non-extraction treatment on oropharyngeal airway volume. Angle Orthod. 2010;80:1068–74.
8) Oh KM, Hong JS, Kim YJ, Cevidanes LS, Park YH. Three-dimensional analysis of pharyngeal airway form in children with anteroposterior facial patterns. Angle orthod. 2011;81:1075–82.
9) T. Muto, A. Yamazaki, S. Takeda, J. Kawakami, Y. Tsuji, T. Shibata, I. Mizoguchi. Relationship between the pharyngeal airway space and craniofacial morphology, taking into account head posture. Int. J. Oral Maxillofac. Surg. 2006;35: 132–6.
10) Ghoneima A, Kula K. Accuracy and reliability of cone-beam computed tomography for airway volume analysis. Eur J Orthod. 2013;35: 256–61.
11) Alexander Jacobson. Radiographic Cephalometry: From Basics to 3-D Imaging; Quintessence Publishing Company,Inc; 1995.p.59-64.
12) Verma SK, Tandon P, Agarwal DK, Prabhat KC. A cephalometric evaluation of tongue from the rest position to centric occlusion in the subjects with class II malocclusion and class I normal occlusion. J Orthodont Sci. 2012:1:34-9.
13) Steiner CC. Cephalometrics for you and me. Am J Orthod. 1953;39:729-55.
14) Ricketts RM. Cephalometric analysis and synthesis. Angle Orthod. 1961;31:141-56.
15) Thomas Rakosi, Irmtrud Jonas, Thomas M. Graber.Orthodontic Diagnosis; Georg Thieme Verlag, Stuttgart, Thieme Medical Publishers Inc, New York;2010.p.154.
16) Rakosi T. An atlas and manual of cephalometric radiography; Wolfe Medical Publications Ltd; 1982.p.96-9.
17) Primozic J, Farcnik F, Perinetti G, Richmond S, Ovsenik M. The association of tongue posture with the dentoalveolar maxillary and mandibular morphology in Class III malocclusion: a controlled study. Eur J Orthod. 2013; 35: 388–93.
18) Subhramanya RM, Gupta S. Assessment and comparison of tongue posture in individuals with different vertical facial patterns. J Orofac Res. 2014;4:67-71.
19) Tarkar JS, Parashar S, Gupta G, Bhardwaj P, Maurya RK, Singh A, Singh P.. An Evaluation of Upper and Lower Pharyngeal Airway Width, Tongue Posture and Hyoid Bone Position in Subjects with Different Growth Patterns. J Clin Diagn Res. 2016;10: ZC79-ZC83.
20) Nagmode S, Yadav P, Jadhav M. Effect of first premolar extraction on point A, point B, and pharyngeal airway dimension in patients with bimaxillary protrusion. J Indian Orthod Soc. 2017;51:239-44.
21) Ucar FI, Uysal T. Orofacial airway dimensions in subjects with Class I malocclusion and different growth patterns. Angle Orthod. 2011;81:460–8.
22) Lee JW, Park KH, Kim SH, Park YG, Kim SJ et al. Correlation between skeletal changes by maxillary protraction and upper airway dimensions. Angle Orthod. 2011;81:426–32.
23) Trotman CA, McNamara Jr JA, Dibbets JM, van der Weele LT. Association of lip posture and the dimensions of the tonsils and sagittal airway with facial morphology. Angle Orthod 1997;67; 425-32.
24) Zhong Z, Tang Z, Gao X, Zeng XL. A comparison study of upper airway among different skeletal craniofacial patterns in non-snoring Chinese children. Angle Orthod. 2010;80:267–274.
25) Abramson ZR, Susarla S, Tagoni JR, Kaban L. Three-dimensional computed tomographic analysis of airway anatomy. J Oral MaxillofacSurg. 2010;68:363-71.
26) Pirila-Parkkinen K, Lopponen H, Nieminen P, Tolonen U, Paakko E, Pirttiniemi P. Validity of upper airway assessment in children: a clinical, cephalometric, and MRI study. Angle Orthod. 2011;81:433–9.
27) Bhatia S, Jayan B, Chopra SS. Effect of retraction of anterior teeth on pharyngeal airway and hyoid bone position in Class I bimaxillary dentoalveolar protrusion. Medical journal armed forces India. 2016;72: s17 – s23.
28) Nuvusetty B, Peddu R, Prakash AS, Kalyani M, Devikanth L, Chadalawada D. Assessment of changes in pharyngeal airway size and hyoid bone position following orthodontic treatment of Class I bimaxillary dentoalveolar protrusion. J Indian Orthod Soc. 2016;50:215-21.
29) Pliska BT, Tam IT, Lowe AA, Madson AM, Almeida FR .Effect of orthodontic treatment on the upper airway volume in adults. Am J Orthod Dentofac Orthop. 2016;150:937-44.