Original Article

Access this article online
Quick Response Code:
Website:
www.jorthodsci.org
DOI:
10.4103/jos.jos_191_21

Three dimensional changes of maxillary arch in Unilateral cleft lip and palate patients following comprehensive orthodontic treatment on digital study models

Sanjeev Verma[1], Sombir Singh[1], Raj K.Verma[1], Satinder P. Singh[1], Vinay Kumar[1], Shagun Sharma[2] and Parveen Kalra[2]

[1]Unit of Orthodontics, Oral Health Sciences Centre, PGIMER, Chandigarh, [2]Production and Industrial Engineering Department, Punjab Engineering College, Chandigarh, India

Address for correspondence:
Dr. Raj K. Verma, Associate Professor, Unit of Orthodontics, Oral Health Sciences Centre, PGIMER, Chandigarh, India.
E-mail: drrajverma876@gmail.com

Submitted: 26-Nov-2021
Revised: 10-Jan-2022
Accepted: 11-Jan-2022
Published: 04-May-2022

Abstract

OBJECTIVE: To compare the effects of comprehensive orthodontic treatment on palatal area, volume, inter-canine and inter-molar width in patients with Unilateral Cleft Lip and Palate (UCLP) using scanned models of the maxillary arch.

DESIGN: Retrospective cohort study.

SETTING: Tertiary setting.

PATIENTS: Two hundred and ten plaster study models of 70 patients with Unilateral Cleft Lip and Palate (Study group SG) and Control Group ($n = 70$) were scanned using Maestro 3D Dental scanner. The study groupwas further divided into subgroups; Subgroup I: treated with orthodontic treatment only (non-surgical), Subgroup II: patientsmanaged with combined orthodontics and orthognathic surgery (either maxillary advancement or maxillary distraction), Subgroup A: age >14 years and Subgroup B: age <14 years.

INTERVENTIONS: Comprehensive orthodontic and Orthosurgical treatment

MAIN OUTCOME MEASURES: Pre- and post-treatment scanned maxillary models of the study group were compared for palatal area and volumeand intercanine and intermolar width. The palatal dimensions of post-treatment scanned models were also compared to that of the control group.

RESULTS: The Palatal area and volume, intercanine and intermolar width were significantly higher in the post-treatment as compared to pre-treatment study models ($P < 0.01$). The measurements ofthe maxillary arch were significantly higher in the control group compared to the post-treatment measurements of the study group. The increase in palatal area and volume was greater in Subgroup I and A compared to Subgroup II and B patients, respectively.

CONCLUSION: The 3-Dimensional palatal dimensions in UCLP group improved after orthodontic treatment but were still not comparable to the normal subjects. The patients with age >14 years showed more improvement in the maxillary arch.

Keywords:

Three dimensional palatal morphology, digital models, palatal area, palatal volume, UCLP

Introduction

Clefts of the lip and cleft palate (CLP) are the most common congenital deformities of the craniofacial region.[1,2] Due to the complexity, the severity of the malformation and diversity in the clinical presentation of CLP, an interdisciplinary approach is required to ameliorate the

How to cite this article: Verma S, Singh S, Verma RK, Singh SP, Kumar V, Sharma S, *et al*. Three dimensional changes of maxillary arch in Unilateral cleft lip and palate patients following comprehensive orthodontic treatment on digital study models. J Orthodont Sci 2022;11:19.

functional, psychosocial aspects of life. The early surgical repair of lip and palate among these patients leads to scarring of palatal and lip tissue and affects the mid-facial growth and maxillary arch dimensions.[2] The common skeleto-dental and functional problems associated with CLP patients are maxillary retrusion,[1] nasal deformities, maxillary arch constriction and collapse, alveolar bone defect, crossbite on the side of the cleft, missing and supernumerary teeth and velopharyngeal variability,[3] altered speech.[4] There is an overall growth deficiency in CLP patients in the sagittal, vertical and transverse planes.

Though there are various protocols for the management of CLP patients starting from birth, they are usually advised for surgical repair of the lip at 3–6 months and palate at 18–24 months of age. The orthodontic management starts during the mixed dentition that aims to accomplish a balanced facial profile and acceptable occlusion. The several treatment modalities viz. orthopaedic maxillary protraction with and without rapid maxillary expansion, expansion with Quad helix, fixed orthodontic appliance, and orthognathic surgeries and/or distraction osteogenesis of the maxillary arch are often indicated from mixed dentition onwards to adult age to improve the skeleton-dental disharmony. The objective of the treatment protocols is an attempt to restore oral functions and aesthetics similar to normal patients.

The morphology of the palatal tissue and the maxillary arch has been widely investigated in CLP patients, mainly using conventional two-dimensional dental study models. The mean transverse dimension has been a reliable method to evaluate the effect of the repaired cleft of lip and palate on arch dimension.[5]All the linear dimensions viz. intercanine, intermolar width, arch circumference and arch depth have shown significant differences among the patients with unilateral cleft lip, unilateral cleft lip and palate, and control.[6]A significantly reduced intercanine and intermolar width of the maxillary arch in patients with CLP deformity was found.[7] The reliability of linear dimensions measured on scanned models was assessed by Verma *et al*.[8] and was found to be clinically acceptable with an error of 0.03 to 0.3 mm.

The palatal morphology has been assessed and compared by linear transverse measurements; however, it does not reveal the actual morphology of the palate and maxillary arch. Thus, 3-dimensional characteristics like palatal volume and area were measured on scanned digital models to get complete information about the palatal morphology. The effects of alveolar bone grafting and presurgical orthopaedics have been investigated using 3-D digital models derived from Cone Beam Cumputed Tomography (CBCT). Digital scanned model provides a better estimate for the volumetric assessment as the distortion of maxillary structures occurs on models obtained from CBCT due to overlapping.[9] The effect of mouth breathing on the Palatal area and volume was evaluated on digital dental models.[10] De Felippe carried out the volumetric evaluation of scanned plaster models after RME.[11] The 3-dimensional changes after slow maxillary expansion and rapid maxillary expansion have also been evaluated.[12-14] A significant correlation between palatal morphology and pharyngeal airway in obstructive sleep apnoea patients was shown.[15] Three-dimensional palatal vault changes in growing patients were evaluated longitudinally.[16]

The recent studies[17,18] estimated the palatal area and volume in patients with cleft deformity using digital models and found that measurements were smaller as compared to normal control. The palatal area in nonsyndromic and unoperated CLP patients evaluated the intrinsic deficiency of maxillary growth and found that the intrinsic deficiency was also a contributing factor for maxillary hypoplasia.[19]

To the best of our knowledge, there is still paucity in the literature regarding the 3-dimensional evaluation of arch width, palatal surface area and volume of UCLP patients before and after comprehensive orthodontic treatment among patients with complete Unilateral Cleft lip and Palate anomaly on 3D scanned digital models of the maxillary arch. The purpose of this study was to compare the effects of the comprehensive orthodontic treatment on the palatal surface area, palatal volume, inter-canine and inter-molar width among patients with Unilateral Cleft Lip and Palate (UCLP) using 3-dimensional scanned digital models of the maxillary arch.

Material and Methods

This retrospective cohort study was conducted on scanned digital models of orthodontically treated patients with UCLP after approval from Institutional Ethics Committee (INT/IEC/2021/SPL-428). The plaster study models of the maxillary arch of all the debonded UCLP patients treated from 2014 to 2020 were enrolled in this study. The sample size calculation was based on the study conducted by Generali *et al*.[18] in 2017 using G power software at a power of 90% and alpha error of 0.05; a minimum sample size of 20 patients in each per group was required.

The Study Group (SG) consisted of 70 patients with Unilateral Cleft Lip and Palate, who had completed fixed orthodontic treatment and complete records were available in the orthodontic archives. The included patients were treated with dentofacial orthopaedics, expansion with quad-helix, fixed appliance treatment including surgical and non-surgical treatment modalities. The patients who did not complete fixed orthodontic treatment, bilateral cleft lip and palate, and syndromic patients were excluded. Table 1 shows the demographic details of the total sample.

Study Group (SG) was further divided into subgroups; Subgroup I: treated with comprehensive orthodontic treatment only (non-surgical), Subgroup II: patientsmanaged with combined orthodontics and orthognathic surgery (either maxillary advancement or maxillary distraction), Subgroup A: age >14 years and, Subgroup B: age <14 years.

Control Group (CG) comprised of age and a gender-matched 70 patients (age range 15–30 years) with orthognathic profile, non-orthodontically treated, and Angle's Class I occlusion with minimal crowding (less than 3 mm in the maxillary arch). The plaster models of the control group and pre-and post-treatment plaster models of SG were scanned using Maestro 3D Dental scanner (Maestro 3D Dental Studio Build 4).

Three-Dimensional Analysis of Scanned Digital Models

A total of 210 plaster study models of SG and CG were scanned using Maestro 3D Dental scanner according to manufacturer's instructions and were saved as the STL file format (Standard Triangle Language) [Figure 1a]. This format stores the surface information by discretization of the entire surface in the form of triangular elements. The intercanine width and intermolar width were measured on digital models using the Maestro 3D software.

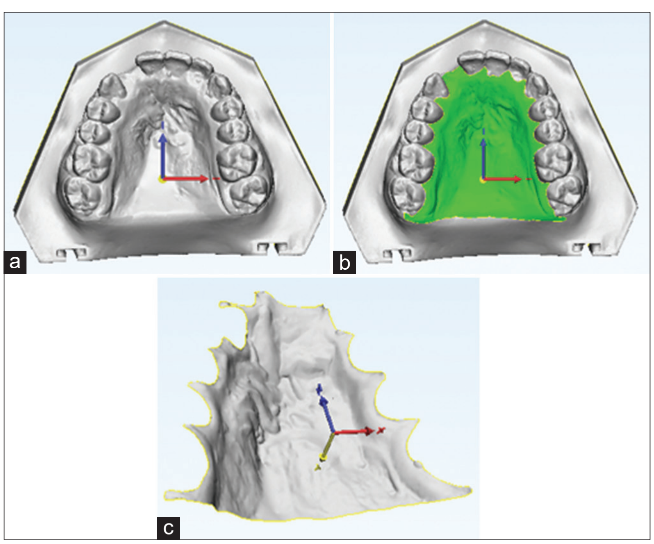

Figure 1: (a) 3D virtual scan of the Plaster models (b) Marking the palatal section with reference to the interdental papillae and cervical margins of last erupted teeth; (c) The palatal section marked and saved as a separate entity

The STL files were imported into 3-Matic (Materialise, Belgium) software to estimate the palatal area and volume. The palatal area was recognized and marked manually by selecting the interdental papilla and cervical margins of the last erupted teeth [Figure 1b]. The region of interest was marked and saved as a separate entity. The selected region contained only the surface area to be measured [Figure 1c].

To estimate the volume, the palatal surface enclosed in a circumscribed box [Figure 2a] was subtracted from the maxilla and filled the palatal area to form a solid entity [Figure 2b]. The plane was selected using 3 points, the deepest point on the cervical region of 1st molars and central incisors,[Figure 2c] which provided the palatal volume [Figure 2d]. The remaining additional section of the subtracted part above the interdental papilla was cut using a cutting plane tool.

Table 1: Demographic characteristics of the study group (*n*=70) and control group (*n*=70)

Characteristics	Study Group *n* (%)	Control Group *n* (%)
Age (in years)		
>14	30 (74.3%)	20 (28.57%)
≤14	40 (15.7%)	50 (71.43%)
Gender		
Male	30	30
Female	40	40
Laterality of Cleft		
Left	28	-
Right	42	-
Alveolar Bone Graft		
Done	12	-
Not done	58	-
Treatment Modality		
Non-surgical	51	-
Surgical	19	-

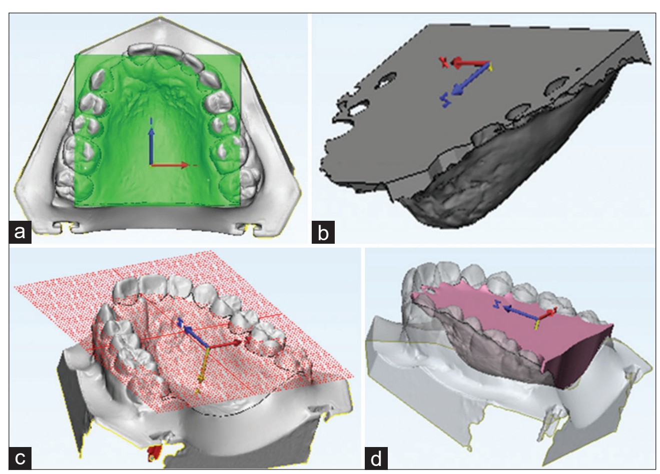

Figure 2: (a) The palatal surface enclosed in a circumscribed box (b) Solid section created after subtraction of the box from maxilla (c) and (d) Cutting plane by the selection of 3 points, cervical margins of last erupted teeth and central incisors and required palatal volume was obtained

The pre and post-treatment digital models in SG were assessed and compared for changes in the palatal surface area (PA), palatal volume (PV), inter-canine (ICW), and inter-molar width (IMW). The post-treatment digital models of SG were also compared to the digital models of the CG.

Blinding

The single independent operator (SS) estimated the palatal area and volume of all scanned digital models. The scanned models were coded and all information revealing the identity of the patients was removed. Thus, the operator who evaluated the pre-treatment and post-treatment records was blinded. Similarly, intercanine width and intermolar width were measured by a single operator (RK) on digital models.

Intra-examiner reliability

A single examiner trained and calibrated for measuring the palatal area and volume, intercanine and intermolar width performed all the measurements. The examiner was calibrated with an operator experienced in using 3-Matic (Materialise, Belgium) software andInter-examiner reliability was found to be satisfactory with the ICC values of 0.981, 0.924, 0.941, and 0.911, respectively. Intra-examiner reliability was checked by repeating 10% of the randomly selected sampleafter 3 weeks by the same operator. The values of ICC calculated for palatal area and volume, intercanine and intermolar width were found to be 0.991, 0.944, 0.971, and 0.931, respectively, and showed a good agreement.

Statistical analysis

The statistical package for social sciences (SPSS) version 25.0 and Med Calc software were used to analyze the data. Descriptive statistics were performed by calculating the mean and standard deviation (Mean ± SD) for the continuous variables. The normality of the data was assessed using Kolmogorov-Smirnov test. Paired *t*-test was used to compare the preand post-treatment Mean ± SD values for PA, PV, ICW and IMW in the SG. The comparison of the Mean ± SD values of PA, PV, ICW, and IMW between SG and CG was done using an unpaired *t*-test. The correlations between the parameters were analyzed using Pearson's correlation coefficient. The level of significance was set at a P value less than 0.05 and a confidence interval of 95%.

Results

The pre-treatment measurements of PA, PV, ICW and IMW in SG were 1416.75 ± 387.79 mm^2, 5804.85 ± 2936.71 mm^3, 25.3697 ± 5.34 mm, and 46.02 ± 5.19 mm respectively. The post-treatment measurements of PA, PV, ICW and IMW in the study group were 1746.56 ± 538.00mm^2, 7550.30 ± 3426.17mm^3, 31.2400 ± 5.25mm, and 49.1854 ± 3.63mm, respectively [Table 2]. The values of mean ± SD of PA, PV, ICW and IMW in post-treatment study models of patients with UCLP were significantly ($P < 0.01$) higher as compared to pre-treatment study models [Table 2].

The mean ± SD of PA, PV, ICW and IMW in the control group were 2033.45 ± 232.21, 11450.21 ± 2396.28, 35.30 ± 2.14, and 52.61 ± 2.17. The means of PA, PV, ICW and IMW in scanned post-treatment study models of SG patients were significantly ($P < 0.01$) lower compared to CG [Table 3]. The range of PA, PV, ICW and IMW was higher in the patients with cleft even after orthodontic treatment as compared to the control group. The increase in palatal area and volume was greater in Subgroup I and Subgroup A patients compared to Subgroup II and Subgroup B, respectively.

The differential PA in SG was significantly correlated to the change in PV [Table 4].The differential ICW and IMW did not show a significant correlation to the changes in palatal area and volume in SG and Sub-Group I andII. Sub-Group B showed a significant correlation between PA and IMW. The correlation coefficient value revealed that there was a positive and statistically highly significant correlation between palatal area and volume among patients in SG, Sub-group I, II and Subgroup B. ICW and PV was positively correlated to IMW in Subgroup II and Subgroup A, respectively and this difference was statistically significant at P value <0.05.

Discussion

Lip and palate surgery during infancy have been found to affect the facial growth in patients with UCLP.[20] In patients with un-operated unilateral and bilateral cleft, near-normal growth occurs, and the corresponding dentoalveolar growth compensates for the transverse constriction, and an optimal occlusion is achieved.[21,22] Whereas in patients with an operated cleft, the severe scarring due to soft tissue repair of the palate (repair of anterior nasal floor and palate) inhibits the transverse separation of the palatal shelves.[22] The healing of the denuded palatal shelves covers the area with scar tissue. The contractile force of the scar tissue leads to deformation and constriction of the bony and dentoalveolar segments. The patients with palatal repair performed after 24–36 months had more percentage of patients with acceptable maxillary arch widths, whereas palatal repair performed before 24 months of age adversely affected the maxillary growth.[23,24] The orthodontic treatment is aimed to assist the growth of the maxilla as well as the development of maxillary arches. Thus, the present study was planned to assess the effect of comprehensive orthodontics and Orthosurgical

Table 2: Comparison of Mean±SD of Palatal Area and Volume, Intercanine and Intermolar width in the maxillary arch of Study Group at time interval T0 and T1 and at time interval T1 with Control Group

Variables	Study Group						*P*	Control Group			*P*
	T0			T1			T0/T1	Mean±SD	95% C.I.		T1/CG
	Mean±SD	95% C.I.		Mean±SD	95% C.I.				Min	Max	
		Min	Max		Min	Max					
Palatal Area	1416.75±387.79	714.15	2534.32	1746.56±538.00	927.61	4836.81	0.001**	2033.45±232.21	1676.10	2595.31	0.001**
Palatal Volume	5804.85±2936.71	1357.68	16317.84	7550.30±3426.17	2291.04	18610.89	0.001**	11450.21±2396.28	7669.94	16739.81	0.001**
ICW	25.37±5.34	13.33	35.10	31.24±5.25	15.42	41.08	0.001**	35.30±2.14	30.54	39.00	0.001**
IMW	46.020±5.19	33.39	56.73	49.18±3.63	41.39	59.17	0.001**	52.61±2.17	47.87	59.81	0.001**

* * Highly Significant $P<0.001$, * Significant $P<0.05$; SG: Study Group: Repaired Unilateral Cleft Lip and Palate patients, CG: Control group; (T0): Pre-treatment ; (T1): Posttreatment; ICW: Inter-canine width; IMW: Intermolar width

treatment on the development of maxillary arches and compare them to the normal control group.

The transverse dimensions were a reliable method to evaluate the effect of repaired cleft lip and palate on maxillary arch dimensions.[5] The patients with repaired unilateral cleft lip and palate showed three timesmore anterior crossbites (Class III incisor relation) compared to patients with repaired unilateral cleft lip. The buccal crossbite was present in 36% of children with UCL and 75% of children with unilateral cleft lip and palate. All the linear dimensions (intercanine and first intermolar width, circumference and arch depth) showed significant differences between the UCL and UCLP and the control children. The mean incisor chord length and intercanine width were significantly smaller in the UCLP cases, whereas the IMW was greater compared to the control group.[6,25] R Blanco *et al*.[7] also observed significantly reduced intercanine and intermolar width dimensions in the maxillary arch. The palatal morphology was often assessed and compared by transverse linear measurements in earlier studies. However, these may not be appropriate methods to appraise the actual morphology of the palate and maxillary arch. Thus, 3D anatomical characteristics like palatal area and volume were evaluated on scanned 3D models.

The palatal volume in operated cleft lip and palate patients both UCLP and BCLP, was evaluated using digital models.[17] The results of the study showed significantly lesser palatal volume in cleft patients compared to non-cleft controls.[18] The palatal volume in operated cleft lip and palate patients, both UCLP and BCLP was estimated using digital models and palatal volume in cleft patientswas found to be smaller compared to non-cleft controls. The findings are similar to the results of the present study, which also showed smaller palatal volume in operated cleft patients. The objective of the present study was to evaluate the effect of orthodontic treatment on 3D palatal morphology. There was a statistically significant increase in all the dimensions evaluated on digital models before and after orthodontic treatment. In the younger patients, this could be as a result of the growth or contributed by the expansion mechanics used during the comprehensive orthodontic treatment.

The study sample was further divided into two groups (Subgroup A and B) to analyze the effect of age at the commencement of orthodontic treatment. Patients with the age of >14 years and <14 years were compared and results showed that the increase in volume after orthodontic was more in the younger group. This may be explained based on more growth and development of the maxillary arches in the younger patients. An increase in the sagittal and vertical dimension of the maxillary arch in some younger children may also have

Table 3: Comparison of Mean±SD of Palatal Area and Volume, Intercanine and Intermolar width in the maxillary arch between Subgroup I and II and subgroup A and B at T1 (Post-treatment)

Variables	Sub-Group I *n*=51 Non-surgical Mean±SD	Sub-Group II *n*=19 Surgical Mean±SD	*P*	Sub-Group A *n*=30 > 14 years Mean±SD	Sub-Group B *n*=40 ≤14 years Mean±SD	*P*
Palatal Area	353.98±508.10	264.93±286.66	0.294	444.40±638.43	243.87±225.77	0.036*
Palatal Volume	1929.29±1428.60	1251.96±1278.20	0.022*	1951.82±1339.90	1590.66±1463.26	0.092
ICW	5.78±4.14	7.17±3.94	0.319	6.28±4.55	6.06±3.80	0.896
IMW	3.29±3.56	2.81±3.90	0.653	3.16±3.34	3.16±3.88	0.934

* Significant *P*<0.05; * * Highly Significant *P*<0.001; Sub-Group I: Non-surgical; Sub-Group II: Surgical : Sub-Group A: <14 years, Sub-Group B: ≥14 years; ICW– Intercanine width; IMW- Intermolar width

Table 4: Correlation of mean changes (T1-T0) of palatal area and volume, intercanine width and intermolar width of the maxillary arch in (repaired unilateral cleft lip and palate patients) Group 1, Sub-Group I, Sub-Group II and Sub-Group A (*n*=30) and Sub-Group B (*n*=40)

	Correlation coefficient & *P* value					
	PV	*P*	ICW	*P*	IMW	*P*
	GROUP 1					
PA	0.485	0.001*	0.068	0.575	0.101	0.403
PV	-	-	-0.160	0.185	-0.026	0.830
ICW	-	-	-	-	0.246	0.040
	Sub-GROUP I					
PA	0.598	0.007*	0.237	0.329	0.172	0.481
PV	-	-	0.119	0.627	0.071	0.772
ICW	-	-	-	-	0.091	0.710
	Sub-GROUP II					
PA	0.450	0.001*	-0.066	0.645	0.006	0.969
PV	-	-	-0.243	0.086	-0.109	0.446
ICW	-	-	-	-	0.306	0.029*
	Sub-GROUP A					
PA	0.314	0.091	-0.039	0.839	0.377	0.040*
PV	-	-	-0.312	0.093	0.091	0.633
ICW	-	-	-	-	0.209	0.267
	Sub-GROUP B					
PA	0.439	0.005*	0.142	0.384	-0.078	0.633
PV	-	-	-0.030	0.852	-0.116	0.477
ICW	-	-	-	-	0.212	0.190

* Significant *P*<0.001, Group 1:- Unilateral cleft lip and palate, Sub-Group I:- Non-surgical, Sub-Group II:- surgical, Sub-Group A:- <14 years (*N*=30), Sub-Group B:- ≥14 years (*N*=40), ICW– Inter-canine width, IMW- Intermolar width, PA:- Palatal area, PV:-Palatal volume

occurred with the eruption of the posterior teeth. In the present study, the effect of surgical and non-surgical treatment on maxillary arch dimensions was also compared [Table 3]. The increase in palatal volume was more in the non-surgical group. This could be because decompensation usually does not involve expansion mechanics, and the treatment plan may also include extraction of certain teeth and thus contribute to lesser 3D changes in the surgical group. The non-surgical group is usually the younger group with growth remaining and also involves expansion mechanics to ensure normal intercuspation with the opposing arch.

In comparison, the palatal dimensions in the orthodontically treated operated UCLP patients were smaller than normal Class I control patients. Thus, the impact of the cleft anomaly and the repair surgery was so high that even comprehensive orthodontic treatment with or without surgery was not able to normalize the palatal morphology. Though the morphology and dimensions improved after orthodontic treatment but were still not comparable to the normal control patients.

In this study, an attempt was also made to evaluate the relationship that may exist between change in the palatal area, volume, ICW and IMW. Among all patients with UCLP, the increase in the palatal area was correlated well with the marked increase in its volume after comprehensive orthodontic treatment. The same finding was also evident among patients in Subgroup I, II, and Subgroup B. Patients who were treated with surgical treatment modality (Subgroup II), the increase in the inter-canine width was found to be correlated to increased Intermolar width. The increase in the palatal area was also positively associated with an increase in the intermolar widthfor the patients >14 years of age (Subgroup A). This finding suggests that change in the palatal area and improvement in the intermolar width after comprehensive orthodontic therapy also improves the palatal volume. These findings are similar to the study reported by Monga N *et al*.[17] and the authors claimed that improvement in the intercanine and intermolar width results in an improvement in the palatal volume and area.

Limitations and future perspective

1. The study was retrospective, and more prospective clinical trials should be planned.
2. The effects of different methods used for arch expansion and preparation were not considered and need to be evaluated in future studies.

Conclusions

Based on the findings of the present study, the palatal morphology and dimensions improved after orthodontic treatment in the UCLP group were still not comparable to the normal subjects. The patients withage >14 years showed more improvement in the maxillary arch.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Doğan S, Önçağ G, Akın Y. Craniofacial development in children with unilateral cleft lip and palate. Br J OralMaxillofacSurg2006;44:28–33.
2. Shi B, Losee JE. The impact of cleft lip and palate repair on maxillofacial growth. Int J Oral Sci 2015;7:14–7.
3. Perry JL, Kotlarek KJ, Sutton BP, Kuehn DP, Jaskolka MS. Fang X, *et al*. Variations in velopharyngeal structure in adults with repaired cleft palate. Cleft Palate Craniofac J 2016;53:e1–13.
4. Lancaster HS, Lien KM, Chow JC, Frey JR, Scherer NJ, Kaiser AP. Early speech and language development in children with nonsyndromic cleft lip and/or palate: A Meta-analysis. J Speech Lang Hear Res 2020;63:14–31.
5. da Silva Filho OG, Ramos AL, Abdo RC. The influence of unilateral cleft lip and palate on maxillary dental arch morphology. Angle Orthod1992;62:283–90.
6. Garrahy A, Millett DT, Ayoub AF. Early assessment of dental arch development in repaired unilateral cleft lip and unilateral cleft lip and palate versus controls. Cleft Palate Craniofac J 2005;42:385–91.
7. Blanco R, Fuchslocher G, Bruce L. [Variations in arch and tooth size in the upper jaw of cleft palate patients]. OdontolChil 1989;37:221–9.
8. Verma RK, Singh SP, Verma S, Kumar V, Bhupali NR, Arora S. Comparison of reliability, validity, and accuracy of linear measurements made on pre- and posttreatment digital study models with conventional plaster study models. Journal of Orthodontic Science. 2019;8:18
9. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 2008;78:387–95.
10. Lione R, Franchi L, HuancaGhislanzoni LT, Primozic J, Buongiorno M, Cozza P. Palatal surface and volume in mouth-breathing subjects evaluated with three-dimensional analysis of digital dental casts-A controlled study. Eur J Orthod 2015;37:101–4.
11. Oliveira De Felippe NL, Da Silveira AC, Viana G, Kusnoto B, Smith B, Evans CA. Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: short- and long-term effects. Am J Orthod Dentofacial Orthop 2008;134:370–82.
12. Bukhari A, Kennedy D, Hannam A, Aleksejūnienė J, Yen E. Dimensional changes in the palate associated with slow maxillary expansion for early treatment of posterior crossbite. Angle Orthod2018;88:390–6.
13. Gohl E, Nguyen M, Enciso R. Three-dimensional computed tomography comparison of the maxillary palatal vault between patients with rapid palatal expansion and orthodontically treated controls. Am J Orthod Dentofacial Orthop 2010;138:477–85.
14. Gracco A, Malaguti A, Lombardo L, Mazzoli A, Raffaeli R. Palatal volume following rapid maxillary expansion in mixed dentition. Angle Orthod 2010;80:153–9.
15. Kecik D. Three-dimensional analyses of palatal morphology and its relation to upper airway area in obstructive sleep apnea. Angle Orthod 2017;87:300–6.
16. Primozic J, Ovsenik M, Richmond S, Kau CH, Zhurov A. Early crossbite correction: A three-dimensional evaluation. Eur J Orthod 2009;31:352–6.
17. Monga N, Kharbanda OP, Balachandran R, Neelapu BC. Palatal volume estimation in operated unilateral and bilateral cleft lip and palate subjects using digital study models. OrthodCraniofac Res2020;23:284–90.
18. Generali C, Primozic J, Richmond S, Bizzarro M, Flores-Mir C, Ovsenik M, *et al*. Three-dimensional evaluation of the maxillary arch and palate in unilateral cleft lip and palate subjects using digital dental casts. Eur JOrthod 2017;39:641–5.
19. Lo LJ, Wong FH, Chen YR, Lin WY, Ko EWC. Palatal surface area measurement: Comparisons among different cleft types. Ann PlastSurg 2003;50:18–23.
20. Capelozza Filho L, Normando AD, da Silva Filho OG. Isolated influences of lip and palate surgery on facial growth: comparison of operated and unoperated male adults with UCLP. Cleft Palate Craniofac J 1996;33:51–6.
21. Narula JK, Ross RB. Facial growth in children with complete bilateral cleft lip and palate. Cleft Palate J 1970;7:239–48.
22. Ross RB. Treatment variables affecting facial growth in complete unilateral cleft lip and palate. Cleft Palate J 1987;24:5–77.
23. Ross RB. The clinical implications of facial growth in cleft lip and palate. Cleft Palate J1970;7:37–47.
24. Shamsudheen M, Utreja A, Tewari A, Chari PS. Effect of timing of palatal repair on the transverse development of maxillary alveolar arch in complete-cleft cases. J Indian SocPedodPrev Dent1991;8:15–8.
25. Lewis BRK, Stern MR, Willmot DR. Maxillary anterior tooth size and arch dimensions in unilateral cleft lip and palate. Cleft Palate Craniofac J 2008;45:639–46.