Original Article

Comparison of the Pharyngeal Airway Volume between Non-Syndromic Unilateral Cleft Palate and Normal Individuals Using Cone Beam Computed Tomography

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KEY WORDS
Cone-beam computed tomography;
Airway volume;
Cleft Palate

ABSTRACT

Statement of the Problem: Individuals with cleft lip and cleft palate mostly have airway problems. Introduction of cone beam computed tomography (CBCT) and imaging software has provided the opportunity for a more precisely evaluating 3D volume of the airway.

Purpose: The purpose of this study was to analyze and compare 3D the pharyngeal airway volumes of cleft palate patients with normal individuals using CBCT.

Materials and Method: 30 complete cleft palate patients were selected from the Department of Orthodontics; Dental University (Shiraz, Iran) who had CBCT scans of the head. The control group included 30 individuals with Class I angle occlusion who were matched for age and gender with the experimental group. ITK-SNAP 2.4.0 PC software was used to build 3D models of the airways for the subjects and measuring airway volumes. The statistical analyses were performed using SPSS software (version 19). Mann-Whitney test was adopted with $p< 0.05$ as statistical significance.

Results: The average volume of the pharyngeal airway of cleft group was 18.6 cm^3, with mean volumes of 6.8 cm^3 for the superior component and 11.3 cm^3 for the inferior component. The total and superior airway volume of cleft group were significantly lower than non-cleft groups ($p= 0.008$, $p= 0.00$, respectively) but the inferior airway volumes were not significantly different between the cleft and non-cleft groups. There was a significant and positive correlation between superior airway volume and inferior airway volume in cleft palate patients (r=+0.786, $p< 0.001$) and control group (r=+0.575, $p= 0.001$).

Conclusion: 3D analysis showed that the nasal and total airway was restricted in individuals with cleft palate but the inferior airway was not compromised in these individuals. This would be a crucial data to be considered for surgeons during surgical planning.

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Introduction

Cleft lip, cleft palate (CLP), or both are the most frequently occurring congenital facial deformities, with an incidence rate of 0.65% in newborns, influenced by ethnic and geographic variations. [1-2]

The nasopharyngeal region is impacted by complex interactions of bony compartments, muscular functionality, and soft tissues. This region also influences aesthetic facial harmony and provides the anatomical basis of speech and hearing. [3] The size of pharyngeal space size is determined principally by relative growth and size of the soft tissues surrounding the dental and facial skeleton. The nasopharyngeal skeleton may change by age. [4] Comprehensive orthodontic diagnoses and treatment plans and orthognathic surgery treatment planning require an understanding of all functional variables, including the upper airway. [5] Volumetric imaging might be useful for planning surgical intervention in cleft patients to improve the patency of the upper airway. [6-8]

Clefts of the lip and palate frequently produce nasal deformities that tend to reduce the size of the nasal airway. Approximately 70% of the cleft patients have nasal airway impairment and about 80% have mouth-breathing to some extent. [9] Anatomical abnormalities associated with CLP increase the risk of airway complications. [10] Craniofacial anomalies, including mandibular or maxillary retrognathism, short mandibular body, and backward and downward rotation of the mandible, may lead to reduction of the pharyngeal airway passage. [11]

The oral, nasal, and pharyngeal structures that are affected by cleft lip and palate during breathing are often compromised for speech. The nasal airway plays a significant role in controlling speech pressures when velopharyngeal function is impaired. [9]

The findings of the pilot study show that more variability exists in airway volume than in airway area. [12] This observation strengthens the viewpoint of Montgomery that reported single plane cephalometric radiographs do not reflect the airway volume in a reliable manner. [13]

Cone beam computed tomography (CBCT) is a new method which uses the reciprocal rotation of a two-dimensional receptor and a cone-shaped x-ray beam to gain volume data.The development of CBCT and computer simulation in treatment planning provide the opportunity for a more precisely evaluating of cases compared with the conventional radiographs with less radiation, shorter acquisition scan times, easier imaging than a medical CT scan at a lower cost. [14-16]

Recent publications have demonstrated the ability of CBCT to accurately image the airway to provide minimum cross section and total airway volume in obstructive sleep apnea patients and controls. [17]

Previous studies have shown that 3D imaging using CBCT is a simple and effective method to accurately analyze the airway. [18-20] Currently, there are a few 3D studies to measure airway volume in individuals with CLP and those studies used different methods. [21-23] Cheung and Oberoi [22] suggested that there was no significant difference in pharyngeal airway volume and smallest cross sectional area between cleft and normal patients, while the airway length was significantly longer in CLP children when compared to non-CLP group. Celikoglu [21] demonstrated that patients affected by CLP had decreased volumetric scores of nasopharyngeal, oropharyngeal, and total airways; however, the oropharyngeal airway volume difference between the unilateral CLP and the control groups was statistically significant.

However, the study of Xu *et al.* [24] showed an enlarged nasopharynx in isolated CLP in the sagittal plane and increased nasopharyngeal airway volume mainly around the palatal plane because of the increase in the sagittal diameter of the pharyngeal airway at this plane.

The goal of this study was to find 3D differences of the pharyngeal airway using CBCT in individuals with non-syndromic CLP versus normal individuals. Regarding the differences in the musculoskeletal and anthropometric proportions of individuals in different ethnics and concerning the current controversies over this subject, we planned to reconstruct another study to investigate this issue over a sample of Iranian population.

Materials and Method

This was a retrospective study from June 2013 to September 2014. The research committee of the medical ethics group of Shiraz Medical Science University approved this study (reference code EC-P-9365-6385). Thirty cleft patients (19 men, 11 women; 17 - 45 years) were selected from the Department of Orthodontics; Dental University (Shiraz, Iran) who had CBCT scans of the head for other reasons (such as evaluating impacted teeth, missing teeth, or to assess the bone level). All patients had complete unilateral CLP. The control group included 30 individuals from the same center with Class I angle occlusion who were matched for gen-

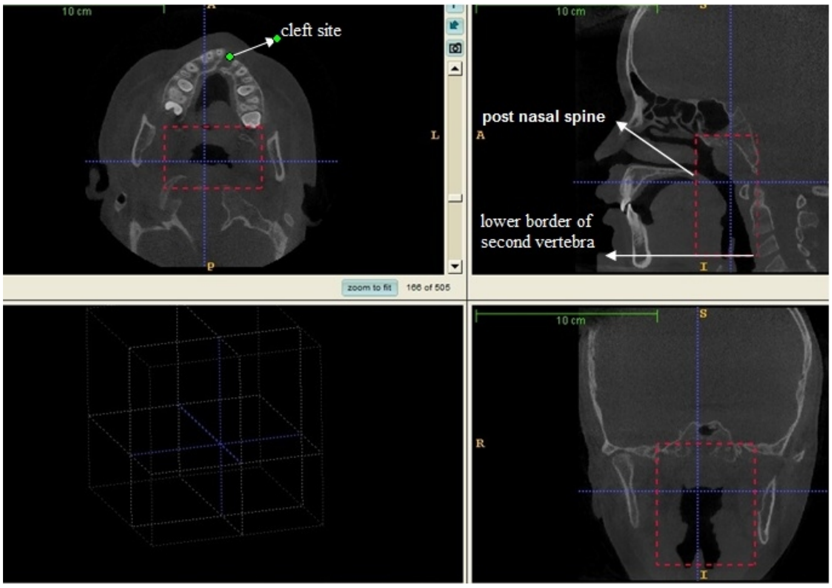

Figure 1: Superior and inferior border of pharynx

der and age variables with the experimental group. The control group had already CBCT scans from for orthodontic treatment purpose or assessment of impacted third molars or evaluating sinusitis.

The exclusion criteria were diagnosis of a syndrome, craniofacial anomalies, previous orthognathic surgery or tonsillectomy or adenoidectomy, and detectable pathology along the upper airway through inspection of the images. All the CBCT images have been made with similar unit and technique, by NewTom VGi Cone Beam CT machine (QR SRL Company; Verona, Italy) with the aid of a guide light. Since the volume of the pharyngeal airway is influenced by head posture, [25] all subjects were seated in the upright position and maximum intercuspation and the heads of patients were then centered and fixed in the CBCT system. The midline laser beam of the CBCT system was adjusted to the midsagittal plane of the skull. The horizontal laser beam was parallel to the Frankfort plane (FHP) of the skull. The maxillofacial regions were scanned by using tube voltage of 110 kVp, tube current of 6.35 mAs, and scan time of 18s. All images had a full field of view [15 ×12] that allowed visualization of the cranial base.

This method was previously used in normal individuals by Grauer *et al.* [26] to assess the relationship of the pharyngeal airway volume with facial morphology and has been validated by Weissheimer *et al.* study [27] to analyze the airway volume.

To reconstruct the 3D models of the airways for the subjects, the anonymous CBCT data in DICOM format were transferred to ITK-SNAP 2.4.0 (Kitware, New York, USA) PC software for semiautomatic segmentation that is used for medical image processing. The images were oriented as a line 6° down from sella-nasion as the horizontal axis.

The semiautomatic segmentation process refers to use “the region competition snake”. The interactive steps of the segmentation are selection of an initial threshold (which consist of the anterior border, a vertical plane through posterior nasal spine perpendicular to the sagittal plane; posterior border, the posterior wall of the pharynx; lateral border, the lateral walls of the pharynx; lower border, a horizontal plane from the most caudal medial projection of the third cervical vertebra) (Figure 1) and then placement of references points (Figure 2). Following the edge detection, the growth of the reference points in the single intensity value, fill up the airway structure (Figure 3). It uses the contrast differences between the airway and surroundings structures on the grey scale images. After segmentation, the airway was subdivided into superior and inferior compartments by a plane from the posterior nasal spine to the lower border of the first cervical vertebra (Figure 4). Subsequent to the segmentation, a 3D graphical model of the volumetric object was generated by the software and the volume in mm3 of the segmented 3D model was obtained. Landmark identification and segmentation were measured by the same investigator and measurement was repeated two times with one month interval by the same investigator to scrutinize intra-observer error.

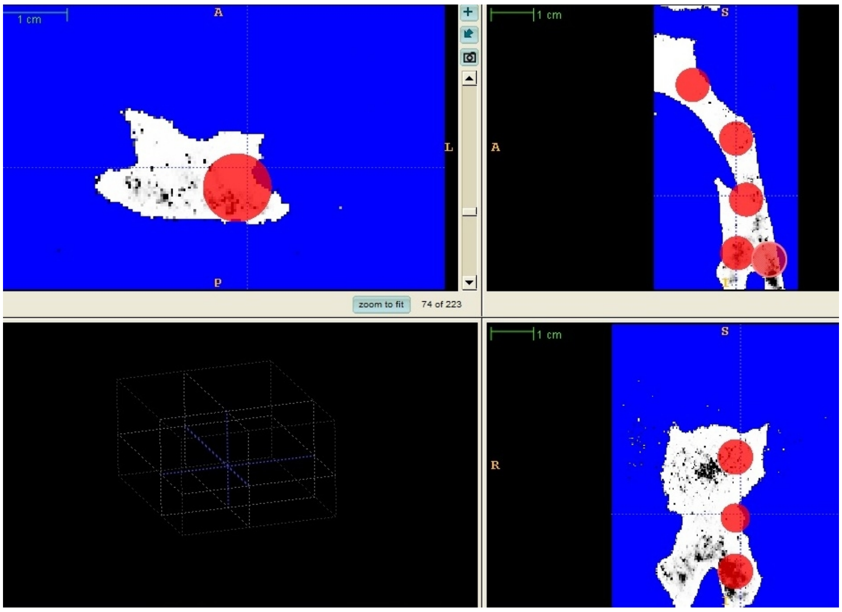

Figure 2: Placement of references points

The databases were collected. The statistical analyses were performed using SPSS software (version 19).

Mann-Whitney test was adopted with $p < 0.05$ as statistical significance. Pearson's correlation coefficient was used to assess the relationship between the superior airway volume and inferior airway volume.

Results

Thirty patients with unrepaired CLP (19 men, 11 women) and 30 normal controls (20 male and 10 female) were enrolled in this study.

The average volume of the pharyngeal airway of normal adult was 23.4 cm^3 (SD, 8.7 cm^3), with mean volumes of 9.7 cm^3 (SD, 2.3 cm^3) for the superior component and 13.7 cm^3 (SD, 7.2 cm^3) for the inferior component. The average volume of the pharyngeal airway of cleft group was 18.6 cm^3 (SD, 9.9 cm^3), with mean volumes of 6.8 cm^3 (SD, 3.5 cm^3) for the superior component and 11.3 cm^3 (SD, 5.8 cm^3) for the inferior component.

The total and superior airway volume of cleft group were significantly lower than non-cleft groups (p= 0.008, p=0.00, respectively) but the inferior airway volumes were not significantly different between the cleft and non-cleft groups (p= 0.2).

Data of the measured and adjusted volumes are

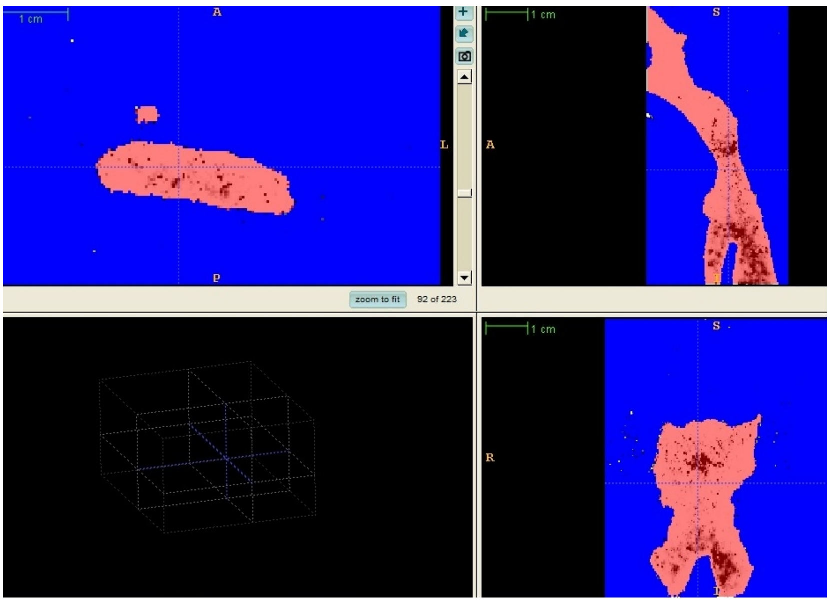

Figure 3: Growth of the reference points to fill up the airway structure

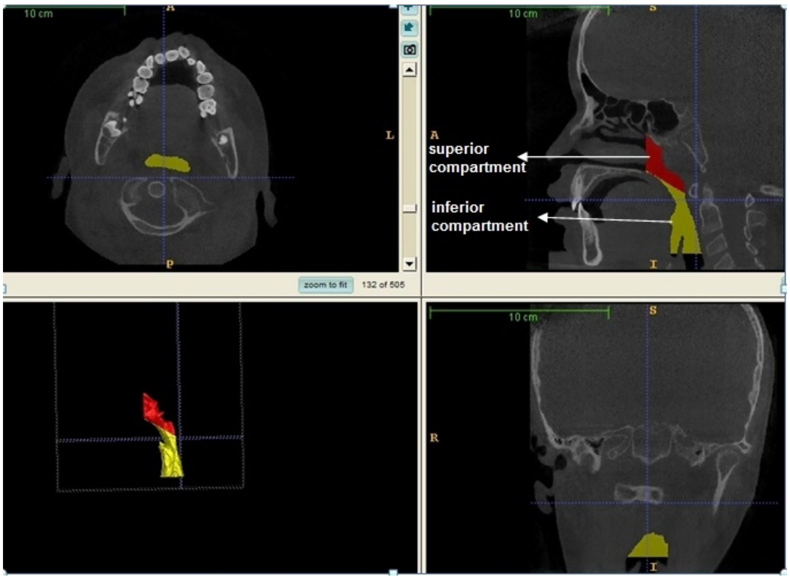

Figure 4: Segmentation to superior and inferior compartments

summarized in Table1 and Figure 5.

Table 1: The airway volumes (mm3) in cleft patients and normal individuals in 3D CBCT and p-value according to Mann-Whitney test

	Upper airway	Lower airway	Total airway
Control			
Number	30	30	30
Mean	9709.9593	13703.5460	23413.5053
Std. Deviation	2313.54455	7251.85482	8789.07214
Median	9595.8100	11379.8500	21082.5400
Cleft			
Number	30	30	30
Mean	6793.9677	11384.5333	18664.2777
Std. Deviation	3512.11487	5801.74629	9966.96677
Median	5868.1750	9092.0950	15307.2450
P-value	0.00	0.2	0.008

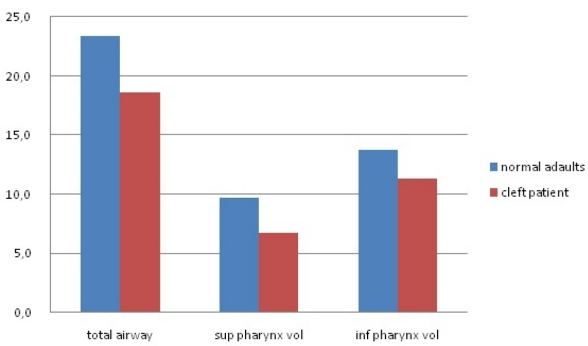

Figure 5: Graph depicting airway volume (mm3) in CLP (Cleft Palate) vs. non-CLP
*Sup pharynx vol=superior pharyngeal airway volume
*Inf pharynx vol= inferior pharyngeal airway volume

There was a significant and positive correlation between superior airway volume and inferior airway volume in CLP patients (r=+0.786, $p< 0.001$) and control group (r=+0.575, $p= 0.001$). Figures 6 shows the scatter diagram as well as regression line for the relationship between superior airway volume in CLP patients (Figure 6a) and control (Figure 6b). In assessing the intra-observer errors, no systemic errors were found based on the paired t-tests. Correlations between the first and second measurements ranged from 0.965 to 0.989 ($p< 0.005$).

Discussion

Regarding the differences in the musculoskeletal and anthropometric proportions of individuals in different ethnics and concerning the current controversies over this subject, our study investigated this issue over a sample of Iranian population.

In the study of Grauer *et al.*, [26], using the same method as the current study, the measurement of the average volume of the pharyngeal airway with the same method was 20.3 cm^3 in normal individuals. Close to their results, in our study the mean airway volume was 23.4 cm^3 for the normal group.

The 3D study of Cheung and Oberoi [22] demonstrated the mean airway volume of 18.1 cm3 for the cleft group similar to our result (18.6 cm^3), however, they reported a 15.1 cm^3 for the non-cleft group which significantly differ from the results yielded by the current study (23.4 cm^3). Moreover, they stated that there was no significant difference in pharyngeal airway volume between cleft and normal patients. [22] The differences might be attributed to their different method

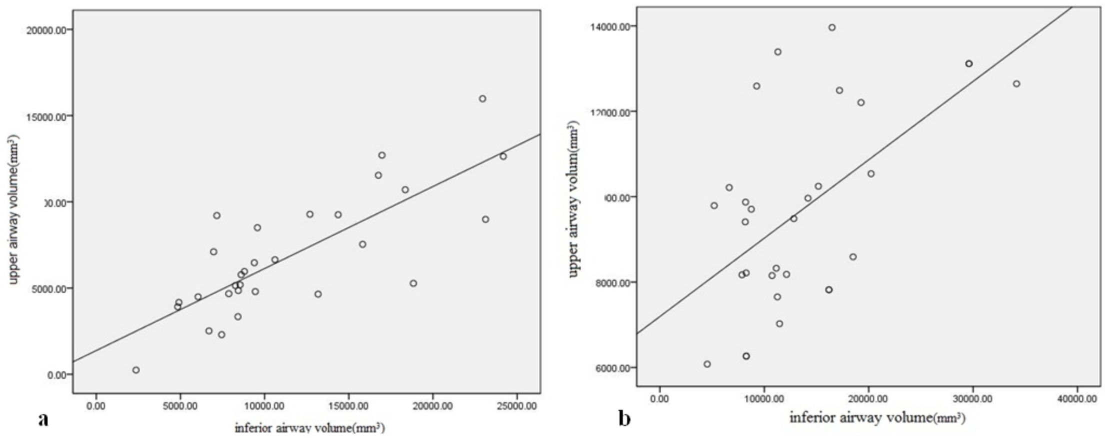

Figure 6a: Scatter diagram of the relationship between superior airway volume and inferior airway volume in CLP (Cleft Palate) group, **b:** Scatter diagram of the relationship between superior airway volume and inferior airway volume in control group

or different referenced points or fewer sample size of the two compared studies.

The results of Diwakar *et al.*'s study [23] showed that the volume of the nasopharyngeal airway was significantly reduced in the CLP group when compared with the non-cleft group which is in agreement with the results yielded by current study.

Our findings were also in agreement with the findings of Celikoglu *et al.* [21] that showed the patients affected by unilateral cleft lip and palate had decreased volumes of oropharyngeal and total airways compared with the well-matched control group without unilateral cleft lip and palate. The 2D study of Imamura *et al.* [28] showed that there was no significant difference between the adenoidal tissue of adults with CLP and control groups. Moreover, the upper airway of adults in the CLP group was significantly smaller than that in the control group. They concluded that the size of adenoid tissue may not affect airway size of cleft patients.

Xu Y *et al.* [24] demonstrated that volumetric analysis of the total volume, volume above the palatal plane, and volume between the palatal plane and C2 plane were larger in patients with isolated CLP, but there was no significant difference below the C2 plane. In their 3D imaging study, the most posterior points of the palatal process was selected to define the posterior nasal spine (PNS), resulting in a PNS that was anatomically more anterior to the pterygomaxillary palatinum which may influence the result.

Yoshihara *et al.* [29] who used CBCT for the evaluation of airways in 15 unilateral CLP girl patients reported that the mandible and the oropharyngeal airway were larger in the adolescent controls than in the juvenile controls without cleft lip and palate, but there were no significant differences between the adolescent and juvenile patients with cleft lip and palate. The small size and retrognathic position of the mandible in the cleft group compared to the control group might be expected to narrow and reduce the volume of the pharyngeal airway.

The evaluation of the nasopharyngeal airways of unilateral cleft lip and palate patients who was previously reported by Aras *et al.* [30] using 3D and 2D methods in which significant difference was detected between the cleft and non-cleft patients in nasal volume. This study also concluded that the upper and middle pharyngeal airway areas were found to display significant larger areas in the non-cleft group on cephalometric images. Hence it seems that the 2D data can be insufficient and therefore might be deceiving. Consequently, they showed that even though the radiation dose of 3D imaging systems was greater; they have benefited from the advantage of superior diagnostic outputs. [30]

There are several methods to calculate the 3D airway volume which may affect the accuracy of the pharyngeal analysis. [27, 31] Our segmentation method has been described, validated, and tested for accuracy, and according to study of Weissheimer *et al.*, [27] ITK-Snap showed less than 2% errors in volumes compared with the gold standard. It is claimed to be more accurate than the conventional manual tracing method and other 3D analysis methods. Shi *et al.* [32] also demonstrated that automatic segmentation of the airway imaged using CBCTwas feasible and could be employed to assess airway cross-section and volume similar to measurements yielded by manual segmentation.

We used Class I occlusion as the control group regardless of vertical facial height. This selection was in accordance with the study enrolled by Grauer *et al.* [26] which reported that in skeletal Class II patients, inferior compartment airway volume was smaller than Class I and Class III patients, but there were no significant differences in airway volume among the long, normal and short face-height groups. Imamura *et al.* [28] suggested that adenoidal tissues in the CLP have similar size compared with normal adults so we didnot consider adenoid size as an affective factor on airway volume.

Reiser *et al.* [33] found no correlations between the size of the initial cleft in infancy and size of the nasal airway in adulthood. So in adult patients who were born with UCLP, the size of the cleft in infancy does not seem to affect the size and function of the nasal airway in adulthood. A major concern about CBCT in children is related to radiation exposure. Our analysis included only patients who underwent CBCT for orthodontic planning, and no CBCTs were performed solely for the purpose of studying airway volume.

Conclusion

3D imaging using CBCT is a reliable diagnostic imaging tool to provide accurate data regarding airway size to allow clinicians to assess and screen the airway structures in CLP patients. Through this 3D analysis the measurement of the pharyngeal airway volume showed that the nasal and total airway is restricted in individuals with CLP but the inferior airway is not compromised in these individuals. The surgeons should consider it during surgical planning.

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Conflict of Interest

There is no Conflict of Interest pertaining to any of the authors.

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