ORIGINAL ARTICLE

Assessment of pharyngeal airway space using Cone-Beam Computed Tomography

Sabrina dos Reis Zinsly*, Luiz César de Moraes**, Paula de Moura***, Weber Ursi****

Abstract

Introduction: Evaluation of upper airway space is a routine procedure in orthodontic diagnosis and treatment planning. Although limited insofar as they provide two dimensional images of three-dimensional structures, lateral cephalometric radiographs have been used routinely to assess airway space permeability. Cone-Beam Computed Tomography (CBCT) has contributed to orthodontics with information concerning the upper airway space. By producing three-dimensional images CBCT allows professionals to accurately determine the most constricted area, where greater resistance to air passage occurs. **Objectives:** The purpose of this article is to enlighten orthodontists on the resources provided by CBCT in the diagnosis of possible physical barriers that can reduce upper airway permeability.

Keywords: Cone-Beam Computed Tomography. Pharynx. Upper airway space.

INTRODUCTION

Clinicians and researchers involved in the treatment of dentofacial deformities have sought to elucidate the determinants of facial morphology. The relationship between respiratory pattern disorders and changes in facial morphology has been extensively debated in the literature[1,2] and remains controversial. Conflicting opinions can be divided into two camps: One that considers breathing pattern an important etiological factor in producing the long face syndrome (LFS) and one which believes that LFS expresses an inherited pattern and breathing pattern would act only as an aggravating factor. Currently the prevailing view is that skeletal morphology is a result of genetically determined growth superimposed by the action of its functional matrix. And, according to this view, the action of soft tissue genotype would continue during growth.

Several factors may be associated with mouth breathing, among which are constriction of the nasal passage, narrow or obstructed nasopharynx, hypertrophic nasal membranes, enlarged turbinates, hypertrophic palatine or pharyngeal tonsils, nasal septal deviation, choanal atresia and tumors in the nose or nasopharynx.

When the size of the nasopharyngeal space appears reduced—either by the presence of adenoids

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* Specialist in Orthodontics, PROFIS/Bauru. MSc in Oral Biopathology, area of Dental Radiology, UNESP - São José dos Campos.
** Head Professor of Dental Radiology, UNESP.
*** Specialist in Dental Radiology. MSc in Oral Biopathology, area of Dental Radiology, UNESP.
**** MSc and PhD in Orthodontics, Bauru, USP. Chairman - UNESP - São José dos Campos. Head of the Specialization Program in Orthodontics, APCD - São José dos Campos, Brazil.

or due to the narrow anatomical structure of the nasopharynx—the resulting functional imbalance can impact craniofacial growth and development, reflected in a tendency toward vertical facial growth, which leads to the stereotype of the adenoid face or long face syndrome (LFS). This syndrome is characterized by lip incompetence, underdeveloped nostrils, maxillary atresia with the presence of deep palate and posterior crossbite, increased anterior inferior facial height, increased gonial angle and mandibular retrognathism.[2,3,4] Because LFS is a multifactorial syndrome it is not always easy to diagnose and, to be successful, treatment requires a multidisciplinary approach.

The upper airway space can be described in terms of height, width and depth. It is known that the limiting factor determining respiratory capacity is a reduced cross-sectional air passage area[5,6] anywhere in the pharyngeal path.

Over the past century extensive research[1,7-10] was conducted to elucidate the relationship between craniofacial morphology and breathing pattern. Most studies were based on lateral cephalometric radiographs because such radiographs are part of the records used for proper planning of orthodontic treatment. Although it can provide a wealth of information, cephalometric radiography is limited in the sense that it produces two-dimensional images (height and depth) of a three-dimensional structure, therefore hindering accurate assessment of the size and complexity of this structure.

Cone-Beam Computed Tomography has made it possible to acquire 3D image volumes of all structures in the maxillofacial complex. With the use of specific software and acquisition protocols based on individual needs, these digital volumetric scans can be turned into multiple planar view images (axial, coronal and sagittal). Software tools also allow bone structure measurements to be obtained as well as 3D assessment of soft tissues, and the shapes, volumes and features of the face and upper airways.

Currently, assessment of upper airway space is a routine procedure in orthodontic diagnosis and treatment planning. Cone-Beam CT equipment has become more efficient, reducing acquisition time and developing specific software, which provides improved image processing and analysis of three-dimensional images of the structures comprised in the maxillofacial region. This information may provide clinical benefits and a foundation for rational decision-making regarding the appropriate treatment to be administered to growing individuals with decreased pharyngeal airway space in order to minimize the etiological influence of breathing pattern on the development of malocclusion.

ASSESSING UPPER AIRWAY SPACE

Understanding the morphology and function of the skeletal structures and soft tissue that make up the upper airway space is essential for an understanding of the physiology and pathogenesis of obstruction. Assessment is complex however because of its location, which does not allow direct visualization. Different forms of image-based exams have been used to evaluate the upper airway space, skeletal structures and adjacent soft tissues. Each method has inherent advantages and disadvantages, and there is no consensus regarding the gold standard procedure for evaluation. Among the methods used are acoustic rhinometry, fluoroscopy, nasopharyngoscopy, MRI, cephalometry and tomography.[11]

Over the last century a large number of tests were suggested for evaluation of upper airway space from lateral radiographs using linear and angular measurements, and sagittal areas between cephalometric landmarks.[12-15] These points are defined by superimposing projections of different structures.

In a comparison between CT and lateral cephalometric radiographs in assessing the pharyngeal airway space, Abouda et al[16] found a significant correlation between sagittal area obtained from the radiographs and the volume obtained from CBCT, although the latter showed greater variability in patients with similar airway space in lateral cephalometric radiographs. This is expected since cephalometric analysis of conventional lateral radiographs only measures pharynx height and depth and therefore does not allow cross-sectional (i.e., width) examination.

Clinically, orthodontists can assess obstructed airway space in conventional cephalometric radiography. When this obstruction is considered severe, the patient is referred to an otolaryngologist. It is imperative that more accurate diagnostic tools be employed that inform otolaryngologists and orthodontists on the proper procedures to be adopted, thereby averting obstacles in the air passage that can affect dentition, speech, and craniofacial development.

ACQUIRING CBCT SCANS FOR AIRWAY ASSESSMENT

CT examinations for assessing the airways have a specific image acquisition protocol. Patients must be sitting, in maximum intercuspation, with the midsagittal plane perpendicular to the horizontal plane and Frankfort plane parallel to the horizontal plane. An extended field of view (EFOV) of 17X 23 cm should be used; 0.25 mm voxel size; 40 seconds. Upon completion of the CBCT examination, some manipulations can be performed using the software provided by the scanner manufacturer. The raw image (raw data) is reconstructed to enable visualization of 3D reconstruction and multiple planar cross-sections. These two-dimensional images of the pharynx can be examined from any direction. The most commonly used are sagittal, coronal and axial (Fig 1).

Images can be better observed using specific tools. Images can be rotated and magnified to allow better assessment of a given region. Images can also be rendered from any angle, and in any scale or position. Different filters can be applied, allowing differentiation between tissues of different densities and the use of transparency, which enables hard tissue to be viewed through soft tissue. A linear measurement tool is also available, which can measure height, width and depth of any portion of the pharynx (Fig 2).

These images can also be converted to DICOM (Digital Imaging and Communications in Medicine) files that can be exported to other 3D assessment software, which in turn enables a wider range of resources useful in airway space evaluation.

VIEWING THE UPPER AIRWAY SPACE USING CONE-BEAM COMPUTED TOMOGRAPHY

Software is available for assessment of the upper airway space, such as InVivoDental, 3dMDvultus and Dolphin Imaging.[17]

Dolphin Imaging program version 11.0 is an airway space analysis tool that not only enables the evaluation of the shape and contour of the upper airway space in three dimensions, but also calculates volume, sagittal area and the smallest predefined cross-sectional area in the airway space. It provides segmentation of the upper airway space through images that can be rotated and magnified. The program features two threshold filters: For hard tissue and soft tissue, displaying the airway space together with skeletal tissue or separately.

To assess images in the program, one must first import the files in DICOM single-file format from CBCT images. Once imported, the three-dimensional image of the patient's head must be oriented in the virtual space in like manner as in the cephalostat, i.e., so that the Frankfort horizontal plane is parallel to the axial plane, the midsagittal plane coincides with the midline of the individual, and the coronal plane is oriented in such a way that it crosses beyond the inferior border of the left and right orbits (Figs 3 and 4). In asymmetry cases, orientation should be as close as possible to these reference planes. This virtual orientation allows the head to be properly rotated so that bilateral structures are coincident.[17]

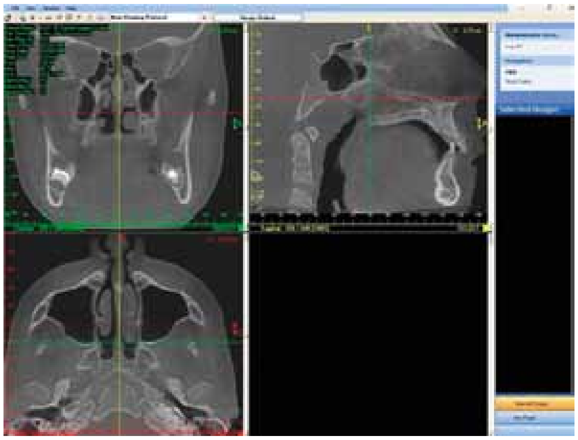

FIGURE 1 - Opening screen of the XoranCat software provided by the manufacturer of the i-CAT scanner, showing the multiple planar views (MPV) (sagittal, coronal and axial) obtained from volumetric reconstruction. The cursor, represented by two intersecting lines, indicates the precise location in virtual space, making it possible to go through these two-dimensional images of the pharynx in any direction.

FIGURE 2 - XoranCat software screen, where anatomy can be evaluated and measurements of the pharyngeal structure performed in any slice.

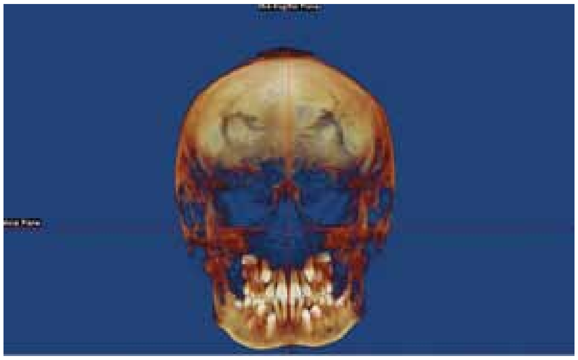

FIGURE 3 - Dolphin 3D software object orientation screen. In frontal view, the midsagittal plane should coincide with the individual's median plane, and the axial plane must be tangent to the infraorbital rim.

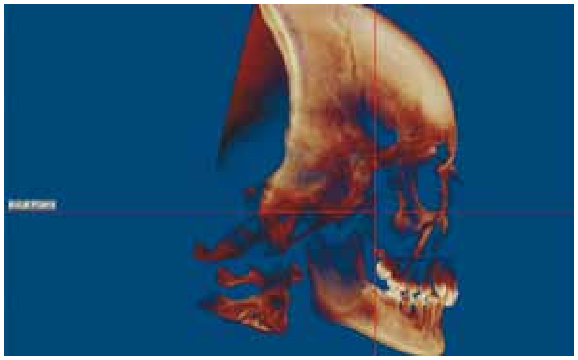

FIGURE 4 - Dolphin 3D software object orientation screen. In the lateral view of reconstruction orientation, the axial plane must coincide with the Frankfort plane.

Once a tool is selected for evaluating the airway space it is necessary to define, in the sagittal cross-section, the area of interest in the airway space. The program automatically provides the area and total volume of any predefined region as well as location and dimensions of the most constricted airway space area (Fig 5).

CREATING TWO-DIMENSIONAL PROJECTIONS FROM A THREE-DIMENSIONAL IMAGE

Most of these cephalometric landmarks created for two-dimensional images cannot be viewed or are difficult to trace on the curved surface of three-dimensional images. Currently, for ethical reasons, longitudinal growth records are forbidden, and there are as yet no normative standards for these three-dimensional dimensions. However, the parameters established for two-dimensional images can be compared with three-dimensional records.[18,19] Softwares have been developed using algorithms that allow projections to be generated similarly to radiographs. These projections can show morphological changes in maxillofacial structures in the 3 orthogonal planes, which might contribute to air passage obstruction.

To create these radiographic projections from a volumetric CT using Dolphin 3D Imaging program version 11.0 (Dolphin Imaging and

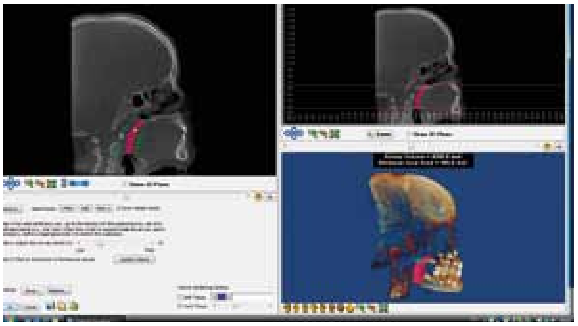

FIGURE 5 - Using Dolphin Imaging Program version 11.0 airway space assessment tool one can obtain the sagittal area, volume and smallest cross-sectional area of a predefined pharyngeal airway space. To this end, one must choose the area of interest by moving the markers that define the green line, starting from the sagittal cross-section.. The yellow marker is then placed within the airway space, and the program performs the calculation of sagittal area and volume. In order to obtain the smallest cross-sectional area, one should drag the red reference lines delimiting the area to be evaluated.

FIGURE 6 - Dolphin Imaging program's radiograph creation tool. One must choose the type of projection desired. In this case, a right lateral projection was selected with the application of Dolphin filter 1, which allows better definition of skeletal structures.

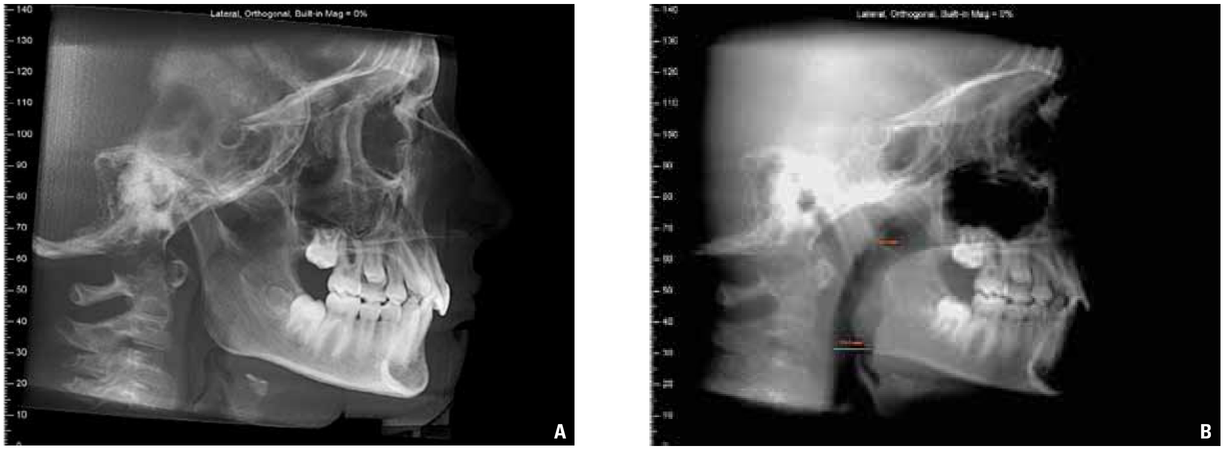

FIGURE 7 - Two different types of filters available in version 11.0 of Dolphin Imaging program, used to obtain lateral projections (**A**) Dolphin Filter 1 provides better visualization of skeletal structures, ideal for use in cephalometric analysis of skeletal tissue (**B**) Ray-sum filter, ideal for disclosure of the upper airway space.

Management Solutions, Chatsworth, CA), it is first necessary that the image be properly oriented. In the radiographic projection construction module, the program lets one choose an orthogonal projection or perspective. The upper and lower limits of the image must be set, as well as its thickness. Once the projection has been created, different types of display filters can be applied. Ray-sum is the filter that provides the best visualization of upper airway space (Figs 6 and 7).

The program also features a measurement tool and cephalometric analysis tool, providing linear and angular measurements in these two-dimensional images, which enable the evaluation of craniofacial factors that may contribute to the obstruction of the upper airway space (retrognathism, crossbite, asymmetries, hypertrophic tonsils).

ASSESSING MORPHOLOGY IN 3D RECONSTRUCTIONS

3D reconstructions also allow assessment of airway space morphology. Resistance to air flow is related to airway space size and shape. Airway space can be large, but a winding path can offer considerable effective resistance to air flow and affect respiratory function. Studies using CBCT have established a correlation between airway space and facial pattern. The oropharyngeal airway space of individuals with Class III anteroposterior skeletal pattern appears to be wider and more flattened,[20] displaying a more vertical orientation relative to the sagittal plane.[17] Individuals with Class II anteroposterior skeletal pattern, on the other hand, showed a more anterior superior airspace.[17] Abransom et al[21] also evaluated changes in the shape of the pharynx and argued that with age the airway space becomes wider in the transverse direction and therefore more elliptical. Ogawa et al[23] associated the shape of the airway space with Obstructive Sleep Apnea Syndrome (OSAS). OSAS patients had a more elliptical or concave air space, unlike non-OSAS individuals, who exhibited a more rounded or square shape.

UPPER AIRWAY SPACE ASSESSMENT AND OSAS

Obstructive Sleep Apnea Syndrome (OSAS) is a disease characterized by the collapse of the pharyngeal airway space resulting in repeated episodes of air passage obstruction, decreased oxygen saturation and sleep disruption. The anatomy of the upper airway space seems to play a critical role in the pathogenesis responsible for upper airway space collapse in OSAS patients. Collapse may occur at different spots in the upper airway space of OSAS patients. The retroglossal and retropalatal regions are most frequently involved.[22] It is known that the pharynx is bounded by a musculomembranous wall supported by a skeletal framework, so that the location of the most constricted area depends on the relationship between craniofacial skeletal structures and surrounding soft tissue. Therefore, the tonsils and adenoids, soft palate, uvula, tongue and lateral pharyngeal walls are soft tissue structures crucial in defining the upper airway space. Moreover, the mandible and hyoid bone are the major skeletal determinants of the airway space. Any abnormality in these structures can affect the airway space and cause SAOS.[22]

SOAS has a multifactorial etiology involving among others a reduced upper airway space, nasal cavity obstruction, distributed body fat mass and muscle tone. The upper airway space is significantly constricted in OSAS compared with non-OSAS

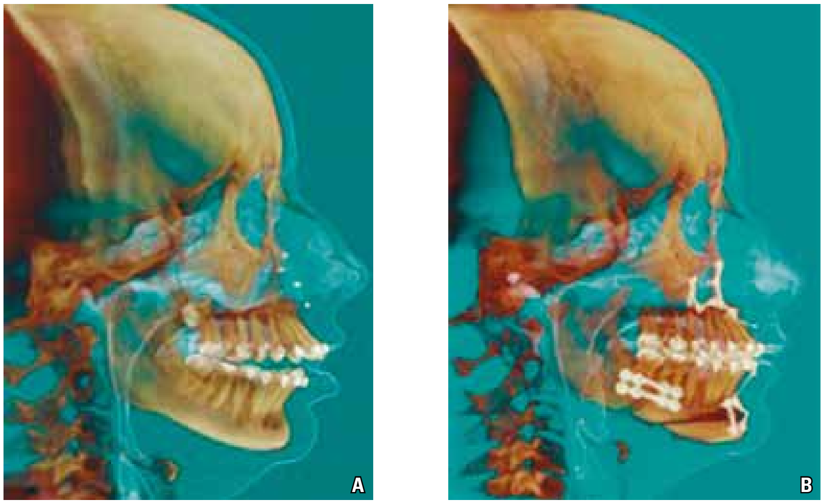

FIGURE 8 - CT images obtained before (**A**) and after surgery (**B**) showing changes made in the airway space (available at www.dolphinimaging.com).

patients, although the most constricted region varies from OSAS patient to OSAS patient.

Treatment of OSAS is primarily geared towards airway space maintenance, which is achieved with the use of a ventilation therapy device named CPAP—continuous positive airway pressure—which provides a constant air flow while keeping the airways open.

Secondarily, treatment seeks to make the airway space less likely to collapse. Increased pharyngeal airway space can be obtained in a reversible manner, with the use of removable appliances, or permanently, with surgery. When secondary treatments are needed, the most constricted oropharyngeal area must be identified in order to determine an appropriate treatment solution. To be able to assess upper airway space morphology, determine the degree and location of constriction and evaluate the effectiveness of treatment, examinations such as nasopharyngoscopy with Muller maneuver, fluoroscopy, cephalometry, rhinomanometry, MRI and CT have been employed.

Cephalometric studies have shown that individuals with OSAS have smaller, retruded mandibles, narrowing of the posterior airway space, larger tongues, more inferiorly positioned hyoid bone and retropositioned maxilla when compared with non-OSAS individuals[23]. Although this information is valuable, it does not enable clinicians to have access to the complex morphology of the upper airway space.

Because CBCT is three-dimensional, it allows clinicians to assess the airway space and surrounding structures, and determine three-dimensional naso-, oro- and hypopharyngeal measurements, such as the most constricted area, volume and the smallest anteroposterior and lateral pharyngeal dimensions in OSAS patients. One can also evaluate changes that might potentially be induced by the treatment modality itself, and identify which patients would benefit from such treatment (Fig 9). Haskell et al[24] asserted that it was possible to predict the amount of increase in total volume and in the cross-sectional area of the oropharynx obtained through appliance-induced mandibular advancement, since the most constricted area could move to any higher or lower point in the pharynx. They argued therefore that CT evaluation would be necessary prior to installing the appliance to determine whether the patient would benefit from its use. They further stressed that, in treating OSAS, it is more important to achieve improvement in the most constricted area than to increase the volume of the pharynx as a whole.

CLINICAL IMPLICATIONS AND LIMITATIONS OF CBCT IN ASSESSING THE UPPER AIRWAY SPACE

Besides the anatomy of the skeletal and soft tissue, airway space depends on some dynamic variables such as lung volume, intraluminal and extraluminal pressure, muscle tone and head position.[21] Since the soft palate and the tongue are structures composed of soft tissue with no rigid support, they are greatly affected by gravitational forces. Therefore, in CT scans and other examinations performed in the supine position, these structures move further toward the posterior pharyngeal wall, which results in changes in the dimensional measurements of the upper airway space, as demonstrated by Lowe et al,[25] Huang et al,[26] Abramson et al[21] and Ono et al.[27] Thus, scan results obtained with the patient sitting cannot be extrapolated or even directly compared to those obtained with the individual in the supine position. The latter position is recommended for individuals with OSAS. Lohse et al[28] suggest that in assessing OSAS patients a modification be made to the CBCT acquisition technique, namely, removing the chin positioner so that the patient can hold their head in a natural position.

Airway space size and morphology vary when the patient inhales or exhales.[11] CT scan acquisition time is around 20-40 seconds, too long for the individual to control their respiratory movements. Hopefully, in the near future CBCT acquisition

FIGURE 9 - CT images obtained with i-CAT software, illustrating the increased air space obtained using a mandibular advancement device in the treatment of OSAS.

time will be faster in order to prevent patient movements (breathing, swallowing and involuntary movements) from interfering with the results.

CONCLUSIONS

Although no normative data are available regarding information gained through CBCT, a host of scientific studies have been conducted for this purpose, which leads us to believe that soon CBCT will be able to guide orthodontic diagnosis and planning by enlightening clinicians about the effects caused by mechanotherapy applied to the airway space and the consequences of these effects.

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Contact address
Sabrina dos Reis Zinsly
Rua Atibaia, 100 - Jd Apolo
CEP: São José dos Campos / SP
E-mail: szinsly@hotmail.com