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Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery

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ABSTRACT

Purpose: This study aimed to compare the reliability of three different imaging software programs for measuring the PAS and concurrently to investigate the morphological changes in oropharyngeal structures in mandibular prognathic patients before and after orthognathic surgery by using 2D and 3D analyzing technique.
Material and methods: The study consists of 11 randomly chosen patients (8 females and 3 males) who underwent maxillomandibular treatment for correction of Class III anteroposterior mandibular prognathism at the University Hospital in Zurich. A set of standardized LCR and CBCT-scans were obtained from each subject preoperatively (T0), 3 months after surgery (T1) and 3 months to 2 years postoperatively (T2). Morphological changes in the posterior airway space (PAS) were evaluated longitudinally by two different observers with three different imaging software programs (OsiriX® 64-bit, Switzerland; Mimics®, Belgium; BrainLab®, Germany) and manually by analyzing cephalometric X-rays.
Results: A significant increase in the upper airway dimensions before and after surgery occurred in all measured cases. All other cephalometric distances showed no statistically significant alterations. Measuring the volume of the PAS showed no significant changes in all cases. All three software programs showed similar outputs in both cephalometric analysis and 3D measuring technique.
Conclusion: A 3D design of the posterior airway seems to be far more reliable and precise phrasing of a statement of postoperative gradients than conventional radiography and is additionally higher compared to the corresponding manual method. In case of Class III mandibular prognathism treatment with bilateral split osteotomy of the mandible and simultaneous maxillary advancement, the negative effects of PAS volume decrease may be reduced and might prevent a developing OSAS.

1. Introduction

Orthognathic surgery is primarily conducted for treatment of congenital or acquired craniofacial deformities and aims to restore proper dental occlusion and facial harmony (Popat et al., 2012; Rustemeyer and Gregersen, 2012). It comprises several surgical techniques that allow to reshape the entire mid-face, mandible and dentoalveolar segments through the modification of the facial bones (Lye, 2008). Surgical alterations in the position of the bony facial skeleton imply secondary changes of the relationship between muscles, soft and hard tissues (Turnbull and Battagel, 2000). These movements have influence on profile and shape of the entire face as well as in alterations of the oral and nasal cavity and the pharyngeal airway dimensions (Lye, 2008; Hernandez-Alfaro et al., 2011).

Interest in the shape and dimensions of the upper airway has increased steadily during the past decades mainly due to the relationship between upper airway configuration and obstructive sleep apnoea (OSA). Together with craniofacial morphology, the posterior airway space (PAS) and respiratory function are highly relevant to the orthodontic specialty (Guijarro-Martinez and Swennen, 2011). Based on lateral cephalometric analysis, many studies have already

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dealt with the effects of orthognathic treatment on the facial skeleton and the upper pharyngeal airway (Mehra et al., 2001; Eggensperger et al., 2005; Goncalves et al., 2006; Muto et al., 2006). Due to soft tissue alterations, several studies have shown that mandibular setback surgery may cause a downward movement of the hyoid bone, the tongue base and consequently narrows the PAS (Eggensperger et al., 2005; Kawakami et al., 2005; Marsan et al., 2010; Hong et al., 2011). This pharyngeal narrowing represents particular interest because of its possible contribute to further development of OSA and its relationship to maintaining normal respiration (Tiner, 1996; Chen et al., 2007; Degerliyurt et al., 2008; Jakobsone et al., 2010). As a result of an untreated OSAS, certain chronic health problems may occur such as cardiovascular diseases which may manifest in arterial and pulmonary hypertension or cardiac arrhythmias up to sudden cardiac death and insulin resistance (Grimm and Becker, 2006).

In contrast, to achieve an enlargement of the posterior airway dimensions, maxillomandibular advancement surgery has been proven to be very efficacious for elimination of OSAS. It stretches the upper airway muscles and tendons (velopharyngeal and suprahyoidal musculature) by advancement of their osseous origin (Hochban et al., 1997; Mehra et al., 2001; Prinsell, 2002; Eggensperger et al., 2005; Fairburn et al., 2007). After surgery, the position of the hyoid bone becomes more anterior with additional alterations in tongue position and consequent widening of the pharyngeal airway dimensions postoperatively (Riley et al., 1990; Turnbull and Battagel, 2000; Li et al., 2001). However Schendel and Epker affirmed only a temporary stability. After a certain period, the hyoid bone tends to return to its original position. This relapse may be caused by adjustments of the tendons and muscles to their location of attachment to the bones, as well as changes in the tendon–bone interface (Schendel and Epker, 1980). Mandibular advancement alone may not achieve a stable increase of the pharyngeal airway dimension over a long-term period (Eggensperger et al., 2005).

During the past few years, three-dimensional imaging procedures of the PAS have become more important for the ability to predict the effects of orthognathic surgery treatment and to understand and diagnose obstructed sleep disordered breathing (Mah et al., 2003; Schendel and Hatcher, 2010).

Traditionally, the PAS has been evaluated using lateral cephalometric radiographs (LCR), which allows precise measurements of the sagittal plane and has the advantages of a low cost and minimal exposure radiation (Li et al., 1999; Muto et al., 2006, 2008). But this method results in the superimposition of all bilateral structures of the craniofacial complex and only provides a two-dimensional anteroposterior linear measurement (Muto et al., 2008). Besides that, the axial plane cannot be examined (Abramson et al., 2010).

In the past few years, airway evaluation became more reliable with the technological advance of three-dimensional recording techniques such as computed tomography (CT), magnetic resonance imaging (MRI) or recently, cone beam-computed tomography (CBCT). CBCT is distinguished by their compact size, relatively low radiation dosage and high image accuracy in identifying the boundaries of soft tissues and empty spaces (Aboudara et al., 2009; Hernandez-Alfaro et al., 2011). The CBCT imaging technique became very popular in different domains, not only in examining the pharyngeal airway (Guldner et al., 2011). The advantage of three-dimensional imaging is shown in spatial resolution, rotatable images in the three axes and selective visualization of certain anatomical structures (Angelopoulos, 2008). To assess anatomical structures, as the upper airway, several software programs designed to manage and analyze digital imaging communications in medicine (DICOM) files are used (Sutthiprapaporn et al., 2008). Many of these have integrated tools to segment and measure the airway linear or volumetrically. A systematic review of the literature attested 18 imaging software programs for viewing, measuring, segmenting, and complete analysis of the upper airway in CBCT. However, validation studies with a clear study design were performed for 4 software programs. The systematic review suggested that studies assessing the accuracy and reliability of current and new software programs must be conducted before these imaging software programs can be implemented for airway analysis (Guijarro-Martinez and Swennen, 2011).

Evaluation of the shape, size and volume of the posterior airway space starts with segmentation. Segmentation means to define different related anatomical structures such as soft tissues, bones or vessels and calculate them into their three-dimensional surface models. Segmentation is used to simply express a specific element and remove all the surrounding structures of noninterest for a better visualization and analysis. Corresponding to the pharyngeal airway dimension, segmentation of the PAS can be evaluated manually or semiautomatic. Fully automated computer-aided segmentation has still many restrictions left. Mostly, the reasons are to be found in the high heterogeneity of the image data (such as noise-induced error, artefacts, etc.). Furthermore, the selection of an initial threshold and placement of initial seed regions depends in each case on the examiner (Riley et al., 1987). Even during the radiographic scanning procedure patients movement may produce motion related artefacts, which can have some influence on the segmentation accuracy (Celenk et al., 2010).

The basis of every segmentation approach is to set a certain image threshold correspondent to the tissue of interest. Every voxel with grey levels inside that interval will then be rendered to a three-dimensional model. A single threshold value is certainly more reproducible than the use of dynamic threshold but implicates more errors, especially in volume analysis (Lenza et al., 2010).

The manual approach of segmentation is performed slice-by-slice, where every region of interest has to be selected individually. This method is inefficient and inappropriate for daily clinical application because of long procedures. Far better, faster and more precisely appears the semiautomatic segmentation. By calculating the difference in density values of the structures the computer is able to automatically differentiate the air and the surrounding soft tissues. Usually an interactive placement of initial seed region in the axial, coronal and sagittal slice helps to determine the region of interest (Grauer et al., 2009).

The purpose of this study was to compare the reliability of 3 imaging software programs for measuring the PAS and concurrently to investigate the morphological changes in oropharyngeal structures in mandibular prognathic patients before and after orthognathic surgery by using CBCT-scans and traditional LCR. Up to now, only a few studies have been trying to compare these two different measurement techniques together to verify the validity of LCR in analyzing the PAS before and after surgery with examining simultaneously the reliability of the used measurement methods.

2. Materials and methods

2.1. Study population

In this retrospective study, 11 patients (8 women, 3 men) underwent maxillomandibular treatment for correction of Class III anteroposterior mandibular prognathism from 2009 to 2011 at the Department of Cranio-Maxillofacial and Oral Surgery at the University Hospital Zurich. The patients were randomly selected from the database of the Department. The median age of the patients at surgery was 26 years, with a range from 19 to 44 years.

The surgical treatment in all cases consisted of bilateral sagittal split ramus osteotomy and Le Fort I osteotomy with fixed rigidly