Cone-beam computed tomography evaluation of relationship between tongue volume and lower incisor irregularity

Tancan Uysal*,**, Ahmet Yagci***, Faruk Izzet Ucar***, Ilknur Veli**** and Torun Ozer****

*Department of Orthodontics, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey, **Department of Pediatric Dentistry and Orthodontics, College of Dentistry, King Saud University, Riyadh, Saudi Arabia, Departments of Orthodontics, Faculty of Dentistry, ***Erciyes University, Kayseri and ****Dicle University, Diyarbakir, Turkey

Correspondence to: Dr Tancan Uysal, Izmir Katip Celebi Üniversitesi, Diş Hekimiği Fakültesi, Ortodonti A.D., Çiğli, İzmir, Turkey. E-mail: tancanuysal@yahoo.com

SUMMARY The aim of this study was to evaluate the relationship between the tongue volume and lower incisor irregularity, using cone-beam computed tomography (CBCT), and to identify the possible gender differences. CBCT images of 60 patients between 16 and 36 years of age were selected from 1400 sets of images in the database. Tomography was carried out using iCAT® (Imaging Sciences International, Hatfield, Pennsylvania, USA) and segmentation was carried out by using Mimics 10.1 software (Materialise NV, Leuven, Belgium). The tongue volume was calculated by using the volume of the voxels from the scan and the number of voxels selected for a given mask. Lower incisor crowding was measured with the Little’s irregularity index and divided into three groups: mild, moderate, and severe. Independent samples t-test, analysis of variance (ANOVA), and Tukey test were used at \( P < 0.05 \) level. Pearson correlation coefficients and linear regression model were calculated to determine the correlation between tongue volume and incisor irregularity. No significant gender dimorphism was found for the tongue volume (females: \( 28.13 \pm 8.54 \) cm\(^3\) and males: \( 31.02 \pm 9.75 \) cm\(^3\)). According to ANOVA, there was statistically significant difference in the tongue volume measurements among subjects with different levels of irregularity. Tukey analysis indicated that mild irregularity group (33.97 cm\(^3\)) showed higher values for tongue volume than severe irregularity group (26.60 cm\(^3\); \( P = 0.025 \)). The relationship between incisor irregularity and tongue volume was evaluated for both genders and significant inverse correlation (\( r = -0.429; \ P = 0.029 \)) was determined between lower incisor irregularity and tongue volume in males. In female group, no significant correlation was determined between tongue volume and incisor irregularity.

Introduction

Imbalances between the outward forces from the tongue and inward forces from the cheeks and lips may contribute to the development of malocclusions and dental arch constrictions (Proffit and Fields, 2007). Larger tongue sizes in children, abnormal tongue position, tongue habits, and other factors influence the jaw growth (Proffit and Fields, 2007). Different studies have investigated the role of the tongue as a critical factor in the neuromuscular balance of forces in the oral cavity (Pommerenke et al., 1988; Macovski, 2009) and its influence on craniofacial skeletal growth (Scarfe et al., 2006; Baumgaertel et al., 2009).

As much as the tongue plays a role in jaw skeletal development, especially the alveolar bone development and interdental width, it is logical to consider the effect of the tongue on the crowding of anterior teeth. Brodie (1952, 1953) maintained that dental arch form and size are directly influenced by tongue size. It has also been suggested that an increase in the volume of soft tissues induces the osteogenic reaction at the growth site of the bone (Frankel and Frankel, 1989).

In orthodontics, probably, the single most persistent, irritating, and recurring problem for both the patient and the clinician is lower incisor crowding. Sinclair and Little (1983) questioned whether lower incisor crowding occurs primarily as a result of orthodontic therapy or as part of the normal developmental process. Several factors can be assumed to affect the development and severity of irregularity, such as direction of mandibular growth (Perera, 1987), early loss of deciduous molars (Ronnerman and Thilander, 1978), mesiodistal tooth and arch dimensions (Howe et al., 1983), and the oral and perioral musculature (Sanin and Savara, 1973).

The interaction between tongue volume and lower incisors irregularity is essential for understanding the mechanism of specific types of malocclusion and stability of various orthodontic treatments. Numerous clinical studies have claimed that tongue volume is correlated with multiple factors, including dentition position (Vig and Cohen, 1974; Howe et al., 1983), mandibular arch size and posture (Tamari et al., 1991), vertical face height (Doual-Bisser et al., 1989), and combined horizontal and vertical location of chin and symphysis.
Functional matrix theory which was proposed by Moss in 1960’s and gained popularity by 1990’s states that major determinant in craniofacial growth is the soft tissue. Bone and cartilage growth is a response to changing functional needs and environmental factors, such as soft tissue growth (Moss and Ranchor, 1968; Moss and Salentijn, 1969). Equilibrium forces from tongue and lips determine the position of lower incisors. If this equilibrium were not established, one may assume that it would affect lower incisor irregularity. Previous studies (Steiner and Gebauer, 1985; Frohlich et al., 1993) demonstrated that volume reduction of the tongue results with reduced tongue pressure on the lower incisors. If tongue with small volume has lower tongue pressure, it could be assumed that there would be more incisor irregularity in individuals with small tongue volumes.

Direct measurements of the tongue have been attempted previously (Bandy and Hunter, 1969; Oliver and Evans, 1986; Tamari et al., 1991) from magnetic resonance imaging (MRI; Lauder and Muhl, 1991) and computed tomography (Roehm, 1982; Lowe et al., 1986). Cone-beam computed tomography (CBCT) has become a popular modality in the evaluation of orthodontic diagnosis and outcomes (Kapila et al., 2011). Recently, with the introduction and gain in popularity of CBCT three-dimensional radiography in dental and orthodontic offices, the possibility of assessing tongue volume for patients becomes interesting as an aid in the diagnostic process (Mandich, 2010).

Several investigators implicated the size of the tongue as essential etiological factors in the development of malocclusion (Proffit, 1978; Lauder and Muhl, 1991; Schwestka-Polly et al., 1995). Cheng et al. (2002) showed that arch length and dentofacial morphology were affected by tongue. To our knowledge, there is no research in the literature that has investigated the correlation between the tongue volume and lower incisor irregularity. Thus, the aim of this study was to evaluate the relationship between the tongue volume and lower incisor irregularity using CBCT and to identify the possible gender differences. Therefore, the null hypotheses assumed that there is no significant correlation between the tongue volume and lower incisor irregularity.

Materials and methods

Before this study, a power analysis with G*Power 3.0.10 (Franz Faul, Christian-Albrechts-Universität, Kiel, Germany) was performed to estimate the sample size. The sample size for the groups was calculated based on a significance level of 0.05 and a power of 70 per cent to detect a clinically meaningful difference of 2 cm³ (±2.0 cm³) for the tongue volume measurement between the three groups. The power analysis showed that 20 patients in each group were required. Permission was obtained from the Dicle University Human Researches Regional Ethical Committee after the Research Scientific Committee at the same institution had approved the experimental protocol. All the patients were selected from the archive of Oral and Maxillofacial Radiology department of our university. The patients were selected and they were called for a second intraoral examination. If the individuals met our inclusion criteria, they were informed about the research and the usage purpose of their CBCT scans. Volunteered patients were asked to fill in an informed consent form.

CBCTs for these patients would have been taken at their usual records appointment as a part of the necessary radiographs; therefore, they were not being unnecessarily subjected to additional radiation. These tomographs were obtained by using CBCT (iCAT®, Model 17-19; Imaging Sciences International, Hatfield, Pennsylvania, USA) at the following settings: the x-ray emission time was 3.5 seconds; exposures were made with 5.0 mA, 120 kV, and exposure time of 9.6 seconds and the voxel size was 0.3 mm³. CBCT images of 60 patients (Class I malocclusion) between 16 and 36 years of age were selected (mean age: 21.5 ± 6.2 years). They met the following criteria:

1. Class I occlusion,
2. Normal growth and development,
3. All teeth present except third molars,
4. Good facial symmetry, determined clinically, and radiographically,
5. No significant medical history,
6. No history of trauma, and
7. No previous orthodontic or prosthodontic treatment or maxillofacial or plastic surgery.

Primary reconstructions of the data were performed with the iCAT software. Secondly, the exported digital imaging and communications in medicine (DICOM) files were viewed and segmentation was carried out by using Mimics 10.1 image analysis software (Materialise NV, Leuven, Belgium). In Mimics software, to modify the images, it was possible to rotate each axial, coronal, and sagittal view to facilitate orientation of perpendicular planes for the tongue segmentation. Easily identifiable landmarks were chosen to form artificial borders. The cemento-enamel junction of the lower first molars and premolars was rotated to be on the same plane on the sagittal and axial views such that this plane was parallel to the x-axis plane. This formed the lower aspect or ventral aspect of the tongues for segmentation (Figure 1). A perpendicular plane descending from the posterior nasal spine from the axial orientation was chosen to form the posterior aspect of the tongue for segmentation on the axial view.

The possibility of using both Hounsfield and Grey values allowed setting the threshold from the scan. As the tongue is a rather uniform soft tissue muscle, the patient-specific Hounsfield values (~700 to 250 HU) were set to include the largest amount of voxels in the volume calculation. The software can calculate the volume of the sculpted model based
on the voxels allowed into the calculation, as set by the threshold. After arranging the threshold for the soft tissue, which was a given number by the mimics software, the region of interest is filled in on every axial slice of the tongue. Based on the Hounsfield range of values selected initially, the selected areas, which fell into that assigned range, were then interpolated to form a three-dimensional mask of the volume of interest. The tongue volume was calculated with using the volume of the voxels from the scan and the number of voxels selected for a given mask (Figure 2). To eliminate interexaminer variability, a single investigator evaluated all CBCTs.

CBCTs were also utilized to perform the amount of irregularity (Figure 3). The irregularity index proposed by Little (1975) was used to evaluate lower incisor irregularity. The scoring method involves measuring the linear displacement of the anatomic contact points of the anterior teeth. The sum of the five measurements was represented the irregularity index value of the case.

Additionally, to identify possible differences in tongue volume in different levels of irregularity index values, irregularity was classified according to the following criteria (Dorfman, 1978): 1. mild: irregularity up to 4 mm (spacing was also included), 2. moderate: irregularity between 4 and 8 mm, and 3. severe: irregularity more than 8 mm. Group I (mild) comprised 9 males and 11 females (mean age: 21.16 ± 4.69 years), group 2 comprised 8 males and 12 females (mean age: 21.72 ± 5.23 years), and group 3 comprised 9 males and 11 females (mean age: 21.60 ± 8.53 years).

**Statistical analysis**

All statistical analyses were performed with the statistical package for social sciences, 13.0 (SPSS for Windows; SPSS Inc., Chicago, Illinois, USA). The normality test of Shapiro–Wilks and Levene’s variance homogeneity test were applied to the data. The data were found normally distributed and
there was homogeneity of variance among the groups. Thus, the statistical evaluation was performed using parametric tests. Arithmetic mean and standard deviation values were calculated for each measurement and separately for males and females. When the $P$ value was less than 0.05, the statistical test was determined as significant.

To evaluate gender differences in tongue measurements, independent samples $t$-test was performed. Statistical comparisons of tongue dimensions in subjects with different levels of irregularity (mild, moderate, and severe) were undertaken by one-way analysis of variance (ANOVA) test and Tukey honestly significant difference (HSD) test. To evaluate the correlation between tongue volume and lower incisor irregularity, Pearson correlation coefficients ($r$) were estimated and simple linear regression analysis was done.

To determine the errors associated with CBCT measurements, 15 CBCT images were selected randomly. Their measurements were repeated 4 weeks after the first measurements. A Bland and Altman plot was applied to assess the repeatability. It was found that the differences between the first and second measurements were not significant.

### Results

Table 1 summarizes the descriptive statistics and gender comparisons for the tongue volume and lower incisor irregularity measurements. According to statistical analysis, there was no statistically significant gender dimorphism in incisor irregularity and tongue volume measurements.

Statistical comparisons of tongue volume in patients with different levels of lower incisor irregularity were shown in Table 2. According to ANOVA, there was statistically significant difference for the measurements among subjects with different levels of irregularity. The highest tongue volume was determined in mild irregularity group ($33.97 \pm 9.79$ cm$^3$). The Tukey HSD analysis indicated that only statistically significant tongue volume difference was seen between mild and severe ($26.60 \pm 7.27$ cm$^3$) irregularity groups ($P = 0.025$).

The relationship between tongue volume and lower incisor irregularity was determined separately for each gender and were presented in Table 3. In female group, no

#### Table 1  
Descriptive statistics and comparisons of gender differences. SD, standard deviation.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Female</th>
<th></th>
<th>Male</th>
<th></th>
<th>Statistical comparison, $P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>Mean (SD)</td>
<td>$n$</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Tongue volume (cm$^3$)</td>
<td>34</td>
<td>28.13 (8.54)</td>
<td>26</td>
<td>31.02 (9.75)</td>
<td>0.226</td>
</tr>
<tr>
<td>Irregularity index</td>
<td>34</td>
<td>6.27 (3.90)</td>
<td>26</td>
<td>5.60 (3.58)</td>
<td>0.494</td>
</tr>
</tbody>
</table>

$n$ indicates sample size.

#### Table 2  
Statistical comparisons of tongue volume measurements in subjects with different levels of irregularity index. SD, standard deviation.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mild crowding (0–4 mm)</th>
<th>Moderate crowding (4–8 mm)</th>
<th>Severe crowding (&gt;8 mm)</th>
<th>$P$ value</th>
<th>Mild–moderate</th>
<th>Mild–severe</th>
<th>Moderate–severe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n$ Mean (SD)</td>
<td>$n$ Mean (SD)</td>
<td>$n$ Mean (SD)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tongue volume (cm$^3$)</td>
<td>20</td>
<td>33.97 (9.79)</td>
<td>20</td>
<td>27.59 (8.71)</td>
<td>20</td>
<td>26.6 (7.27)</td>
<td>0.04</td>
</tr>
</tbody>
</table>

$n$ indicates sample size.
Table 3  Correlation between tongue volume measurements and irregularity index.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Irregularity index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td>n  r   P value</td>
</tr>
<tr>
<td>Tongue volume (cm$^3$)</td>
<td>34 −0.282 0.106</td>
</tr>
</tbody>
</table>

$n$ indicates sample size; $r$ is the Pearson correlation coefficient.

Discussion

Lower anterior irregularity is a relevant topic to investigate because it has an impact on prognosis, treatment methods, and retention (Miethke and Behm-Menthel, 1988). More recent studies, however, found narrow intercanine width and high pretreatment incisor irregularity to be significant predictors of dental crowding and post-retention relapse (Rothe et al., 2006). The role of tongue in lower incisor irregularity has not been investigated comprehensively. Thus, the aim of this study was to evaluate the relationship between tongue volume and lower incisor irregularity, using three-dimensional volumetric tomography.

Controversy as to whether the tongue adapts to existing oral morphology, or actively molds its surrounding tissues, is longstanding (Ingervall and Schmoker, 1990; Frohlich et al., 1993). As a result, determining the size of the tongue becomes an important part of diagnosis. Some clinicians implicate a large or forwardly positioned tongue in the development of certain malocclusions (Brodie, 1952, 1953). Others have rejected a role for tongue volume in mandibular prognathism and cranial size (Yoo et al., 1996). Besides, Subtelny and Sakuda (1966) observed a forward movement of lower incisors in only 44 per cent of patients treated with lip bumpers. They implied that the influence of the tongue had possibly been overemphasized in the literature.

Various techniques have been used to estimate tongue volume. Bandy and Hunter (1969) measured the volume of the anterior portion of the tongue by water displacement. Oliver and Evans (1986) measured tongue length, width, and thickness by a Boley gauge. Takada et al. (1980) measured tongue size in 25 subjects by alginate impressions. Furthermore, alginate impressions of the tongue were unsuccessful since the tongue does not remain immobile during the material setting. Measurements made from lateral cephalograms are commonly used to assess the size of tongue (Lauder and Muhl, 1991; Ozbek et al., 2009).

Measurements of lingual volume and the oral cavity have also been undertaken using computed tomography (CT; Roehm, 1982; Lowe et al., 1986). MRI techniques are more appropriate to study the soft tissues and are particularly applicable to dentofacial orthopaedics (Lauder and Muhl, 1991). However, MRIs are not routinely taken before commencing orthodontic treatment nor during treatment, although such information offered by this three-dimensional imaging technology could be invaluable to orthodontists during the diagnostic phase (Macovski, 2009). Furthermore, Lauder and Muhl (1991) recognized the difficulty in locating the inferior and lateral borders of the tongue even on MRI images, which may have resulted in some error in measurement. Roehm (1982) concluded that CT was a reliable and effective method to view and compare tongue and oral cavity sizes. CBCT radiographic technology has lower radiation doses, rapid scan time minimizing image distortion from patient movement, isotropic voxel resolution, and are gaining in popularity and accessibility in dental offices (Scarfe and Farman, 2008). In the current study, CBCT was used for assessment of tongue measurements.

Baumgaertel et al. (2009) investigated the reliability and accuracy of dental measurements made on CBCT reconstructions. They indicated that dental measurements from CBCT volumes could be used for quantitative analysis. Similarly, Lim and Lim (2009) informed that digital model and CBCT images were clinically acceptable. Thus, instead of collect and use of plaster study models in the present study, we preferred CBCT scans regarding to measurements of irregularity index.

It is a weakness of this study that the age range of the evaluated subjects is wide (from 16 to 36 years). However, the age distributions of the groups were similar. Moreover, Temple et al. (2002) stated that anterior portion of the tongue does not significantly grow after 10 years of age and posterior portion of the tongue demonstrates most of its growth until 15 years of age. So the individuals that we had...
used in the study whom have an age range of 16–36 years do not have significant tongue growth. On the other hand, investigations on the effect of age on the occlusion clearly show significantly increased lower incisor crowding between the ages of 23 and 34 years. Further investigation is needed to determine underlying factors, which are responsible for lower anterior crowding.

Tongue volume, posture, and function are of crucial importance in the aetiology of malocclusions and dentofacial deformities. Lowe et al. (1985) reported that identified the rest position of the mandible as an important determinant of muscle activity and tooth position. Tongue position is supposed to be even more important than tongue function since the total time of swallowing is too short to affect the equilibrium of forces on teeth and bones (Proffit and Fields, 2007). On the other hand, tongue volume is integrated functionally with tongue position (Cohen and Vig, 1976). Prolonged low tongue position from oral breathing during critical growth period in children may initiate a sequence of events resulting in excessive molar eruption, causing a clockwise rotation of the growing mandible, a disproportional increase in anterior lower vertical face height, retrognathia, and open bite (Liu et al., 2008a). Tongue posture has been evaluated by using lateral cephalograms, but disadvantages such as distortion, magnification, and errors in landmark identification complicate the assessment and therefore repetitions of the radiographs may be necessary. Because of these concerns, tongue volume measurements determined from CBCT scans, in the current study.

Dempsey et al. (1995) discovered that overall males had larger dimensions than females. Similarly, Lauder and Muhl (1991) stated that males were found to have larger mean tongue, oropharynx, and total oral cavity volumes. This gender dimorphism is also present in the dental arches and can play a confounding role in analysis. Tamari et al. (1991) studied the gender differences in tongue volume and lower dental arch size measurements and found that the mean tongue volume was 22.6 cm³ for females and 25.3 cm³ for males and mean tongue volume was significantly larger in males than in females. In the present study, there were no significant gender differences in tongue volume measurement. We found that the mean tongue volume was 28.13 ± 8.54 cm³ for females and 31.02 ± 9.75 cm³ for males. Although the mean tongue volume was larger in males than females, according to present results, we thought that the tongue volume was similar in both genders.

The equilibrium forces from tongue, lips, and cheeks influence the vertical and horizontal tooth position as well as its position in the dental arch (Proffit and Fields, 2007). There is limited information about the effects of tongue volume on craniofacial growth and dental arch formation. Yoo et al. (1996) concluded that the tongue volume was not associated with dental arch size nor that female adults with mandibular prognathism had larger tongues. Correlatively, Bandy and Hunter (1969) found that the tongue volume had little influence on mandibular width and length, as well as little effect on degree of interincisal relationship and angle of the lower incisor teeth to the mandibular plane. On the other hand, Liu et al. (2008a,b) have studied extensively the effects of tongue volume reduction and its consequence on muscle activity, mastication, and the resultant response on craniofacial growth. The volume reduction of the tongue decreased the functional load along the mandibular lingual surfaces (Liu et al., 2007). Using rhesus monkeys, Harvold et al. (1972) demonstrated that reducing tongue volume by partial glossectomy caused the dental arch to collapse lingually and results as incisor crowding. In the current study, we observed that mild irregularity group showed higher values for tongue volume than severe irregularity group. In accordance to the above described results, we thought that higher volume of the tongue in mild irregularity group reduced the risk for collapse of the incisors lingually and results as lower irregularity values.

In the current study, statistically significant inverse correlation was found between lower incisor irregularity and tongue volume in males. These results also confirm the accuracy of the findings of Harvold et al. (1972). This conclusion is supported by the fact that patients are suffering from congenital aglossia show maxillary and mandibular incisor teeth erupting lingual to their normal erupted positions (Eskew and Shepard, 1949). As children with normal tongue function continue to grow, the jaws increase in size and the teeth erupted in normal position. Pommerenke et al. (1988) concluded that partial glossectomy in young animals caused reduction in mandibular length and width. In a similarly study using the miniature pig animal model, the alveolar bone height development and overall mandibular length showed markedly less development in the partial glossectomy group (Schumacher et al., 1988). Congruently, Tamari et al. (1991) showed a higher correlation between tongue volume and the posterior lower dental arch size.

The current study showed that subjects with severe crowding have smaller tongue volume than others. So we deduced that tongue volume affects crowding. Moss and Rankow (1968) claimed that soft tissues are primer factor to effect morphology, and skeletal unit is the secondary factor. Ackerman and Proffit (1997) indicated that teeth position determined by the relationship between cheeks and lips and tongue. Anterior crowding or irregularity occurs when tongue is small and the arches enlarge when cheek pressure is absent. In subjects with crowding and smaller tongue volume, we protrude incisors to solve crowding, but stability after treatment is depends to the ability of the soft tissues to adapt to changes in hard tissue morphology.

As the craniofacial measurements are bigger in males than in females, tongue volume does not grow as the same proportion with the craniofacial structures. As a result of this, the equilibrium between the tongue and lower lip is not established, so incisor irregularity becomes negatively correlated with the tongue volume.
Observation of the values and correlations of tongue volume and incisor irregularity suggested a possible quadratic relationship; however, when this was explored through regression analysis, it would appear that there was no quadratic or even simple linear relationship. Tongue volume appeared not to be a strong predictor for incisor irregularity. Future longitudinal follow-up studies are required to understand whether the tongue grows in spurts or phases and how it relates to the late lower anterior crowding.

Conclusions
To date, no study has yet evaluated the relationship between tongue volume and lower incisor irregularity. Using CBCT scans to determine this relationship following conclusions can be drawn:

1. Male and female tongue volumes were found similar.
2. Patients with mild lower incisor irregularity showed higher tongue volume than the patients with severe irregularity.
3. In males, significant inverse correlation was determined between lower incisor irregularity and tongue volume.
4. According to linear regression model, tongue volume appeared not to be a strong predictor for incisor irregularity.

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