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Comparison between tongue volume from magnetic resonance images and tongue area from profile cephalograms

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SUMMARY The aim of this study was to measure lingual volume and to correlate it with and predict it from the area of the radiographic shadow of the tongue as well as with demographic and biometric characteristics.

In 70 healthy subjects (35 males and 35 females) aged between 20 and 37 years, tongue volume was determined using magnetic resonance imaging (MRI). Volumes were correlated with the area of the tongue on the sagittal plane determined from the lingual shadow on profile cephalometric radiographs. Demographic and biometric characteristics were also available for each subject.

The mean lingual volume was 79.5 ± 14.2 cm^3 and was gender dependent. The mean lingual volume was 89.9 ± 11.5 and 68.9 ± 7.0 cm^3 in males and females, respectively. Correlations between tongue volume and body height, weight, and the body mass index (BMI) were highly significant. A strong correlation ($r = 0.83$, $P < 0.001$) was found between lingual volume measured using MRI and the radiographically determined area of the lingual shadow. The associated regression line allowed the area of the lingual shadow to be used to estimate the corresponding tongue volume in individual subjects.

Multiple regression analysis showed that lingual volume was best predicted by the lingual shadow, gender, age, and BMI ($R^2 = 0.80$).

Introduction

Clinicians generally agree on a morphogenetic role for the tongue. Biourge (1967) stated that 'The influence of tongue on the morphology of dental arches and on the occlusion depends not only on the lingual volume but also on its posture and on its mobility'. However, tongue volume has rarely been studied and, generally, the consequential effects of the variations of this parameter are only analysed in terms of deformations that can appear, such as infraclusions, diastemas, crowding, prognathism, retrognathism, or open bite.

Several animal investigations have reproduced clinical observations by creating modifications of tongue volume. Such studies have been carried out on rats (Stutzmann and Petrovic, 1974; Simard-Savoie and Lamorlette, 1976) and monkeys (Harvold *et al.*, 1972, 1973; Bernard and Simard-Savoie, 1987). In humans, different glossoplasties can lead to spontaneous correction of a variety of malocclusions (Deplagne, 1968, 1985, 1993) with results similar to those obtained in animal studies. The lingual volume is also a factor in obstructive sleep apnoea (OSA; Iida-Kondo *et al.*, 2006).

The ability to precisely determine tongue volume is important for two reasons. Firstly, it would allow the influence of tongue size on the morphology of face and dental arches to be evaluated, and secondly, it would permit an accurate diagnosis of micro- or macroglossia and allow appropriate planning of the amount of tissue volume to be removed in glossoplasty.

Unlike the dental arches, the teeth, and the skull, where linear and angular measurements are easily performed, the tongue has, for a long time, not been subject to standard measurement techniques. This is because of the mobility, shape variation, variable posture of the tongue, and lack of natural radiographic marker points.

Various techniques have been used to estimate lingual volume. Some interesting direct post-mortem measurements have been made (Kunimoto, 1912; Hopkin, 1967; Siebert, 1985) but the techniques are not applicable *in vivo*. Another approach, based on a fluid displacement procedure, has been used to estimate the volume of the free part of the tongue *in vivo* (Bandy and Hunter, 1969). Using a plaster model of the tongue, Tamari *et al.* (1991a,b) estimated the corresponding volume. Impressions were taken of the tongue at rest and in the protruded position. The volumes of the plaster models of the tongue were then estimated using a fluid displacement technique. In the same context, different authors have used cephalometric measurements from profile radiographs (Eifert, 1960; Cookson, 1967; Vig and Cohen, 1974; Natali and Polacco, 1981). Nevertheless, determination of the size of the tongue from the size of the radiographic shadow of the tongue gives only an approximate measure of its actual volume. Measurements of lingual volume and the oral cavity have also been undertaken using computed tomography (CT; Roehm, 1982; Lowe *et al.*, 1986). However, magnetic resonance imaging (MRI) techniques are more appropriate to study the soft tissues and are particularly applicable to dentofacial orthopaedics (Unger, 1985; Lauder and Muhl, 1991). These technologies allow imaging without the necessity of exposing the patient to the potential danger of ionizing radiation. Lauder and Muhl (1991) reported the measurement of tongue volume using MRI in rabbits followed by volume measurement after dissection, when the volume was estimated from the surface areas of tongue slices multiplied by their thickness. Subsequently, they used MRI in humans for measuring the volume of the tongue, the oropharynx, and the oral cavity. Since that time, virtual techniques have permitted reconstruction of organs allowing automatic estimation of their corresponding volumes. Different studies have utilized this technique to objectively quantify the upper airway and surrounding soft tissue structures (Do *et al.*, 2000; Welch *et al.*, 2002).

The aim of this study was to measure lingual volume using MRI and to correlate it with and predict it from the area of the radiographic shadow of the tongue, evaluated from classic profile cephalometric radiographs, as well as with demographic and biometric characteristics.

Subjects and methods

The protocol for this study was approved by the local ethics committee of the Faculty of Medicine. All subjects were informed of the purpose of the research and gave their agreement before any examination.

Seventy healthy subjects (35 males and 35 females) aged 20–37 years with a complete dentition were investigated. The presence or absence of the third molars was not a selection criterion. None of the subjects had undergone orthodontic treatment, dentofacial orthopaedics, or speech therapy.

All the radiographs were taken for diagnostic purposes at the Department of Orthodontics, University of Liège. For each subject, gender, age, height (cm), weight (kg), and body mass index (BMI) were recorded. BMI was calculated using the formula BMI = Weight (kg)/Height (m^2).

The area of the tongue shadow (cm^2) was determined from lateral skull radiographs taken with a Polydoros (Siemens, München, Germany). The magnification of the cephalostat was negligible due to the long distance (5 m) between the object and the anode.

A barium mixture was applied to the dorsal surface and tip of the tongue so that, radiographically, the tongue borders could be more easily identified. The inferior border of the tongue was defined as the separation between the genioglossus and the geniohyoid muscles from the genial tubercle to the hyoid bone body. This inferior border was defined as a line from the genial tubercle to the hyoid bone body. The tracing continued above the hyoid bone.

The cephalometric tracings were digitized and the area of the radiographic shadow of the tongue was calculated twice by the same operator (ML) using Autocad®2000 (Autodesk, San Rafael, California, USA). The mean value was used in the study.

The volume of the tongue (cm^3) was calculated from the MRI tracings. A semi-automatic calculation of the borders permitted virtual reconstruction of the tongue. The tongue was defined as all of its intrinsic muscles plus the entire genioglossus and hyoglossus muscles. For each subject, a series of images including 15 sagittal slices, 4 mm thick, were collected. Because sagittal orientation gave greater resolution than frontal orientation, only sagittal views were used in this study. The measurement of tongue volume was made twice by the same operator (ML) and the mean value was used in the study. The images were obtained at the Department of Medical Imaging of the University Hospital of Liège, using a Siemens (Erlangen, Germany) machine with a 1.5 T magnet. A head/neck phased-array surface coil was used for signal reception.

All examinations were performed in the supine position and the subjects were asked not to move or swallow and to keep their tongue against the roof of the mouth with their teeth in occlusion during imaging.

Virtual reconstruction of the tongue (Figure 1) and estimation of its volume were made on an ISG® Allegro workstation (Ontario, Canada).

Statistical analysis

The results are presented as the mean ± standard deviation (SD). Correlation coefficient were used to assess the association between two variables. The mean values were compared using an unpaired Student's *t*-test. Multiple regression analysis was applied to determine the relationship between MRI lingual volume and the radiographically determined area of the lingual shadow, as well as the demographic and biometric parameters. The quality of the regression was 'appraised' by the coefficient of determination R^2.

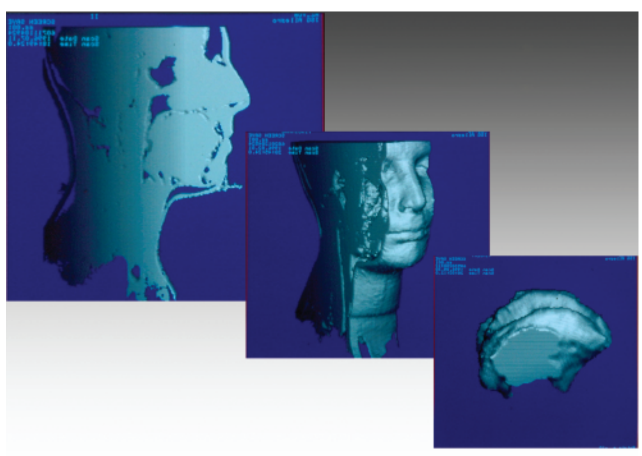

Figure 1 Digitization and three-dimensional reconstruction of slices of the face and the tongue.

To determine the 95 per cent reference values for the lingual volume in males and females, respectively, the method of Guttman (1970) was used because of the small sample sizes ($n = 35$). Guttman tolerance interval limits are given as the mean ± k·SD, where $k = (1 + 1/n)^{½} \cdot Q_t(0.975; n - 1)$ and $Q_t(0.975; n - 1)$ is the 97.5th percentile of the Student's t distribution on $n - 1$ degrees of freedom. For large n, k is equal to the classic 1.96 value.

Test results were considered to be significant at the 5 per cent level ($P < 0.05$). All calculations were performed using SAS® 6.12 for Windows (SAS Institute, Cary, North Carolina, USA) and S-Plus 2000® (Mathsoft, Cambridge, Massachusetts, USA) software.

Results

Demographic, biometric, and lingual characteristics of the study subjects are reported in Table 1.

Demographic and biometric characteristics

The mean age of the subjects was 24.5 ± 4.4 years. However, males were slightly but significantly older than females (25.5 ± 4.4 versus 23.5 ± 4.3 years, $P < 0.05$).

Global mean height was 175 ± 9.5 cm with a highly significant difference between genders ($P < 0.001$). A similar significant difference was also found for body weight, with a mean of 73.3 ± 12.6 and 59.6 ± 9.4 kg for males and females, respectively ($P < 0.0001$). BMI was also significantly different for males and females with a mean of 23.6 ± 3.2 and 21.1 ± 2.5 kg/m^2, respectively ($P = 0.0006$).

No correlation was observed between age and biometric parameters (height, weight, and BMI). By contrast, height and weight were significantly correlated ($r = 0.79$, $P < 0.001$).

Lingual shadow area and volume evaluation

The lingual shadow was significantly greater in males (32.4 ± 4.1 cm^2) than in females (26.6 ± 3.0 cm^2; Table 1). A low correlation was found with age ($r = 0.29$, $P = 0.016$). Correlations between lingual shadow area and height ($r = 0.66$), weight ($r = 0.69$), and BMI ($r = 0.52$) were all highly significant.

Lingual volume was significantly greater in males (89.9 ± 11.5 cm^3) than in females (68.9 ± 7.0 cm^3; Table 1). No correlation was found with age ($r = 0.13$, $P = 0.29$). Nevertheless, correlations between lingual volume and height ($r = 0.73$), weight ($r = 0.74$), and BMI ($r = 0.55$) were highly significant ($P < 0.001$). As biometric parameters were gender dependent, the variables related to the lingual shadow area and tongue volume were examined.

Comparison of the area of the radiographic shadow of the tongue and its volume

As shown in Figure 2, a highly significant and clinically relevant correlation was found between the area of the lingual shadow and the calculated volume from the MRI data ($r = 0.83$, $P < 0.001$). The corresponding linear regression is given by the equation

$$\text{Volume} = 3.91 + 2.56 \times (\text{Area of tongue shadow}),$$

which allows the lingual volume to be satisfactorily determined from the area of the tongue shadow ($R^2 = 0.69$).

Prediction of tongue volume

To improve prediction of tongue volume from the area of the tongue shadow, multiple regression analysis was applied to the demographic and biometric characteristics of the subjects. Specifically, tongue volume could be best predicted from the following equation (where gender is set equal to 1 for males and 0 for females):

$$\text{Volume} = 20.5 + 1.76 \times (\text{Area of tongue shadow}) + 10.3 \times (\text{gender}) - 0.49 \times (\text{age}) + 0.62 \times (\text{BMI}).$$

The impact of each parameter was highly significant and the multiple determination coefficient increased to $R^2 = 0.80$. Thus, the volume was found to be positively related to an increase of the surface ($P < 0.001$), male gender ($P < 0.001$), and BMI ($P < 0.05$), and negatively correlated with age ($P < 0.05$).

Determination of standards of reference

Globally, and independently of gender and other parameters, 95 per cent reference intervals were established using Guttman's method ($k = 2.01$) for the lingual shadow and calculated volume.

Table 1 Demographic, biometric, and lingual characteristics of the study subjects.

Variable	Total ($n = 70$)	Males ($n = 35$)	Females ($n = 35$)	P value
Age (years)	24.5 ± 4.4	25.5 ± 4.4	23.5 ± 4.3	0.05
Height (cm)	175 ± 9.5	182 ± 5.7	168 ± 6.8	<0.001
Weight (kg)	68.9 ± 14.5	78.3 ± 12.6	59.6 ± 9.35	<0.0001
Body mass index (kg/m^2)	22.3 ± 3.12	23.6 ± 3.22	21.1 ± 2.48	0.0006
Lingual surface (cm^2)	29.5 ± 4.6	32.4 ± 4.1	26.6 ± 3.0	<0.001
Lingual volume (cm^3)	79.5 ± 14.2	89.9 ± 11.5	68.9 ± 7.0	<0.001

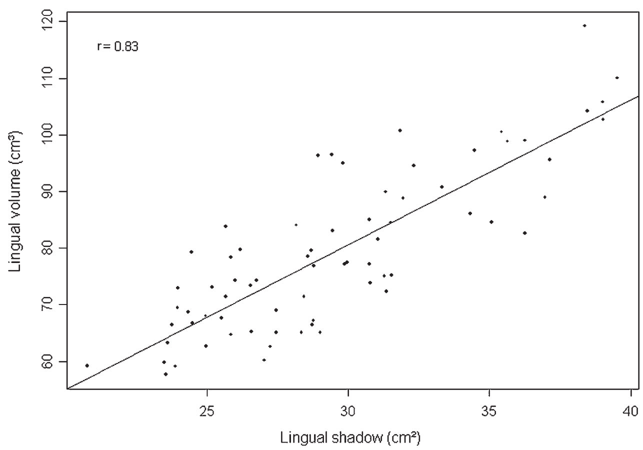

Figure 2 Correlation between the area of the radiographic shadow of the tongue and its calculated volume on magnetic resonance images.

For the area of the tongue shadow, reference limits were equal to 29.5 ± (2.01 × 4.585), yielding a 95 per cent reference interval of 20–39 cm^2 For lingual volume, reference limits were equal to 79.5 ± (2.01 × 14.17), yielding a 95 per cent reference interval of 51–108 cm^3.

Reference intervals for lingual surface and volume are also given in Table 2 by gender ($k = 2.06$).

Variable standards of reference

The results show that the area of the radiographic shadow and the volume of the tongue were significantly correlated with gender and the weight of the subject. Height was not taken into account because a high correlation existed between this parameter and the weight of the subject. It was possible to use BMI instead of weight, but in this case the relationship was weaker.

Reference limits for the lingual shadow in relation to weight for each gender (1 = male, 0 = female) are shown in Figure 3 and for lingual volume in Figure 4.

For the area of the lingual shadow, the equations were

$$\text{Shadow area} = 17.5 + 2.86 \times (\text{gender}) + 0.154 \times (\text{weight}),$$
$$\text{Shadow area} = 16.8 + 4.59 \times (\text{gender}) + 0.466 \times (\text{BMI})$$

and for lingual volume,

$$\text{Volume} = 43.0 + 12.8 \times (\text{gender}) + 0.435 \times (\text{weight}),$$
$$\text{Volume} = 40.6 + 17.7 \times (\text{gender}) + 1.35 \times (\text{BMI}).$$

Discussion

MRI is an objective means of measuring the tongue or soft tissues. The limits of the tongue can be defined more easily with MRI than by radiography and also avoids exposing the patient to ionizing radiation. The calculated mean tongue volume of 79.5 cm^3 found in this study was comparable with that reported by Lauder and Muhl (1991) of 79.29 cm^3. The volume was also shown to be gender related with a mean value of 89.9 and 68.9 cm^3 in males and females, respectively. Yoo *et al.* (1996) found a mean tongue volume of 64.6 cm^3 in a control group of 10 adult females. This value was lower than that in the present

Table 2 Standard reference limits for lingual shadow (surface) and volume of the tongue in healthy subjects, totally and for each gender.

Variable	Total (n = 70)	Males (n = 35)	Females (n = 35)
Lingual surface (cm^2)	20–39	24–41	20–33
Lingual volume (cm^3)	51–108	66–114	55–83

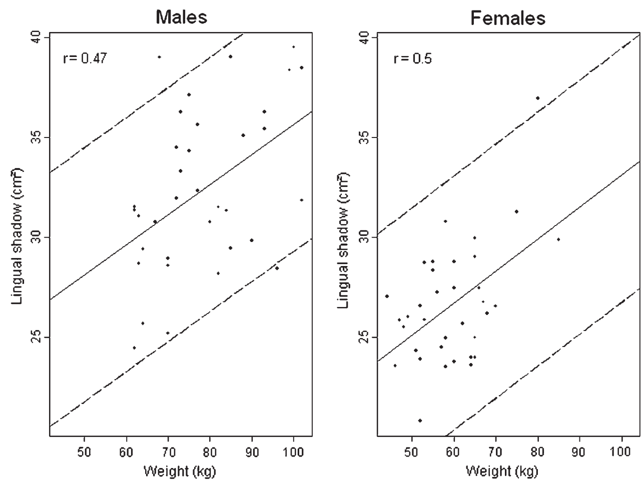

Figure 3 Correlation between the lingual shadow (surface) and weight for each gender.

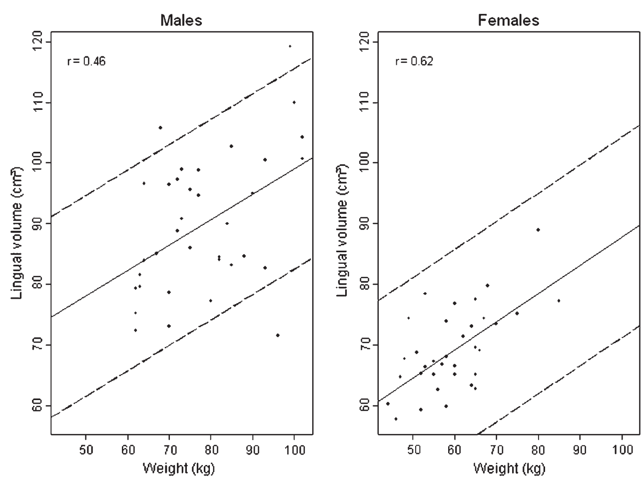

Figure 4 Correlation between lingual volume and weight for each gender.

study but the mean weight of the subjects was different (53.4 kg). However, when using the equation relating lingual volume and weight, the mean value obtained, namely, $43 + (12.8 \times 0) + (0.435 \times 53.4) = 66.2$ cm^3, was much closer to 68.9 cm^3.

Roehm (1982) and Lowe *et al.* (1986) both used CT to draw tongue outlines of the section and then to determine tongue volumes. However, they obtained disparate results with mean tongue volumes of 59.12 and 71.96 cm^3, respectively.

Recently, Iida-Kondo *et al.* (2006) calculated the tongue volume with MRI in normal male adults and in male sleep apnoea patients. They found a mean tongue volume value of 86.98 cm^3 in the controls and 90.56 cm^3 in the apnoea subjects. These results are close to those reported in this study.

Using a MRI technique (real-time TrueFISP) imaging, Ajaj *et al.* (2005) studied 50 subjects selected on the basis of age, dental status, and other factors. A mean tongue volume of 117 cm^3 was found for males and 77 cm^3 for females, which is substantially greater than the values of the present study (mean of 89.9 and 68.9 cm^3, respectively). No clear explanation can be offered for these differences although the two groups of male and female subjects may have differed in height and weight.

The strong correlation between lingual volume and the weight of the subject was clinically significant. It is known that excess weight can be associated with OSA, and thus, excess lingual volume can be responsible for such a disorder. Similar to Do *et al.* (2000), it is considered that a variation in tongue size alone cannot explain the severity of apnoea and that tongue size may simply reflect the larger body mass often seen in these patients.

Some dental, dentoalveolar, or dentoskeletal consequences of tongue size can be expected. It would therefore be useful to determine the influence of excess tongue volume on tooth position and dental arch morphology.

In future research, it would be helpful to clarify the discrepancy between studies supporting the well-known hypothesis that a large tongue is highly correlated with mandibular prognathism or to confirm the contradictory findings of other studies (Natali and Polacco, 1981; Yoo *et al.*, 1996).

The highly significant correlation found in this study between the area of the radiographic shadow of the tongue and the lingual volume determined by MRI indicates that lingual volume can be accurately estimated from classic lateral skull radiographs in daily practice. However, a precise value, in some cases, may require MRI assessment.

The correlation between MRI-derived volume and the radiographically determined area of the tongue shadow confirmed the results of previous studies in which, due to technical limitations, only data on the area of the tongue shadow were available (Eifert, 1960; Cookson, 1967; Vig and Cohen, 1974; Natali and Polacco, 1981).

The present results indicate that studies with an appropriate number of subjects can be carried out accurately on the basis that the areas of the lingual shadows represent useful quantitative data. However, although the MRI technique is more time-consuming and expensive than radiography, it has the advantage of avoiding irradiation of the subject.

Overall, the lingual volume estimated by MRI or derived from the lingual shadow will permit a more precise analysis of the morphogenetic influence of the tongue on the orofacial region.

Conclusions

MRI is a precise and reliable procedure for determining tongue volume. Virtual computerized reconstructions greatly facilitate volume measurements. Nevertheless, this costly technique is not appropriate for daily orthodontic practice.

The results of the present research show that not only the size of the tongue is closely related to other demographic and biometric characteristics but also a highly significant correlation exists between lingual volume measured on MRI and the area of the lingual shadow measured on profile radiographs. This equation was used to propose an estimation of the tongue volume from the latter parameters.

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References

Ajaj W *et al.* 2005 Measuring tongue volumes and visualizing the chewing and swallowing process using real-time TrueFISP imaging-initial clinical experience in healthy volunteers and patients with acromegaly. European Journal of Radiology 15: 913–918

Bandy H E, Hunter W S 1969 Tongue volume and the mandibular dentition. American Journal of Orthodontics 56: 134–142

Bernard C L P, Simard-Savoie S 1987 Self-correction of anterior openbite after glossectomy. The Angle Orthodontist 87: 137–143

Biourge A 1967 Langue et orthopédie dento-faciale. Actualités Odontostomatologiques 79: 295–333

Cookson A M 1967 Tongue resting position. A method for its measurement and correlation to skeletal and occlusal patterns. Dental Practitioner 18: 115–119

Deplagne H 1968 Glossectomies et orthopédie dento-faciale. Orthodontie Française 39: 795–796

Deplagne H 1985 Intérêt et résultats de la glossectomie dans les béances. Revue de Stomatologie et de Chirurgie Maxillofaciale 86: 95–98

Deplagne H 1993 Action dento-alvéolaire et basale des glossoplasties. Orthodontie Française 64: 25–28

Do K L, Ferreyra H, Healy J F, Davidson T M 2000 Does tongue size differ between patients with and without sleep-disordered breathing? Laryngoscope 110: 1552–1555

Eifert D F 1960 A roentgenographic cephalometric study of the tongue. American Journal of Orthodontics 46: 226–227

Guttman I 1970 Statistical tolerance regions: classical and Bayesian. Charles Griffin & Co. Ltd, London

Harvold E P, Chierici G, Vargervik K 1972 Experiments on the development of dental malocclusions. American Journal of Orthodontics 61: 38–44

Harvold E P, Vargervik K, Chierici G 1973 Primate experiments on oral sensation and dental malocclusions. American Journal of Orthodontics 63: 494–508

Hopkin G B 1967 Neonatal and adult tongue dimension. The Angle Orthodontist 37: 132–133

Iida-Kondo C, Yoshino N, Kurabayashi T, Mataki S, Hasegawa M, Kurosaki N 2006 Comparison of tongue volume/oral cavity ratio between obstructive sleep apnea syndrome patients and normal adults using magnetic resonance imaging. Journal of Medical and Dental Sciences 53: 119–126

Kunimoto K 1912 Uber die Zungenpapillen und die Zungengrösse der Japaner. Morphologie et Antropologie 14: 339–366

Lauder R, Muhl Z F 1991 Estimation of tongue volume from magnetic resonance imaging. The Angle Orthodontist 61: 175–183

Lowe A A, Gionhaku N, Takeuchi K, Fleetham J A 1986 Three-dimensional C.T. reconstructions of tongue and airway in adult subjects with obstructive sleep apnea. American Journal of Orthodontics and Dentofacial Orthopedics 90: 364–374

Natali M, Polacco C 1981 Le développement sagittal de la langue dans les malocclusions de classe II, division 1, de classe II, division 2 et de classe III d'Angle: étude comparative. Revue d'Orthopédie Dento-Faciale 15: 327–334

Roehm E G 1982 Computed tomographic measurements of tongue volume relative to its surrounding space. American Journal of Orthodontics 81: 170–172

Siebert J R 1985 A morphometric study of normal and abnormal fetal to childhood tongue size. Archives of Oral Biology 30: 433–440

Simard-Savoie S, Lamorlette D 1976 Effect of experimental microglossia on craniofacial growth. American Journal of Orthodontics 70: 304–315

Stutzmann J, Petrovic A 1974 Le muscle ptérygoïdien externe, un relais de l'action de la langue sur la croissance du condyle mandibulaire. Données expérimentales. Orthodontie Française 45: 385–399

Tamari K, Murakami T, Takahama Y 1991a The dimensions of the tongue in relation to its motility. American Journal of Orthodontics and Dentofacial Orthopedics 99: 140–146

Tamari K, Shimizu K, Ichinose M, Nakata S, Takahama Y 1991b Relationship between tongue volume and lower dental arch sizes. American Journal of Orthodontics and Dentofacial Orthopedics 100: 453–458

Unger J M 1985 The oral cavity and tongue: magnetic resonance imaging. Radiology 155: 151–153

Vig P S, Cohen A M 1974 The size of the tongue and the intermaxillary space. The Angle Orthodontist 44: 24–28

Welch K C *et al.* 2002 A novel volumetric magnetic resonance imaging paradigm to study upper airway anatomy. Sleep 25: 532–542

Yoo E, Murakami S, Takada K, Fuchihata H, Sakuda M 1996 Tongue volume in human female adults with mandibular prognathism. Journal of Dental Research 75: 1957–1962