Three–dimensional ultrasound evaluation of tongue volume

Tridimenzionalna ultrazvočna evalvacija volumna jezika

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Abstract

Background: The purpose of this study was to find a three-dimensional (3D) ultrasound technique for tongue volume estimation, to compare male and female groups and to find the correlation between tongue volume and body characteristics.

Methods: 3D ultrasound was performed in a group of 14 men and a group of 18 women with normocclusion. The collected data were analysed by annexed software and the tongue volume was estimated. The repeatability as well as intra- and inter-rater agreement was determined by calculating intra-class correlation coefficient. The Student t-test was used to determine if there were significant differences in tongue volume and body characteristics between the male and the female groups. Pearson correlation coefficients were used to assess the relationship between tongue volume and body characteristics.

Results: The 3D ultrasound estimation of tongue volume was highly repeatable in terms of good intraclass correlation coefficients of repeatability (ICC: 0.997) as well as intra- and inter-rater reliabilities (ICC: 0.998 and 0.993 respectively). The male group were significantly taller, heavier and with higher BMI than the female group, and had significantly larger tongue volumes (mean of 89.2 cm^3 in males vs. 67.2 cm^3 in females). Only the body weights and BMIs in the male group correlated with the tongue volume.

Conclusion: This study did demonstrate a valid and reproducible 3D ultrasound technique for tongue volume assessment.

Izvleček

Uvod: Namen študije je bil utemeljiti tridimenzionalno (3D) ultrazvočno tehniko za določitev volumna jezika, jih primerjati med moško in žensko skupino ter poiskati korelacijo med volumni jezika in telesnimi značilnostmi.

Metode: 3D ultrazvočna preiskava je bila narejena pri 14 moških in skupini 18 žensk z normalno okluzijo. Zbrani podatki so bili analizirani z dodatnim računalniškim programom in izračunani volumni jezikov. Določili smo ponovljivost ter zanesljivost metode. Student-t test smo uporabili za določitev značilnih razlik volumnov jezika pri različnih telesnih značilnostih moške in ženske skupine. Pearsonov korelacijski koeficient je bil uporabljen za določitev odnosa med volumnom jezika in telesnimi značilnostmi.

Rezultati: 3D ultrazvočno merjeni volumni jezika so se izkazali tako za dobro ponovljivo (korelacijski koeficient ponovljivosti ICC: 0,997) kot tudi zanesljivo (ICC: 0,998 in 0,993) metodo. V moški skupini je bila značilno večja telesna višina, teža in večji BMI (*angl.* body mass indexom) kot v ženski skupini, pa tudi značilno večji volumni jezika (povprečno 89,2 cm^3 pri moških vs. 67,2 cm^3 pri ženskah). Z jezičnim volumnom korelirata samo telesna teža in BMI pri moških.

Zaključek: S to študijo smo dokazali zanesljivost in ponovljivost ultrazvočne metode za določanje volumna jezika.

Background

The tongue represents a powerful muscle force within the orofacial region and for years orthodontists have been theorising about the roles of tongue sizes, postures and functions in the development of dental arches. Brodie[1,2] in the 60's hypothesised that dental arches' forms and sizes were directly influenced by tongue sizes. That is why the determination of tongue size is an important tool for research in the etiology of malocclusions and may later become important during clinical evaluations of patients with malocclusions.

There are many techniques for tongue size estimation. In the past, the alginate impression technique[3] and plaster models[4] were used for tongue volume estimation and the water displacement technique with the tongue at its most protruded position[5] was used to measure tongue volume. Measurements were also made in vivo by direct measuring to assess the two-dimensional size of the tongue[6] and a method was also presented of estimating tongue volume from the stretched length of the tongue at its most protruding position.[4] Lateral cephalograms were used to assess the two-dimensional size of the tongue.[7,8] Computerised tomography (CT),[9] cone-beam computed tomography (CB-CT)[10] and magnetic resonance imaging (MRI)[11] have been used for tongue volume measurements.

At the moment, estimation of the tongue by MRI seems to be the more promising, being the most accurate and without any radiation side effects. Unfortunately, it is also a time-consuming, expensive and not always available diagnostic tool.

Two-dimensional ultrasound, being a non-invasive, radiation-free procedure, has been used for assessments of tongue functions such as swallowing[12,13] and speech[14] as well as for evaluating tongue thickness[15,16] and estimation of tongue volume.[17]

It was for this reason that we focused our research on three-dimensional (3D) ultrasound imaging as another possible tool for tongue volume estimation. 3D ultrasound has been accessible for approximately 20 years. This technology makes it possible to obtain a multi-planar display of the investigated anatomical area or of certain pathology and perform more accurate analyses of them. 3D ultrasound has been already used for determining tongue position,[18] during quantitative analysis of tongue protrusion, grooving and symmetry in normal speakers and in partial glossectomee[19] and also when estimating the sizes of tongue tumors.[20]

Methods

The study was based on 32 healthy volunteers in whom normocclusions had been determined by clinical examinations and none of whom had previously undergone any orthodontic treatment. The test group consisted of 14 men (age 24.7 ± 3.5 years) and 18 women (age 24.7 ± 2.2 years). The study was approved by the Medical Ethical Commission of the Republic of Slovenia. Informed consent was obtained from all subjects involved in the study. The height and body mass of each test subject was measured by the same calibrated scale using a height meter and on the same day of tongue ultrasound acquisition.

Ultrasound of the tongue was carried out on subjects while sitting in upright positions with their heads fixed so that the Frankfurt horizontal was parallel to the floor. The subjects were instructed to be as relaxed as possible. The equipment used was the ultrasound apparatus Vo-

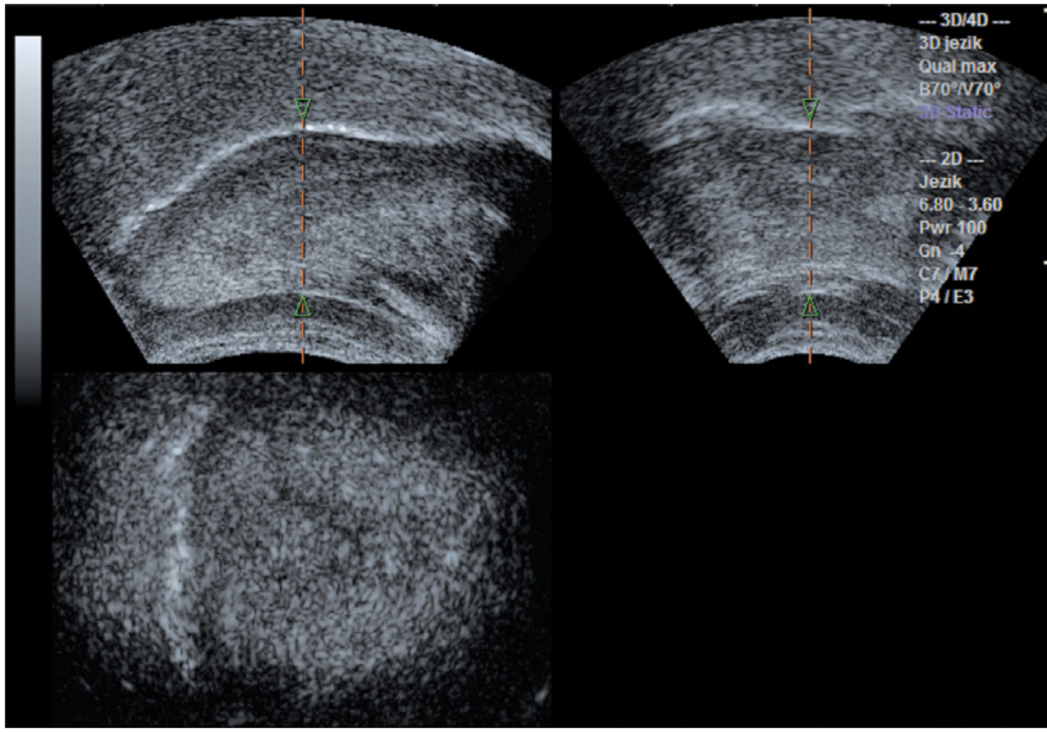

Figure 1: Ultrasound image of the tongue.

luson 730 expert (GEMS Kretztechnik, Zipf, Austria)) and a 3D transducer (SRI 3 RAB 2–5L). The transducer was positioned along the medial line under the chin and the 3D/4D mode setting (3D static render, max. quality, vol. angle 70°) for tongue assessment was selected. When the data was being recorded (not more than 5 seconds for each subject), the subject was asked to hold the tongue still in a relaxed position. Each tongue was recorded three times and two more distinctive ultrasound images were used for analysis (Fig. 1).

Tongue volume was measured by GE Kretz 4D VIEW software (Kretztechnik Gmbh, Zipf, Austria) using application VOCAL II, by manual determination of the tongue outline, on twelve sections of the same tongue obtained by turning the tongue over 180 degrees around its vertical axis through the centre. Each step was taken by turning over 15 degrees. The outline of the tongue followed the curvilinear surface of the dorsum of the tongue, including the genioglossus muscle and following the boundary between the tongue and the floor of the mouth (Fig. 2 and 3). The volume of the outlined object (the tongue) was then calculated automatically with 4D VIEW software.

SPSS for Windows version 18 (SPSS Inc., Chicago IL) was used for analysis. The accuracy of the measurement method was determined by calculating the intra-class correlation coefficient (ICC). ICC values equal to 0 represent an agreement equivalent to that expected by chance, whilst 1 represents perfect agreement [21]. For repeatability, ICC(2,1) was computed for two measurements taken at the same time by the same person. Intra-rater agreement was determined by calculating ICC(3,1) for measurements of the tongue volumes made by the same investigator after one month. Inter-rater agreement was determined by calculating ICC(3,1) from measurements taken by two different investigators on two different images of the tongues of 10 randomly selected subjects. The Student's t-test was used to determine if there were

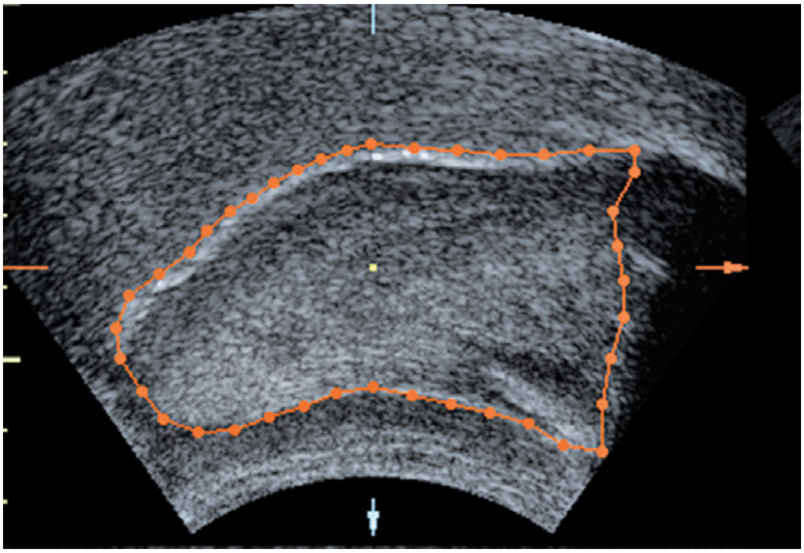

Figure 2: Delineated tongue on an ultrasound image on central sagittal images.

any significant differences in tongue volumes and body characteristics between male and female groups. Pearson correlation coefficients were used to assess the relationships between the tongue volume and different body characteristics (height, body weight, BMI). The results are considered to be significant at a 5 percent level ($p < 0.05$).

Results

First we evaluated the repeatability of the tongue volume measurement as well as the intra- and inter-rater agreement (Table 1).

In Figure 4 the frequency of tongue volume was plotted indicating the genders of the subjects. In both groups the tongue volumes approached normal distribution.

Table 1: Accuracy of measurements as determined by intra-class correlation coefficient.

	ICC	95 % CI for ICC
Repeatability-ICC(2,1)	0.997	(0.994–0.999)
Intra-rater reliability-ICC(3,1)	0.998	(0.993–1.000)
Inter-rater reliability-ICC(3,1)	0.993	(0.972–0.998)

The mean tongue volumes of the female and male groups together with body characteristics are listed in Table 2.

The relationship between tongue volume and body characteristics (body weight, body height and body mass index) for male and female groups separately as well as the whole group of subjects was determined by Pearson correlation. P values < 0.05 were judged to be statistically significant (Table 3).

As can be seen above, only body weight and consequently BMI in the male group correlated with the tongue volume. For the female group, this was not the case. The same is also demonstrated in Figure 5.

Discussion

Ultrasound investigation is a non-invasive, harmless and not very time-consuming technique and represents a possible innovative approach to tongue volume evaluation. An advantage of 3D ultrasound is also the possibility of collecting an unlimited amount of digital data, which can be saved for later use and processed with annexed software to measure or investigate different characteristics of interest.

An ultrasound image provides a clear image of tongue surface and makes it possible to distinguish tongue musculature from the mouth floor musculature.[17,22] The image is not obscured by the teeth because the transducer is placed submentally and the beam is directed upward and bypasses the teeth.[22] In our study, the lateral and front borders of the tongue as well as the dorsum and the caudal border of the tongue were easily determined when outlined on the saved images. However, difficulties appeared when determining the surface border of the radix of the tongue, where a hyoid bone presented a shadow and sometimes

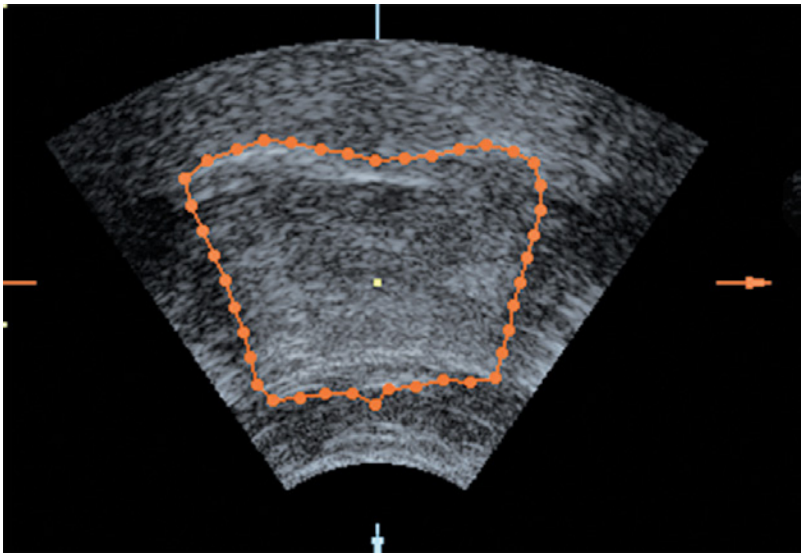

Figure 3: Delineated tongue on an ultrasound image of the same tongue as in Figure 2 on central coronal images.

obscured the back border of the tongue on the sagittal images, while in some cases the border was in front of the shadow and distinct. We could not find out what influences the position of the shadow.

The use of 4D VIEW software makes it possible to determine quite easily the borders of the tongue on the saved images. It first requires delineating the borders on 12 different images for the same tongue and then editing the contour on all 12 images. Nevertheless, we believe that it still takes less time in comparison with the technique of tongue volume assessment from MRI images.[11]

We would also like to point out the difference in body position during MRI and during ultrasound investigation, which could affect the measured volume of the tongue. The tonus of tongue musculature in a supine position differs from the tonus of tongue musculature in an upright sitting position.[23] However, MRI probably makes it possible to distinguish more accurately the intrinsic and also some extrinsic tongue muscles.

Then we looked whether the tongue volumes were normally distributed, to verify whether statistical methods for analyzing normally distributed data can be applied. The tongue volume distributions in both groups approached normal distribution. As can be seen in Table 2, the male group was significantly taller, heavier and had higher BMI than the female group and had significantly larger tongue volumes. Generally, the results of the estimated tongue volumes of our study are comparable to the findings of other studies. Liégeois et al.[24] presented similar results for male and female groups. The results of both studies are highly comparable especially as the characteristics of the other groups (age, height and weight) are surprisingly similar to ours.24 Even the results of tongue volume estimated from sagittal images in Lauder et al.[11] research are comparable. Nevertheless, these results differ from the results of the Do et al.[25] study, in which the tongue volumes of a group of patients without sleep-disordered breathing were much larger ($130 \pm 20.47 cm^3$). The differences occurred because anatomical outlines differ as extrinsic tongue

Table 2: Dimensional characteristics of subjects.

	Combined (n = 32)	Females (n = 18)	Males (n = 14)	Stat. sign. p
Body weight (kg) *	69.6 ± 14.8	58.5 ± 6.6	83.8 ± 8.6	< 0.001
Height (cm)*	175.5 ± 9.5	168.5 ± 5.5	184.6 ± 4.4	<0.001
Tongue volume (cm3)*	76.8 ± 12.5	67.2 ± 5.6	89.2 ± 6.3	< 0.001
Body mass index (kg / m2)*	22.3 ± 2.9	20.6 ± 1.6	24.6 ± 2.7	<0.001

Values are means ± standard deviation. Statistical significance was determined by Student's t-test.

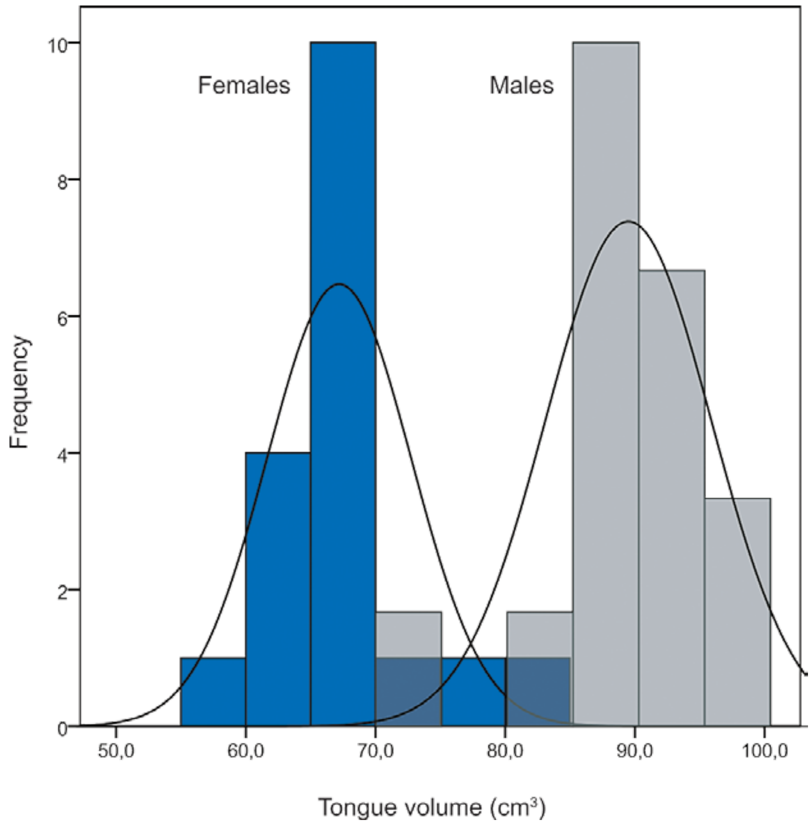

Figure 4: Distribution of tongue volumes in females and males.

muscles, mylohyoid and anterior belly of digastric muscle were included in the Do et al. study .[25] Iida-Kondo et al.,[26] who also included palate-pharyngeal and palatoglossus muscles as well as a pharyngeal constrictor, had results that were comparable to those of Do et al..[25] Wojtczak[17] also determined larger tongue volumes but his group consisted of 12 obese and morbidly obese patients and it is not comparable with our group. He used 2D ultrasound and estimated biplane tongue volume by multiplying 2D midsagittal area and tongue width.[17] In his preliminary study he concluded that the BPTV method overestimates the tongue size compared to the 3D SUS method, which better detects the true geometry of the tongue but the error is relatively small. From his published abstract we could not recognize how he determined the tongue outline (geometry) or which tongue muscles he included, the positions of his subjects were supine with the chin in perpendicular plane to the bed and they were asked to keep their tongues on the mouth floor.[17] This leads to change in tongue muscle tonus and activity[23], which probably affects the tongue volume. The supine position of his patients is understandable because of the purpose of pre-operative assessment of airway space to predict difficult intubation.[17]

When examining the correlation of body characteristics with the estimated tongue volume, the latter correlated with the body mass and consequently with the body mass index only in the group of male subjects (Table 3, Fig. 5). The existence of such correlation would enable us to standardize the tongue volume on the basis of the characteristic. In contrast with other studies,[24] the correlation between body characteristics and tongue volume could not be proved in our female group. Our study did not give reasons for such absence. However, when we considered the male and the female

Table 3: Correlation between body dimensions and tongue volume.

	Females (n = 18)	Males (n = 14)	Combined (n = 32)
Body weight*	0.052 (0.836)	0.842 (< 0.001)	0.804 (< 0.001)
Height*	0.183 (0.467)	0.180 (0.538)	0.764 (< 0.001)
Body mass index*	-0.080 (0.752)	0.736 (0.003)	0.710 (< 0.001)

** Pearson correlation coefficient values (statistical significance)*

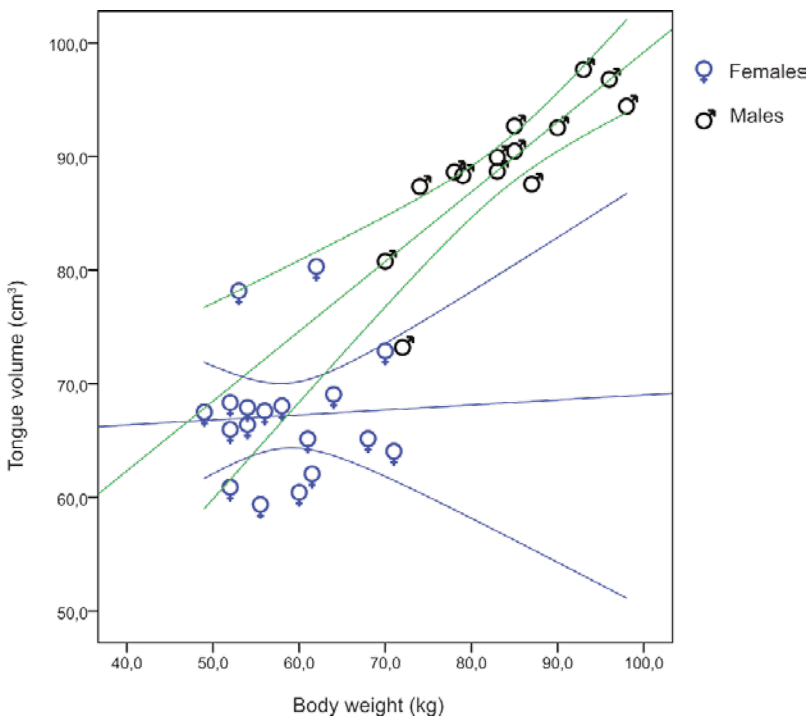

Figure 5: Relationship between bodyweight and tongue volume.

group as one group, the correlation between tongue volume and weight could be seen but was weaker than the one mentioned above. Similar correlation was proven also by Lauder et al..[11] The reason for the absence of strong correlation in our study could be in the relatively small sample. However, on the other hand, Iida-Kondo et al.[26] also could not prove the correlation between tongue volume and BMI in a control group of healthy male subjects, while there was correlation in patients with obstructive sleep apnea syndrome.[26]

Looking critically at our work, we realize that what is missing is the assessment of method accuracy. More attention should be given to how close to the real volume the estimated one is, what might be done with an ultrasound image of a cadaver's tongue and measurements of the volume of ex-vivo tongues, but the problem of such research is the loss of normal muscle tonus. Another consideration is that if we relied on the accuracy of the presented MRI tongue volume estimation,11'26 in the future we could acquire MRI images of the tongues of some of our subjects and compare the estimated tongue volumes from MRI with the tongue volumes estimated from ultrasound images. Overall, we believe that our technique is accurate enough for a comparison of the tongue volume between two different groups of subjects, especially if we compare our estimated group tongue volumes with comparable groups from other studies.9'11'24

Relatively low-dose CB-CT scanners are now being widely used in dental practices for examining bone and dental structures during orofacial diagnosis. It was already being applied for investigating soft tissues,[27] as well as tongue postures28 and sizes.[10] Uysal et al.[10] did present a potentially useful and promising method for tongue volume determination by CBCT, but had artificially delineated ventral and posterior borders of the tongue at the cemento-enamel junction of the lower first molars and premolars and probably this was the reason for the smaller tongue volumes they reported.[10] It might prove to be a non-invasive, reliable, cost-effective, and useful method for tongue volume assessment but still with low dose of radiation.

Conclusions

We can conclude that the method of 3D ultrasound estimation of tongue volume proved highly repeatable in terms of good intra-class correlation coefficients of repeatability as well as of intra- and inter-rater reliability. It could be useful in the future for comparing different groups of dentofacial deformities, syndromes and obstructive sleep apnea patients, and to evaluate the influence of tongue volume on the development of dental arches and facial structures.

Competing interests

None of the authors have any competing interests in the manuscript.

Authors' contribution

UB performed majority of ultrasound measurements, with the support of MMM. Precise study design and statistics were done by IV. The general idea and whole organisation was done by NIH and the article was also written by NIH.

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Ethical approval: Approved by the Ethics Committee of the Republic of Slovenia.

Patient consent: Informed consent was obtained from all the subjects involved in the study. For published images also consent to publish was obtained from the involved subjects.

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