Estimation of tongue volume from magnetic resonance imaging

By Robert Lauder, DDS and Zane F. Muhl, DDS, PhD

There is debate over the role of the tongue in the development and morphology of the dental arches. For years orthodontists have theorized that the size, strength and position of the tongue must have some relationship to the surrounding oral cavity. Brodie[1,2] maintained that dental arch form and size are directly influenced by tongue size. However, investigators have been unable to consistently identify specific cause and effect relationships. Proffit[3] stated that he and others were unable to find an equilibrium between the outward force of the tongue and the inward force of the lips.

Some clinicians implicate a large or forwardly positioned tongue in the development of certain malocclusions.[1,2] As a result, determining the size of the tongue becomes an important part of diagnosis. Currently, clinical assessment of tongue size is very subjective. Other than computerized tomography,[4] no technique has been demonstrated as accurate in evaluating the volume of the tongue relative to the oral cavity in living subjects. The present study was undertaken to demonstrate that magnetic resonance imaging (MRI) is an objective means of measuring tongue and available oral cavity volume.

Past studies of tongue size used a variety of techniques. The anatomical definition of the tongue and how much of it was measured are usually inconsistent among authors. Therefore, comparing the results of these studies becomes difficult and has limited usefulness.

Hopkin[5] made linear measurements of the tongue in 30 adults postmortem. Cadaver studies have limited applications in a clinical situation. However, they do provide a reasonable baseline to which the more inexact clinical measurements can be compared.

Abstract

Magnetic resonance imaging was used to estimate the volume of the tongue, oropharynx, and oral cavity in 19 adults. Each subject was imaged and had volume estimations made from the coronal and sagittal orientations. Volume was found by measuring area from a series of images and then multiplying by the thickness of each slice and the gap between each slice in the series. Mean tongue volumes of 71.2cc (coronal) and 79.3cc (sagittal) were found. The estimated volumes were found to be reproducible and each orientation was equally good for defining the anatomy of the tongue and oropharynx. Tongue volumes were found to correlate well with subject body weight, $r = 0.86$ for the coronal and $r = 0.82$ for the sagittal orientations.

To test the reliability of this technique, tongue volume was estimated for ten New Zealand white rabbits by the same method. The rabbit tongues were then removed and their actual volumes were determined. The estimated tongue volumes from imaging were found to compare closely to the actual volumes but, on average, slightly underestimated actual size. When converted to a percentage, 95% confidence intervals for the estimation of rabbit tongue volume by MRI are $-4.3 \pm 25.9\%$ for the coronal and $-5.9 \pm 16.5\%$ for the sagittal.

This manuscript was submitted August 1990. It was revised and accepted for publication January 1991.

Key Words

Tongue • Magnetic resonance imaging (MRI) • Volume

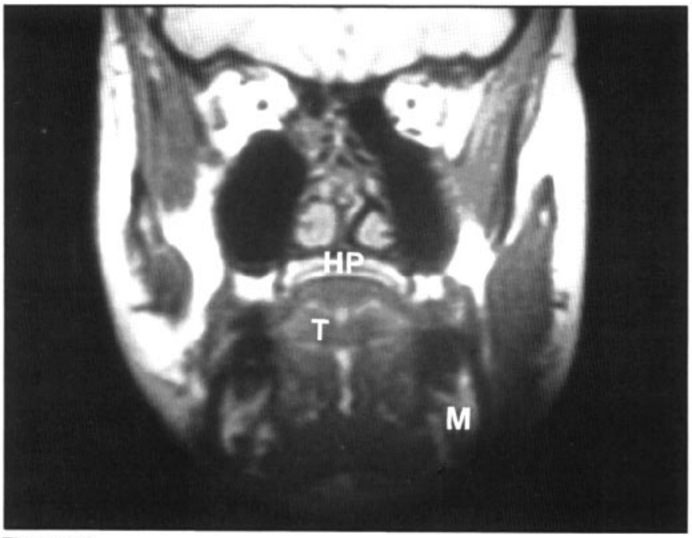

Figure 1A

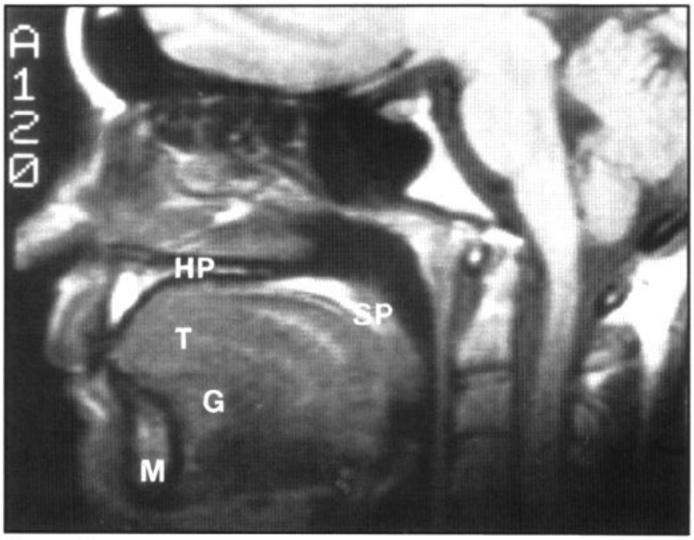

Figure 1B

Figure 1
Magnetic resonance images of human subject #13. The superior is at the top of the figure, T — tongue, M — mandible and HP — hard palate. A: Coronal; the patient's right is to the left of the figure. B: Sagittal; the anterior is to the left of the figure, SP — soft palate, G — genioglossus muscle and H — hyoid bone.

Measurements made from lateral cephalograms are commonly used to assess the two-dimensional size of the tongue in living subjects. Vig and Cohen[6,7] compared sagittal tongue area to sagittal oral cavity area in adults and children. Since adjacent muscles cannot be distinguished on lateral cephalometric x-rays, Vig and Cohen[6,7] were forced to use bony landmarks when defining the limits of the tongue and the intermaxillary space.

Other studies have evaluated tongue size in living subjects by direct measurements. However, in each of these studies, the investigators were not able to measure the posterior portion of the tongue. Bandy and Hunter[8] measured the volume of the anterior portion of the tongue by water displacement. Subjects protruded their tongues as far as possible and displaced a column of water. Takada et al.[9] measured tongue size in 25 Japanese females by an alginate impression technique. Casts were made of the tongues, and volume was determined by displacement of the casts in water. Oliver and Evans[10] attempted to determine tongue volume in 35 adults. Tongue length, width and thickness were measured with a Boley gauge, and alginate impressions were also taken.

Computerized tomography (CT) has also been employed to estimate tongue and oral cavity volume. Roehm[4] measured these structures with CT in 32 subjects with a mean age of 14 years 4 months. Using human cadaver heads, she was able to determine the accuracy of her measurements on living subjects. In the living subjects, the mean tongue volume was 59.12cc. A mean ratio for tongue volume to oral cavity was determined to be 0.86. Subjects with an anterior openbite demonstrated a significantly higher ratio of 0.91. Roehm[4] found that computerized tomography is a reliable and effective way to view the tongue, oral cavity, and oropharynx and to make size comparisons. However, the harmful effects of ionizing radiation may make CT unsuitable for this purpose alone.

Lowe et al.[11] compared tongue volume to airway volume in 25 adult men with obstructive sleep apnea. They also used CT to estimate tongue and airway volume. Tongue volume had a mean of 72.0cc and airway volume had a mean of 13.9cc.

Magnetic resonance imaging is similar to computerized tomography in that slices of a specific thickness are taken and images of only the desired sections are produced. However, no ionizing radiation is used and there are few known hazards associated with this technique. MRI has been used to inspect the entire head and neck.[12,13] It demonstrates more internal soft tissue anatomy than is possible with CT. Magnetic resonance images are not degraded by dental amalgam; however, crowns or bridges made from ferromagnetic materials as well as silver point fillings may cause local artifacts on the image.[14]

Materials and methods

In this study, the volumes of the tongue, the oropharynx, and the oral cavity were estimated from MR images on adult human subjects. The volume of the tongue was also estimated from MR images on domestic white rabbits.

Human subjects

All human imaging was completed at Brokaw Hospital in Normal, Illinois, on a General Electric (Milwaukee, Wisc.) Sigma System with a 1.5 tesla magnet. Each subject was asked not to move or swallow and to keep his or her tongue against the roof of the mouth with teeth in occlusion during imaging. Each subject was free of oral cavity anomalies and had at least a nearly

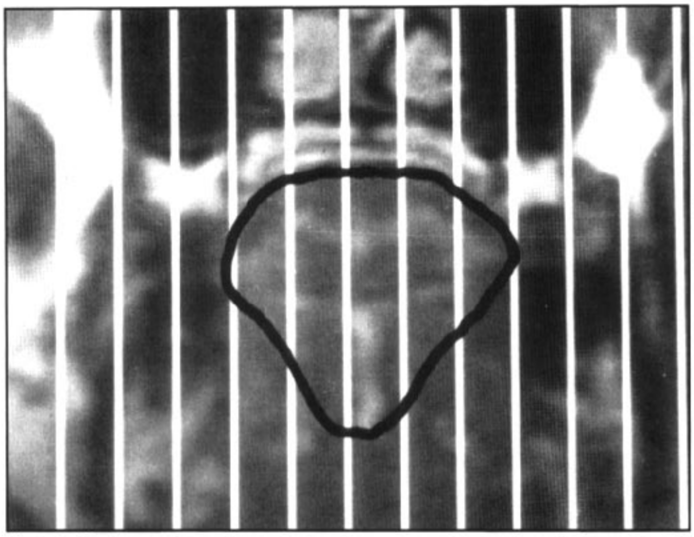

Figure 2A

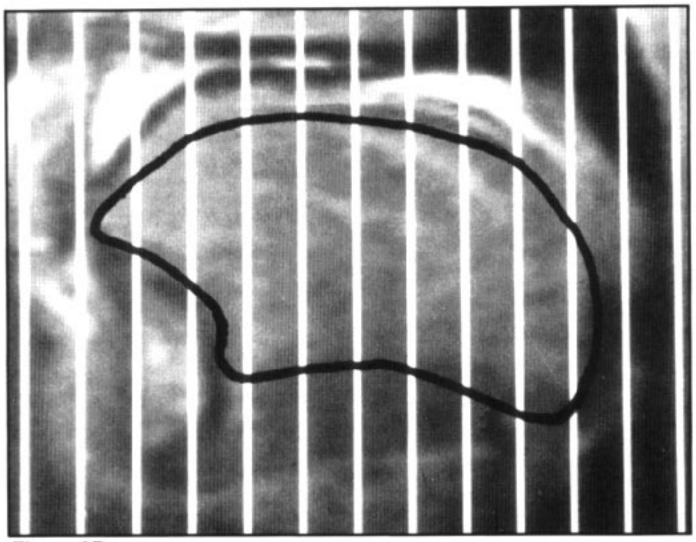

Figure 2B

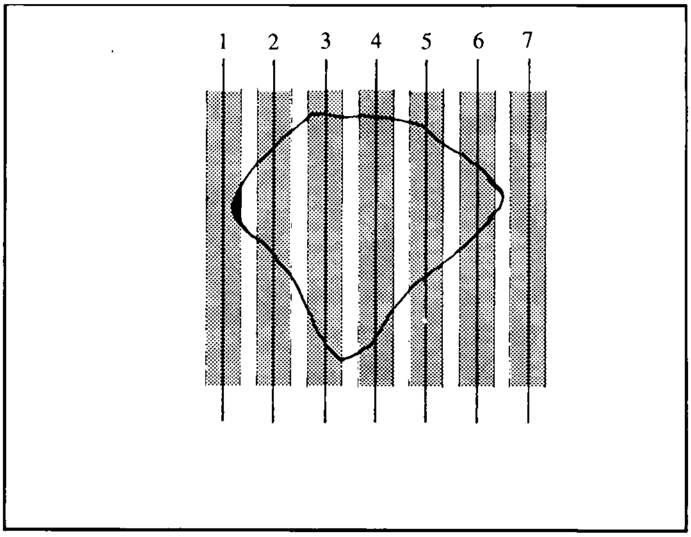

Figure 3A

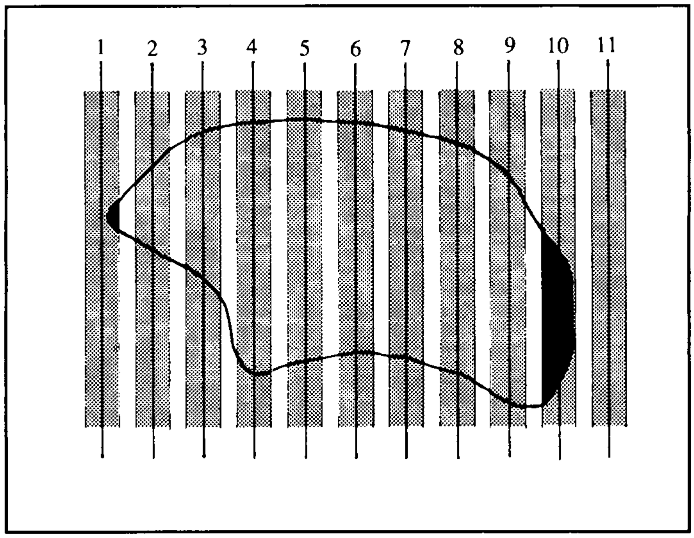

Figure 3B

complete set of teeth in both upper and lower arches. A total of 26 subjects were imaged. However, some subjects had dental restorations that caused distortions on the images. Therefore, 19 subjects — eight males and 11 females — were selected based on image quality.

For each subject, a series of images was collected with a field of view of 24cm^2 and a matrix size of 256 x 128 picture elements (pixels). Sagittal and coronal images provided better views for determining tongue and oral cavity volume than did axial images. Images were taken from the anterior part of the spinal column to the tip of the nose in the coronal orientation and from ear to ear in the sagittal orientation. In both orientations, T_1 weighted images were used with a TR of 600ms and a TE of 20ms. Each slice was 5.0 mm thick with a 2.5 mm gap between each slice (Figure 1).

For this study, the tongue was defined as all its intrinsic muscles plus the entire genioglossus and hyoglossus muscles. 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. The posterior-inferior border of the tongue was defined as a line from the hyoid bone to the vallecula (Figure 2).

The volume of the oropharynx was also determined. Its posterior border was the posterior pharyngeal wall. The superior border was a constructed line from the most posterior contact point of the soft palate and the dorsum of the tongue back to the posterior pharyngeal wall. The inferior limit was a constructed line from the vallecula to the closest point of posterior pharyngeal wall. The lateral borders were the lateral walls of the pharynx.

The oral cavity was defined here as the entire tongue, any empty space which surrounds it, plus the oropharynx. The inferior border of the hard and soft palate defined the superior limit of the oral cavity. The inferior border of the oral cavity was the same as that defined for the

Figure 2
The same MR images as Figure 1. A: Coronal; B: Sagittal. The tongue is outlined and the vertical lines demonstrate the center of slices taken from the other orientation. See Figure 1 for identification of landmarks.

Figure 3
Drawing of human tongue outlines, thickness of slices (hatched), gap between slices, and end sections (solid). A: Coronal; B: Sagittal. Numbers denote order of slices. The coronal image is sagittal slice #7 and the sagittal image is coronal slice #4. The superior is at the top of the figure.

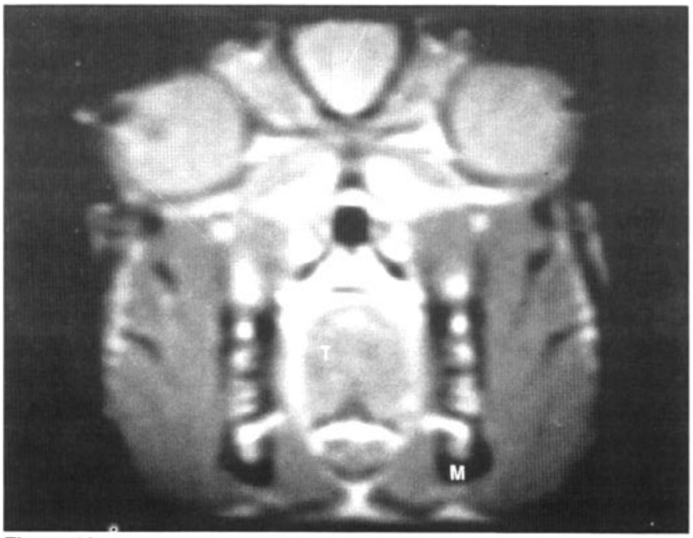

Figure 4A

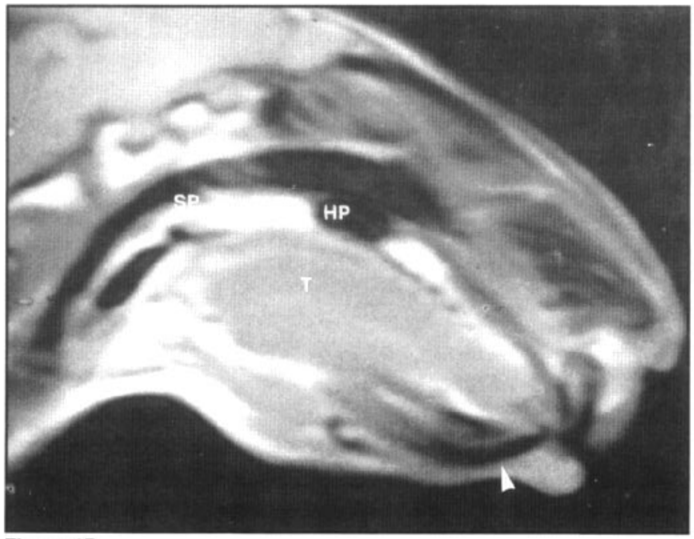

Figure 4B

Figure 4
Magnetic resonance images of rabbit #9. Superior is orientated at the top of the figure, T — tongue. A: Coronal; the rabbits right is to the left of the figure, M — mandible. B: Sagittal; anterior is to the right of the figure, HP — hard palate, SP — soft palate, and arrowhead points to the lower incisor.

tongue and the oropharynx. The lateral boundaries were the dental arches and the pharyngeal walls.

In each image of the series, the tongue, oropharynx, and oral cavity were outlined on tracing paper. From these tracings, the area of each slice was measured with a planimeter (Keuffel and Esser, W. Germany). Once the area of each slice was determined, the volume was calculated by multiplying the area of each slice by its thickness and the gap between each slice. Then, the tongue, oropharynx, and oral cavity volumes were found by adding together the slice volumes.

As area measurements were taken from the coronal images, the position of each coronal slice was demonstrated by the computer on the mid-sagittal image (Figures 2 and 3). This made it possible to positively identify any part of the tongue or oropharynx that did not completely fill the end slices, or a part that was missed between the end slices.

The volumes of the tongue, oropharynx, and oral cavity were estimated from the coronal images and again from the sagittal images. Each volume was estimated twice for each subject, from the same images, on two separate occasions. This was done so that the consistency of this technique and the operator error could be tested.

The data from the human subjects were used to determine the relationships between tongue volume, oropharynx volume, oral cavity volume, patient sex, and body weight.

Animal subjects

Since it was impossible to check the accuracy of the volumetric measurements in the humans, an animal study was performed. The animal portion of this project attempted to determine the accuracy of making such measurements from MRI. Ten domestic white rabbits were imaged at the University of Illinois at Chicago Magnetic Resonance Imaging Animal Research Center on a General Electric (Milwaukee, Wisc.) Chemical Shift Imaging unit. This unit has a 2.0 tesla magnet and is specifically designed for animal research.

Each animal was imaged from both the coronal and sagittal orientations. In the coronal plane, images were taken with a T_2 weighted image with a TR of 2800ms and a TE of 30ms. The thickness of each slice was 2.0 mm, and the distance between each slice was 4.0 mm. In the sagittal images, a T_1 weighted image was used with a TR of 600ms and a TE of 20ms. The thickness of each slice was 2.0 mm, and the distance between each slice was only 1.0 mm. Changing the TR and TE between orientations does not change the dimensions of the image or the tongue, but gives a slightly different contrast in the image in each orientation and helps to define anatomic boundaries. The images were produced with a field of view of 10.0cm^2 and a matrix size of 128 x 128 pixels.

The images were photographed directly from the MRI unit monitor with a matrix camera (Figure 4). The resulting photographic images were projected on an enlarger in a darkroom. The outline of the rabbit tongues were then traced on paper. Total tongue volume was then estimated for each animal, from the coronal and sagittal orientations, in the same manner as in the human portion of this study.

Tongue volume was estimated twice for each subject, from the same images, on two separate occasions. This was done to test the reproducibility of enlarging the images in the darkroom, identifying and tracing the boundaries of the tongue, and measuring slice area with the planimeter.

Table 1
Mean volume (in cc) and mean differences for tongue volume found by weighing and by MRI for 10 rabbits.

	Weight divided by density	Volume found from coronal			Volume found from sagittal		
		Estimation from MRI	Difference in ccs	Percent difference	Estimation from MRI	Difference in cc	Percent difference
Mean	5.05	4.80	-0.24	-4.3	4.77	-0.28	-5.9
S.D.	0.87	0.92	0.60	13.2	1.05	0.42	8.4

Table 2
Mean estimated volume (in cc) of the tongue, oropharynx and oral cavity from MRI for 19 adult humans.

	Coronal			Sagittal		
	Tongue	Oropharynx	Total oral cavity	Tongue	Oropharynx	Total oral cavity
First trial						
Mean	72.74	6.07	79.48	80.18	7.54	87.73
S.D.	10.79	3.48	12.81	13.61	2.82	15.43
Second trial						
Mean	69.65*	5.33	76.07	78.40	6.84	85.24
S.D.	11.73	2.34	12.18	12.67	2.58	14.52
Average of trials 1&2						
Mean	71.20**	5.70	77.77	79.29	7.19	86.48
S.D.	11.04**	2.81	12.21	12.71	2.64	14.59

* significantly different from first trial, $p \leq 0.01$
** values averaged despite difference between trials

The tongue was then removed from the rabbits by cutting the mucosa below the tongue and finding the transverse plane between the genioglossus and the geniohyoid muscles. The posterior portion of the tongue was sectioned flush to the superior surface of the hyoid bone and cut back to the vallecula. This dissection attempted to duplicate the same boundaries of the tongue as in the MR images.

The tongues were weighed (wet weight) with an analytical balance. The resulting weight was then divided by the density of rabbit muscle (1.06 gm/cc)[15] to find the actual tongue volume. The direct measurements of the rabbit tongues were then compared to the estimated volumes made from the MR images, from both orientations. For each subject, the error in cubic centimeters and the percentage error of the estimated tongue volume from the MRI technique were calculated.

Results

Paired t-tests were done to find differences in determined volumes. All tests were made with an alpha value of 0.01. For the rabbits, there were no significant differences in estimated tongue volumes found from either the coronal or the sagittal orientations between the first and second trials. Therefore, the results found from both trials were averaged for the coronal and sagittal orientations.

The mean volumes of the rabbit tongues measured by dividing wet weight by the density of muscle is listed in Table 1. Also shown in

Table 3
Mean body weight (in lbs), tongue, oropharynx and oral cavity volume (in cc) by sex.

		Coronal			Sagittal		
Sex	Weight	Tongue	Oropharynx	Total oral cavity	Tongue	Oropharynx	Total oral cavity
Male	163.9	81.47	7.08	88.55	89.64	9.14	98.78
Female	137.4*	63.73*	4.60*	69.16*	71.77*	5.77*	77.54*

* significantly different from males, $p \leq 0.01$

Table 4
Pearson correlation coefficients between subject body weight, tongue volume, oropharynx volume and oral cavity volume.

	Coronal			Sagittal		
	Tongue	Oropharynx	Total oral cavity	Tongue	Oropharynx	Total oral cavity
Body weight	0.86	0.54	0.88	0.82	0.55	0.82
p-value	0.0001	0.0212	0.0001	0.0001	0.0143	0.0001
Coronal tongue		0.46	0.98	0.92	0.62	0.91
p-value		0.0546	0.0001	0.0001	0.0048	0.0001
Coronal oropharynx			0.63	0.42	0.79	0.51
p-value			0.0049	0.0818	0.0001	0.0292
Coronal total oral cavity				0.89	0.68	0.90
p-value				0.0001	0.0019	0.0001
Sagittal tongue					0.66	0.99
p-value					0.0020	0.0001
Sagittal oropharynx						0.76
p-value						0.0002

Table 1 are the mean estimated tongue volumes from MRI found from the coronal and the sagittal images. There were no significant differences in the estimated tongue volumes found between the coronal and sagittal orientations or between these orientations and the actual tongue volumes found by weighing.

The mean differences and percentage differences between the actual tongue volumes measured by weighing and the estimated tongue volumes from imaging are also given in Table 1. The mean differences (in cc) and the percentage errors are all negative. This indicates that the tongue volumes were usually underestimated. The 95% confidence intervals for the estimation of rabbit tongue volume by MRI are -4.3 ± 25.9% for the coronal and -5.9 ± 16.5% for the sagittal.

The mean estimated tongue volumes, oropharynx volumes and oral cavity volumes found from MRI for the human subjects are shown in Table 2. There was no significant difference in estimated tongue volume between the first and second trials from the sagittal orientation. The estimation of tongue volume was smaller in the second trial from the coronal orientation. There were no significant differences in oropharynx volume between the first and second trials from either the coronal or sagittal orientations. Also, there were no significant differences in the total oral cavity volume between the first and second trials from either the coronal or sagittal orientations. The values for the first and second trials were than averaged and these means are also shown in Table 2.

The averaged estimated volumes of the tongue, oropharynx and total oral cavity from both orientations were compared to subject body weight and sex. The means are given in Table 3. Males weighed significantly more than females and had larger tongue volumes. Males also had significantly larger oropharynx volumes and total oral cavity volumes in both the coronal and sagittal orientations.

Pearson correlation coefficients were done between subject body weight, tongue volume, oropharynx volume and oral cavity volume from each orientation. The values are given in Table 4. The relationship between subject weight and estimated tongue volume from the sagittal orientation is demonstrated in Figure 5.

Discussion

When viewing the images of the rabbits and the humans, each orientation presented difficulties in defining the borders of the tongue along the inferior and inferior-lateral edges. All other borders of the tongue were easily seen in both the coronal and sagittal. Neither orientation showed the anatomy better than the other. However, the coronal orientation could be considered superior since a greater number of images can be obtained in this orientation as a result of the anatomy of the tongue (being longer than it is wide).

The volume of a rabbit tongue could be consistently estimated on separate occasions. This demonstrates that defining the boundaries of the tongue, tracing its outline, measuring it with the planimeter, correcting for enlargement, and then estimating total volume are reproducible by the same operator. As a result, the data found from each separate estimation were pooled.

The purpose of comparing estimated tongue volume to actual tongue volume in the rabbits was to find the error of using MRI to estimate volume. Estimated mean tongue volumes from both MRI orientations appeared to be less than the volume from weighing and dividing by density, but no significant difference was found. This may reflect the small sample size; a larger sample might have shown a significant difference.

In order to use this technique to estimate the volume of objects of a different size, mean percentage errors were calculated. Converting the mean difference from ccs into a percentage eliminated the effects of size. As a result, the percentage error for volume estimation of a larger object such as a human tongue can be assumed to be no worse than the percentage error for volume estimation of a smaller object such as a rabbit tongue. Confidence intervals were then constructed using the percentage errors found for the rabbit tongues. These could be used to suggest the accuracy of estimating tongue volume for human subjects. These confidence intervals for the rabbits can only be used as a reference for comparisons to volume estimations of the human tongue, oropharynx, and oral cavity.

For the human subjects, the error between trials was greater than with the rabbits. For an unknown reason, the tongue volume was estimated to be significantly smaller in the second trial from the coronal orientation. Also, for all other objects and orientations, the estimated volumes appeared to be smaller in the second trial; although, the differences were not significant.

The calculated mean tongue volumes of 71.20cc and 79.29cc are both greater than the mean tongue volume found by Roehm[4] of 59.12cc. However, this difference could be accounted for by the older and presumably larger,

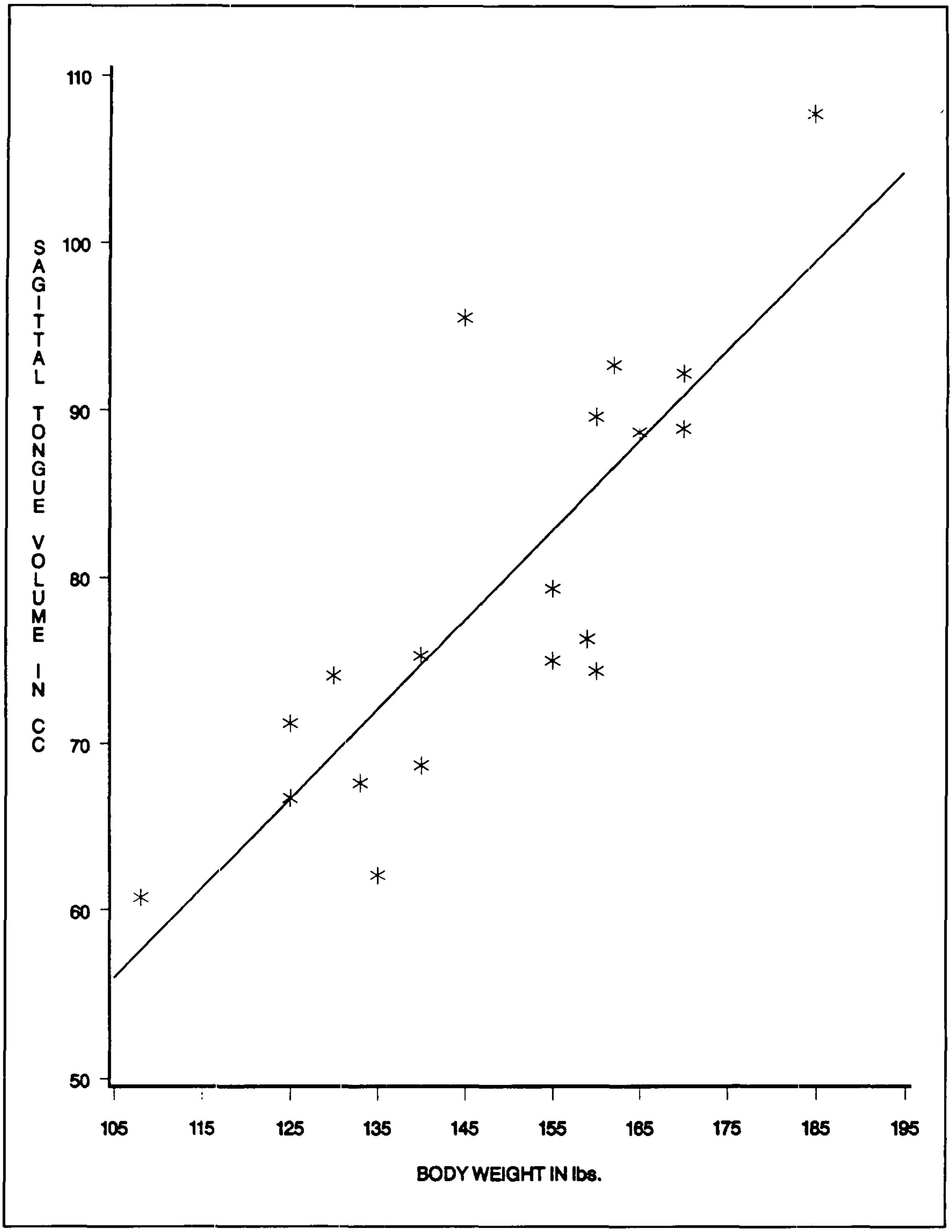

Figure 5
Estimated human tongue volume from the sagittal dimension plotted against subject body weight with linear regression line; Y = 0.54X - 0.43.

subjects in the present study. The study by Lowe[11] used only adult subjects and the mean tongue volume found of 71.96cc is closer to the value found in the present study. However, the mean oropharynx volumes of 5.70cc and 7.19cc in the present study are much less than the airway volume of 13.9cc found by Lowe.[11]

Mean ratios of tongue volume to total oral cavity volume were also determined. These ratios were found to be 0.93 for the coronal and 0.92 for the sagittal, greater than the 0.86 found by Roehm[4] for non-openbite subjects. Her ratio of 0.91 for openbite subjects is closer to the values found for this study. In the present study, no dental casts or radiographs were taken. However, by viewing the mid-sagittal MR image, the relationship of the maxillary and mandibular incisors could be seen. None of the human subjects demonstrated a dental openbite.

It is not surprising that the male subjects weighed more and were found to have larger mean tongue, oropharynx, and total oral cavity volumes. It is interesting that oropharynx volume correlated less with body weight than did tongue volume. The correlations between the tongue, oropharynx, and oral cavity from each orientation are r = 0.92, 0.79, and 0.90 respectively. The volume found for one subject from one orientation correlated well with the volume found for the same subject from the other orientation.

Unfortunately, this study was only able to select a human sample of normal subjects. By definition, none of the patients selected demonstrated any pathology associated with the tongue or oral cavity. However, this study did demonstrate a technique by which the volume of the tongue, oropharynx, or oral cavity could be measured. This type of information may be of great importance when treating or studying craniofacial anomolies such as cleft palate, Pierre Robin syndrome, microglossia, or macroglossia. In addition, future studies could use the technique demonstrated here to compare tongue volume and oropharynx volume to the development of the dental arches and facial structures in normal growing subjects.

Conclusions

For both the humans and rabbits the technique presented for estimating volume from MR imaging was found to be accurate and reproducible to a certain degree. However, defining the inferior and lateral boundaries of the tongue was found to be difficult at times, and this resulted in some error in estimating volume.

The estimated volume of the rabbit tongues compared well with the actual volume of the tongues. This demonstrated that the technique worked; volume could be reliably estimated from MR imaging.

For the human subjects, tongue volumes of 71.20cc from the coronal orientation and 79.29cc from the sagittal orientation were found. This resulted in ratios of tongue volume to oral cavity volume of 0.93 and 0.92 respectively. The estimated volumes of the human tongue, oropharynx, and oral cavity were all found to correlate well with subject body weight. Also, the estimated volumes of the tongue, oropharynx, or oral cavity were found to be similar when estimated from either the coronal or the sagittal orientations.

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Commentary: Estimation of tongue volume

By Alan A. Lowe, DMD, PhD, FRCD(C)

The researcher's logical extension from computerized tomography to magnetic resonance imaging provides valuable information with regard to the quantification of tongue and airway size. The findings are of significant interest to the orthodontic profession: the problem of measuring tongue size accurately has occupied us for years. These authors have carefully examined a difficult and challenging organ. Adding both sagittal and coronal evaluations of tongue size is a significant advantage over CT techniques. The animal verification of the reliability of the technique has been carefully done, although it is unfortunate subjects were not classified according to skeletal type. Body Mass Index (rather than weight alone) might have provided higher correlation coefficients.