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Abstract

Effect of Maxillary Features on Tongue Anteriority in Glossectomy and Control Speakers

Jun Hyuk Hwang, Master of Science, 2015

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This study examines the behavior of glossectomy (N = 15) and normal tongue (N =20) movement using combination of high-resolution and cine- MRI. The speech task "a souk" was used to measure anterior tongue displacement, termed "anteriority", from /uh/ to /s/. Effects on anteriority due to palate height, /s/ type, arch perimeter, canine width, and orthodontic extraction of teeth were measured on controls and patients. Results showed that all factors except canine width had no significant difference in anteriority of tongue. Canine width was significantly related to anteriority in an inverse relationship. The fact that arch perimeter is less important than canine width on anteriority is consistent with our understanding of the criticality of the location of the tongue tip, rather than the tongue body, in producing /s/. Data also suggests that less than average arch perimeter improves speech intelligibility in patients with T2 tumor of the tongue.

Effect of Maxillary Features on Tongue Anteriority in Glossectomy and Control Speakers

by
Jun Hyuk Hwang

Thesis submitted to the Faculty of the Graduate School of the
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of the requirements for the degree of
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Table of Contents

List of Tables

List of Figures

1. Introduction

1.1. Tongue Cancer

The Center for Disease Control and Prevention (CDC) estimates more than 30,000 new cases of oral and pharyngeal cancer are diagnosed each year (Jemal et al,. 2010). One of the most commonly affected sites of oral cancer is the lateral border of the tongue and squamous cell carcinoma makes up the majority of lesions found here. The 5-year survival rate for oral cancer is approximately 50% and treatment of this disease with surgery has become one of the most important treatment modality for these patients. The preferred method of surgery is glossectomy, which is removal of the tongue tumor in addition to an extra margin of healthy tissue. Resected area may be closed primarily with sutures or with a free flap usually from the radial forearm. Size of the tumor and the extent of surgery often affect the patients' tongue motor adaptation. Cancer patients used in this research had smaller tumor of the lateral tongue, T1 or T2 that were closed primarily with suture (see **Figure 1**). T refers to the size of the tumor using the TNM system (National Cancer Institute). In the tongue, T1 is <2cm in the largest dimension and T2 is 2-4cm in the largest dimension. All these patients were also N0 and M0 (no lymph node involvement or metastasis).

Figure 1. Control tongue during protrusion does not deviate

Patient Control

Glossectomy patients' tongue deviates to the affected side during protrusion. This is due to the resected lateral border of the tongue. Control tongue during protrusion does not deviate. In the case above, right lateral border of the tongue was resected. Blue marking on the patient tongue is to help visualize the tongue deviation during protrusive movement.

1.2. Anteriority

Acoustic differences between glossectomy patients and controls are small in these T1, T2 tumors because most of the lateral tongue is intact and the remaining muscles are able to compensate for the missing tissues. These acoustic differences were measure by intelligibility test from each subject. However, what we do not understand is how the glossectomy differs in comparison to controls in order to compensate for the resected tongue. As acoustics alone cannot determine the compensatory mechanism of glossectomy tongue, a measurable parameter is needed in order to compare controls vs. patients. The anterior portion of the tongue is of particular importance to us as we believe this is where the tongue shape changes the most (Stone et al., 2010). Thus this study looks at tongue anteriority, which is the volumetric differences in the anterior portion of the tongue when the tongue moves from rest /uh/ to /s/, using cine-MRI. Anteriority differences were compared by measuring anterior volume change (mm^3), during a simple and repeatable speech task. This study selected the task "a souk" to compare anteriority because it was an easily reproducible speech task that only took one second to repeat multiple times. This speech also required anterior displacement of tongue to produce /s/ thus giving the anterior displacement of tongue that can be measured. During speech we can isolate timeframe of tongue at neutral position; tongue at /uh/, and compare to the timeframe of maximum anterior tongue displacement; tongue at /s/. The tongue anteriority can then be compared between subjects to determine which parameters have the greatest effect on anteriority. In this study, the anteriority was compared between controls and patients, palate height; low or high, arch perimeter, canine width and the /s/ types; apical or laminal.

1.3. MRI: Magnetic Resonance Imaging

Since the inception of Magnetic Resonance Imaging (MRI), many studies have been done on soft tissue analysis. Using a powerful magnetic field, sensors detect radio frequency signals emitted from excited hydrogen atoms, such as from water molecules. As our tissues are filled with water molecules, MRI provides researchers with great visibility of soft tissue in our body while hard tissue such as bone will show as radiolucent. High resolution MRI is able to show tissue shapes and structures with great details.

In this experiment, we also employed cine-MRI (like cinema) where series of MRI are linked together to form a movie of soft tissue in motion. Cine-MRI is of particular importance in this research as we are able to track the changes during production of phonemes. Unlike high-resolution MRI, cine-MRI is of lower quality (pixel resolution) and one cannot differentiate fine details. However, the purpose of this study was not to delineate one muscle from another. Instead, we wanted to observe the entire tongue volume shifts in the tongue tissue between /uh/ and /s/, thus cine-MRI was the ideal imaging modality to observe and measure these changes.

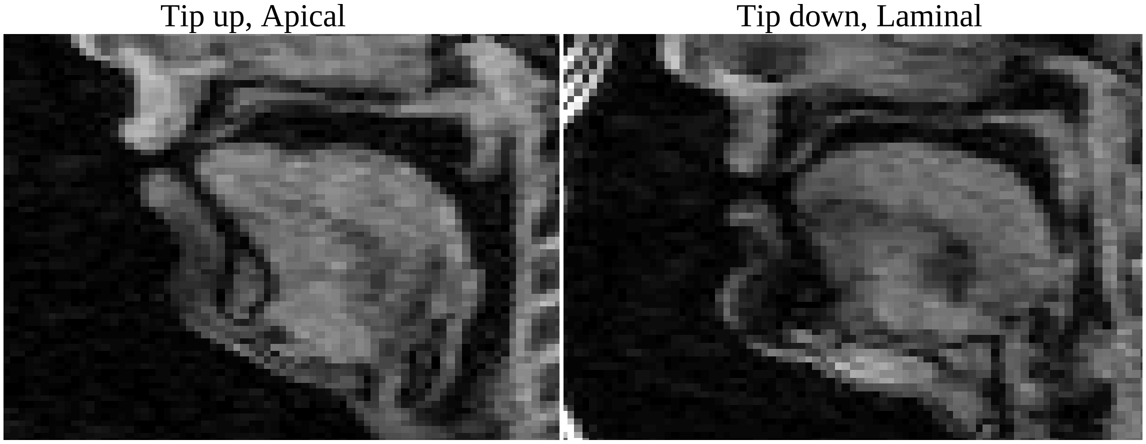
1.4. Palate Features and /s/ types

During the production of /s/ in “a souk”, Stone et al [2013] identified that the tongue tip may be up or down (See Figure 2). They classified this as apical or laminal /s/ respectively. Stone et al [2013] proposed and noticed that the palate height affected the type of /s/ produced during “a souk”. In that study, control subjects (unaffected tongue) with high palate displayed more laminal /s/ and low palate showed apical /s/. However in glossectomy patients, palate height did not seem to affect /s/ type and instead favored laminal /s/. This may be related to the difficulty in patients controlling the tip of the tongue due to the resection. Although tip of the tongue is preserved during surgery, discontinuous fibers and reduced motor innervation of the tongue makes control of the tongue challenging. Thus differences in anteriority of /s/ types are expected to be seen during /uh/ to /s/. This study also hopes to investigate the differences in anteriority of high vs. low palate subjects as palate height appeared to influence the type of /s/ made during “a souk”.

Figure 2. Apical vs. Laminal tongue shape at /s/.

Tip up, Apical

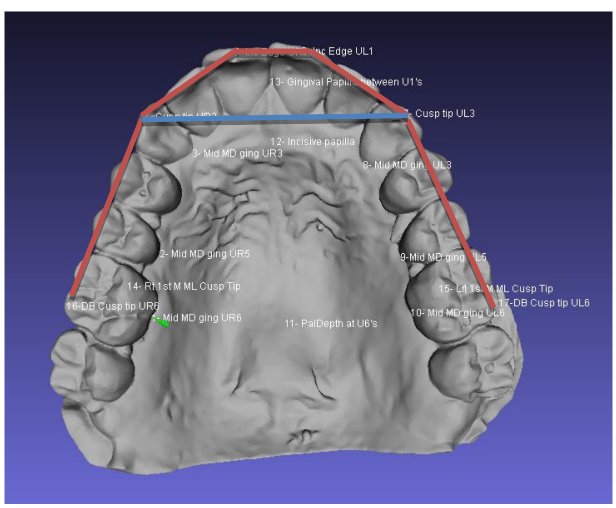
Tip down, Laminal



1.5. Arch Perimeter and Canine Width

In addition to palate height, other features of the oral cavity may influence tongue anteriority. Most notably the teeth surrounding the tongue have the potential to influence tongue anteriority as the teeth create a physical barrier for the tongue both laterally and anterior. In this study, only the upper arch was taken into consideration as most of the contact with the tongue was made with the upper arch and not with the lower arch during "a souk". Arch perimeter is defined as the distance formed along the cusp tip of disto-buccal 1st maxillary molar (M1) to the contra-lateral disto-buccal cusp tip 1st maxillary molar (See Figure 3**)**. Arch perimeter is important in anteriority because the teeth form the physical boundaries of the oral cavity thus limiting the movement of the tongue anteriorly. This experiment also measured upper canine width from cusp tip to cusp tip. As canines are the anchoring teeth and one of the first teeth to come in contact with the tongue during speech, canine width may influence anteriority during speech.

Figure 3. Arch perimeter is shown on this cast labeled in red. Canine width is labeled in blue.



With the palate features and arch perimeter, anteriority of the tongue can be compared between controls and patients during the speech task “a souk”. The following hypothesis can be made about anteriority between controls and patients.

1.6. Hypothesis

H1: High palate will have greater anteriority than low palate

Rationale: Past study showed high palates (>14mm) were associated more closely with laminal /s/ types in controls and low palates (≤14mm) were associated with apical /s/ types. As laminal /s/ type requires more bodily movement of tongue than just the tip of the tongue, greater anteriority is expected in subjects with high palate.

H2: Patients will have greater anteriority than controls

Rationale: In the majority of glossectomy patients, laminar tongue movement was observed during /s/ irrespective of palate height. Patients are missing some of their tongue, and this reduced volume has the effect of giving the patients a higher palate. Thus greater anteriority is expected in patients in producing /s/. Our second hypothesis is that in patient, we hope to find that the tongue volume will have a significant anterior displacement of the tongue as patients will tend to favor the laminal tongue motion. Thus as seen in control subjects with high palate, we expect greater tongue anteriority in patients.

H3: Laminal /s/ will have greater anteriority than apical /s/.

The adaptation of tongue movements during /s/ is a sound that requires great precision because it is made in a region of the vocal tract where small errors can be heard. The phoneme /s/ is particularly difficult sound for glossectomy patients due to the technical requirement of extending the tongue tip and making a mid-sagittal tongue groove.

Rationale: This is because the lateral tongue, between the tip and the root of the tongue, is the most commonly affected site of tongue cancer. Thus in glossectomy patients, the lateral body of the tongue is removed and the apical portion or the tip of the tongue loses its motor and sensory innervation and muscle fiber connections. Thus apical tongue movement becomes a challenge for patients to produce /s/. Thus we expect to see greatest changes in anteriority in patients. In controls, we expect that laminal movement of tongue will show greater changes in anteriority than apical tongue movement simply because bodily movement of tongue is required to produce the /s/ versus a controlled apical tongue movement.

H4: Smaller arch perimeter and canine width will result in lesser anteriority.

Rationale: Subjects with smaller arch perimeter/canine width will have less anteriority than those with larger arch perimeter. This is because small arch perimeter is associated with smaller oral cavity which requires less movement of tongue to produce /s/.

2. Methods

2.1. Subject and Speech Material (Adopted from Stone et al 2013)

Subjects

In total, 35 subjects were selected based on the quality of the MRI. Twenty were control subjects (9 male, 11 female; mean age 35.7) and the other 15 were patients (10 male, 5 female; mean age 47.7). Subjects were selected based on normal hearing acuity, word recognition tests, and speech reception threshold. All subjects were native speakers of English from mostly the Maryland-Pennsylvania region of the US. All subjects were required to have first molars present as well as all anterior teeth. Patients had undergone a partial glossectomy procedure at the University of Maryland Hospital or Johns Hopkins Hospital for treatment of squamous cell carcinoma at least 8 months prior to the study. Partial glossectomy was defined in this study, as preserving at least one side of the tongue lengthwise and also the tongue tip. All tumors resected were small or moderate sized tumors defined as T1N0M0 <2cm in largest dimensions and T2N0M0 2-4cm in largest dimension respectively. N0 means no active lymph nodes; M0 means no metastasis. One T2 patients had undergone a radial forearm free flap closure procedure (RFFF). The other 14 patients had primary closures, that is, the resection was sutured closed.

Orthodontically treated subjects with upper and/or lower premolar extraction

Five subjects had orthodontic treatment done prior to this study involving treatment with at least upper bicuspids and/or upper and lower bicuspid extractions with complete space closure. Three were control subjects and two were patients. These subjects were matched with non-orthodontically treated subjects to compare any differences in anteriority.

Intelligibility test and speech material

The Sentence Intelligibility Test (Tice Technology, Lincoln, NE) (Yorkston et al., 1996) was administered and scored by naïve listeners. Intelligibility testing scores indicated that patients were well understood, in the range from 94% to 100%. Controls were not accepted for the study unless their intelligibility was 100%.

The speech task “a souk” was studied for several reasons. (1) It takes less than 1 second to be repeated which is within the limits of the cine-MRI recording system. (2) The first MRI frame has a neutral tongue position, the vowel “uh” (called schwa), from which it moves into the /s/. (3) The word uses very little jaw motion, so tongue deformation is the main component of the /s/ motion.

Apical vs. Laminal /s/

Apical vs. laminal tongue categorization on all subjects were determined by visual inspection using a DICOM image viewer to ascertain if there was tip up (apical) or tip down (laminal) tongue movement at /s/ (See Figure 2).

2.2. Dental Cast Data Collection

Dental casts were needed in this study to measure arch perimeter, to obtain palate height, to help verify presence of upper teeth in the MRI images, and also to determine reference points for anteriority calculations.

Dental impressions of all subjects' upper and lower arch were made using alginate which was later poured in dental stone. All stone models were then digitized into 3D models using an optical scanner (3D Ortho Insight). Various anatomical points were identified as shown in figure 4. Points 16-4-5-6-7-17 were connected to form the arch perimeter. Arch perimeter was measured starting from the distobuccal tip of right M1 to the contralateral M1. All points were saved in x,y,z co-ordinates in MeshLab and later calculated in millimeters from Microsoft Excel (see Figure 4). Canine width was also measured from points 4-7.

The palate height was obtained from a previously study done by Payne et al. (2006). The palatal height from the cast was used to categorize subjects into high palate or low palate. Any palate height greater than 14mm was categorized as high palate and 14mm and below was categorized as low palate. Palatal height was measured from the lingual gingival margin of the maxillary first molars perpendicular to the occlusal plane. The median palatal height of 14mm was used to categorize subjects as high palate (>14mm depth) or low palate (≤14mm depth). The average height of 14mm was the mean palatal heights for men (14.9mm) and women (12.7mm) as measured by Shapiro, Redman, and Gorlin, (1963) and is also the average palate height for our data set.

Figure 4.

Picked points legend on digitized dental cast. Points 16-4-5-6-7-17 were connected to establish the arch perimeter for each upper casts. Points 4-7 was used to establish canine width. Height of palate was measured from point 11 from the midpoint of points 1-10. Palates height ≤14mm were categorized into low palate and those with >14mm was categorized as high palate. There were additional points that were recorded on the cast because this was part of a larger study. Only those that are highlighted were used in this research.

Legend: ML = mesio-lingual, DB = disto-buccal, MD = mesio-distal, ging = gingival, Inc = incisal, PalDepth = palatal depth, U = upper, R = right, L = left, 1 = central incisal, 3 = canine, 5 = 2nd premolar, 6 = =1st molar

Point #	Landmark
1	Mid MD ging UR6
2	Mid MD ging UR5
3	Mid MD ging UR3
4	Cusp tip UR3
5	Mid MD Inc Edge UR1
6	Mid MD Inc Edge UL1
7	Cusp tip UL3
8	Mid MD ging UL3
9	Mid MD ging UL5
10	Mid MD ging UL6
11	PalDepth at U6's
12	Inc Foramen
13	Gingival Papilla between U1's
14	ML Cusp Tip UR6
15	ML Cusp Tip UL6
16	DB Cusp Tip UR6
17	DB Cusp Tip UL6

2.3. MRI Data Collection and Reduction

Pre-MRI Training

Pre-MRI training was given to each subject to improve precision of phoneme repetition. Subjects were trained for about 15 minutes to repeat the speech task to a metronome set containing 4 beats. The beats occurred at 0, 300, 700, 1400 ms with a 2 second repeat cycle. The subject produced the two syllables on the first two beats, followed on an inhalation and exhalation on the last two beats. The MRI data collection lasted 1 second, capturing the word and the inhalation. The experimenter stopped the training when the subject's repetitions indicated accurate timing had occurred for several minutes. This method was adopted from Masaki and colleagues (Masaki et al., 1999). Each MRI movie is constructed from a summation of 5 repetitions, so the speaker's ability to repeat the phoneme synchronously and precisely with the metronome during the scan was critical to image quality.

An acoustic recording of the speech task was also done in the MRI using a noise-cancellation fiber optic microphone (OptoAcoustics Ltd, Israel). Another recording was made in the VTV lab, in supine position in a dental to mimic the MRI environment. The MRI audio recordings were used to synchronize phonemes to the frames of interest. The VTV lab recordings were used for acoustic and perceptual analyses.

High Resolution and Cine-MRI

As mentioned above, the scanning protocol used in this MRI data collection required 5 repetitions of the task per slice which were summed by the MRI machine to create a single movie (called: cine-MRI) at each slice. The high number of repetitions was to ensure good image quality (spatial resolution). The MRI machine was a 3.0 T Siemens Tim Trio with a 12 channels head coil and a 4 channel neck coil. The recording parameters were: 26 time-frames per second; in-plane resolution of 1.875 mm; slice thickness of 6 mm.

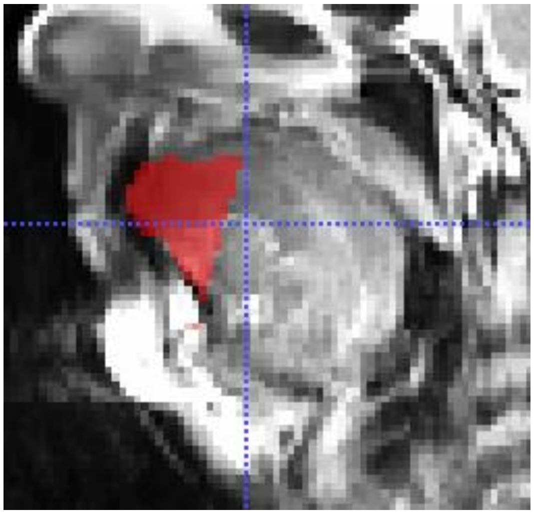
High resolution MRI was also recorded with an in-plane resolution of 0.9mm and slice thickness of 3mm. Two high resolution slices fit within one cine slice, so they were spatially aligned. The high resolution MRI was crucial as it provided information on dental roots for use in determining the planes of the oral cavity along which to cut the tongue during speech for the determination of amount of anteriority. That is, the amount of the tongue that was anterior to the maxillary landmark of interest. To do this, high resolution MR images were collected in 20-30 3 mm thick slices in each of 3 directions (sagittal, coronal, and axial) and combined into a single super-resolution 3D volume (Woo et al. 2014). The super-resolution volume consisted of 1 mm thick slices with an in-plane resolution of 0.9mm. This 'supervolume' was used to identify maxillary anatomical landmarks. In particular, maxillary 1st molars (M1s), maxillary 2nd premolars (PM2s), and height of palate, which were used as reference points in determining tongue anteriority. Reference points were selected at the mid mesio-distal distance of tooth on the lingual gingival margins of M1s and PM2s by moving through slices to determine areas of molar root furcations. The lingual gingival margins were usually located 1-2 slices away from the furcations of the M1s. Reference points on PM2s were selected in the same plane as the M1s mid-mesio distal distance from the tooth. Height of the palate was selected perpendicular to the plane of occlusion at M1s.

Supervolumes were also created for each of the 26 time-frames of the speech task "a souk" on cine-MRI, but with a lower resolution than the high resolution, that is a 2mm slices and an in-plane resolution of 1.7. Since the high resolution volumes had better spatial resolution, they were used to extract the roots needed to determine the planes for anteriority. The supervolume of the high resolution maxilla was overlaid onto the cine supervolume using rigid registration of the head and hard structures. Thus the high-resolution roots and the cine tongue could be measured and compared to each other.

2.4. Data Analysis: Tongue Segmentation and Volume Calculation

In order to determine tongue volume, the tongue had to be segmented from within the supervolume and all pixels within it labeled. This had to be done for the tongue volume at each time-frame of interest. All 26 timeframes of cine-MRI for each subject were segmented using custom software (Lee et al., 2014). Using DICOM image viewer, timeframes were visually determined for /uh/ and /s/ during “a souk”. Each respective timeframe was then uploaded into a 3D rendering program (ITK –SNAP, Yushkevich et al., 2006) which calculated tongue volume by adding all the pixels labeled as tongue during the segmentation (See Figure 5).

Figure 5. High-resolution MRI image with a superimposed anterior tongue segment from a cine-MR image (red). The cine-tongue is not identical to the high-resolution tongue, and shows anteriority at M1 during /s/.

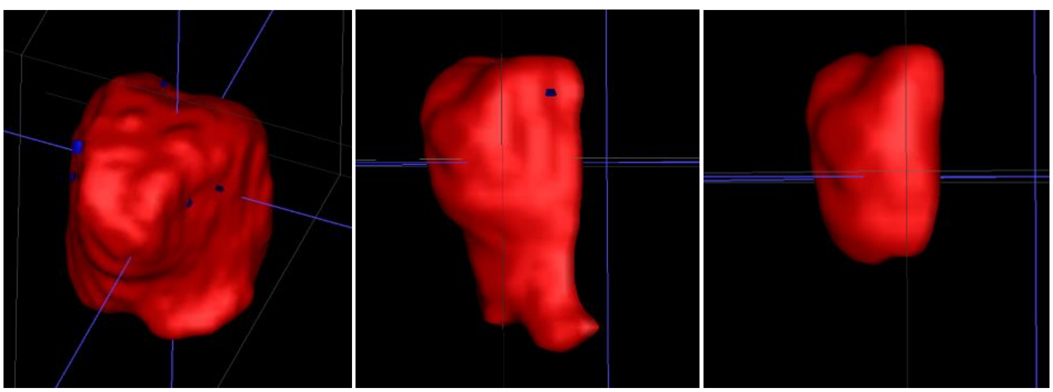


The whole tongue volume was determined first. Then three reference points were selected to determine the anteriority plane, that is, the plane to determine the portion of the tongue considered to be anterior. These three points were the gingival margin of the right and left M1s, and the height of the palate at this M1 location and perpendicular to the occlusal plane. The portion of tongue anterior to this reference plane was isolated and its volume was calculated using ITK-SNAP. This protocol was repeated using a parallel plane drawn at the PM2 as the dental reference point (See Figure 6). Then the anterior tongue volume change from /uh/ to /s/ was converted as a percentage change respective to the whole tongue. A percent change was used rather than the absolute value of the anteriority during the /s/ to normalize for difference in tongue sizes.

Anteriority in three variables was tested in both the control and the patient groups: high and low palate, apical and laminal /s/, lastly, arch perimeter and canine width.

Figure 6. 3D segmentation of tongue (in red) during /s/. Blue dots indicate tooth positions and palate height.

Whole Tongue Anterior segment at M1 Anterior segment at PM2



3. Results

This study considered four independent variables, glossectomy surgery, palate height, /s/-type, and arch perimeter/canine width on the position of the tongue in the oral cavity. The distribution of subjects in these groups was so skewed, that the 35 subjects used was not enough to allow ANOVA, which would allow interaction effects. Table 1 shows that the largest sub-group had 9 subjects and the smallest had 1. In addition, a small group of 5 subjects had previously had extraction of upper and/or lower premolar teeth. Thus there are two phenomena that could not be captured statistically. The statistical analyses had to be performed on each variable separately in order to have large enough groups; they did not include any interaction effects. Tables 2 and 5 show those results. All results are presented, however, and the non-significant results are considered in more detail in the Discussion.

3.1. The effects of glossectomy, palate height, and /s/-type on tongue anteriority.

Table 1 summarizes the data collected on all subjects. All subjects were categorized by palate height, subject type, and /s/ type. The data also shows anteriority from M1 and PM2 as both references points were used to measure anteriority in this study. However, statistics were only done from M1 as PM2 showed much redundancy to M1 with less accentuation. Results indicate that controls with low palate had favored apical /s/ type while high palate control favored laminal /s/. In patients, subjects with low palate favored laminal /s/. However there were not enough subjects in patients with high palate to determine if laminal /s/ was more favored than the apical /s/. Due to limited sample size, no interaction affect was analyzed. Also, each independent variables were compared separately in order have enough samples for comparison. This independent comparison is shown in table 2. Table 2 summarizes the paired t-test results comparing palate height, subject type and /s/ type. As mentioned above, no interaction affects were analyzed in order to increase sample size on each variables examined.

Table 1: Percent change in Anteriority from /uh/ to /s/ at M1 and PM2 for all subgroups.

Palate type	**Low Palate**				**High Palate**			
Subject type	Controls		Patients		Controls		Patients	
/s/ type	Apical	Laminal	Apical	Laminal	Apical	Laminal	Apical	Laminal
Anteriority from M1 (% change)	2.0	8.4	2.1	3.4	4.1	2.5	4.4	8.0
Anteriority From PM2 (% change)	1.0	3.6	1.1	2.3	2.5	2.3	2.9	4.6
N	7	1	2	8	3	9	2	3

Table 2: Percent change (%) in Anteriority from /uh/ to /s/ at M1 during a souk.

Independent Variables	N	Anteriority – Mean	Anteriority – SD	95 Confidence Interval	P value
1. Low palate	18	3.3	2.7	-2.8 to 1.4	0.5
2. High palate	17	4.0	3.3		
3. Control	20	3.1	2.5	-3.4 to 1.0	0.3
4. Patient	15	4.3	3.5		
5. Apical /s/	14	3.2	2.0	-2.6 to 1.2	0.5
6. Laminal /s/	21	3.9	3.5		

The first hypothesis proposed in this study, high palate subjects will use greater anteriority than low palate subjects, was not supported statistically. Rows 1 and 2 of Table 2 show a very slightly greater (0.7 %) anteriority for subjects with a high palate.

Mean anteriority for low palate was 3.3% with SD of 2.7 while high palate was 4.0% with SD of 3.3. P-value was 0.5. Results indicate that there is no significant difference between anteriority in high vs. low palate. Confidence interval showed that there is still a chance, however, that the results may still be of value as interval ranged from -2.1 to 1.4 (see table 2). This result indicates that there is little change in anteriority regardless of palate height.

The second hypothesis in this study, patients will have greater anteriority than controls, was also found to not be statistically significant. Row 3 and 4 of Table 2 shows that patients were 1.2% more anterior on average than controls.

Mean anteriority for control was 3.1% with SD of 2.5 while patient was 4.3% with SD of 3.5. P-value was 0.3. Results indicate that there is no significant difference in anteriority between controls and patients. Confidence interval showed that there is still a chance, however, that the results may still be of value as interval ranged from -3.4 to 1.1. Results indicate that anteriority between control and patient is not significantly different. However, patients had a tendency for greater anteriority change than controls. Like H1, more samples will need to be tested in order to investigate further the anteriority change between controls and patients (see table 2).

The third hypothesis, laminal /s/ will have greater anteriority than apical /s/, was not significantly different. Row 5 and 6 of Table 2 shows that laminal /s/ had a very slightly greater anteriority (0.7%) than apical /s/.

Mean anteriority for apical /s/ was 3.2% with SD of 2.0 while laminal /s/ was 3.9% with SD of 3.5. P-value was 0.5. Results indicate that there is no significant difference between apical /s/ and laminal /s/. However, the trend showed that apical /s/ had lesser anteriority than laminal /s/. More samples will be needed to continue to investigate this trend (see table 2).

3.2. The effects of arch perimeter and canine width on tongue anteriority

The fourth hypothesis, smaller canine width and smaller arch perimeter (length) will result in lesser anteriority. Canine width was significantly related to anteriority, but arch perimeter was not (See Table 3 and 4).

Canine width's effect on anteriority was compared within controls and patients. Table 3 indicates that canine width is inversely related to anteriority significantly; for the control group, R= -0.6 and for patients, R= -0.5. Results also suggest that there is no noticeable difference in anteriority of patients and control due to canine width as shown in figure 7.

Table 3. Canine width vs. anteriority at M1

Canine width	**N**	**Correlation Coefficient**	**P-value**
Controls only	19	-0.6	0.02
Patients only	15	-0.5	0.04

Arch perimeter effect on anteriority was also compared between controls and patients at M1. Negative correlation of -0.3 between anteriority at M1 and arch perimeter was found on all subjects however the result was not significantly different. Negative correlation was also seen between anteriority and arch perimeter in controls and patients -0.3 and -0.1 respectively. However, there were no significant differences within the two groups (see table 4). Results indicate that there is no significant relationship between anteriority and arch perimeter in either controls or patients.

Table 4: Arch perimeter vs. anteriority at M1

Arch perimeter	N	Correlation Coefficient	P-value
All subjects	34	-0.3	0.1
Controls only	19	-0.3	0.2
Patients only	15	-0.1	0.7

3.3. The effect of upper first premolar extraction on canine width, arch perimeter, and anteriority

Five subjects had previous orthodontic treatment of bicuspid extraction. Two controls and two patients had all four bicuspids extracted; one control had two upper bicuspids extracted. The extraction sites were orthodontically closed. The figure 7 and 8 shows the subjects with extractions as squares. The mean arch perimeter on all subjects was 91 mm. As expected, due to missing teeth, these subjects had lower arch perimeter than the majority of the subjects (see figure 8) however canine width was not affected (see figure 7). These subjects also had lower anteriority than most subjects (see table 5). Although this figure shows a trend for patients and controls with previous history of bicuspid extraction to have decreased anteriority, the results cannot be confirmed with statistics as there are only 5 extraction subjects.

Table 5: <u>Anteriority comparison of all subjects treated with extraction vs. no treatment</u>

Ortho treatment vs. no ortho	N	Anteriority –Mean	Anteriority – SD
1. All ortho subjects	5	2.6	1.7
2. All non ortho treatment	30	3.8	3.2
3. Extraction tx control	3	2.9	2.0
4. No extraction control	17	3.2	2.7
5. Extraction tx patient	2	2.1	1.7
6. No extraction patient	13	4.6	3.7

Figure 7. Scatterplot of canine width vs. anteriority at M1 showing controls, patients, and all subject with previous history of orthodontics involving upper bicuspid extractions. Subjects with orthodontic treatment showed no apparent difference in anteriority behavior than those without treatment. Canine widths of orthodontically treated subjects were comparable to all subjects.

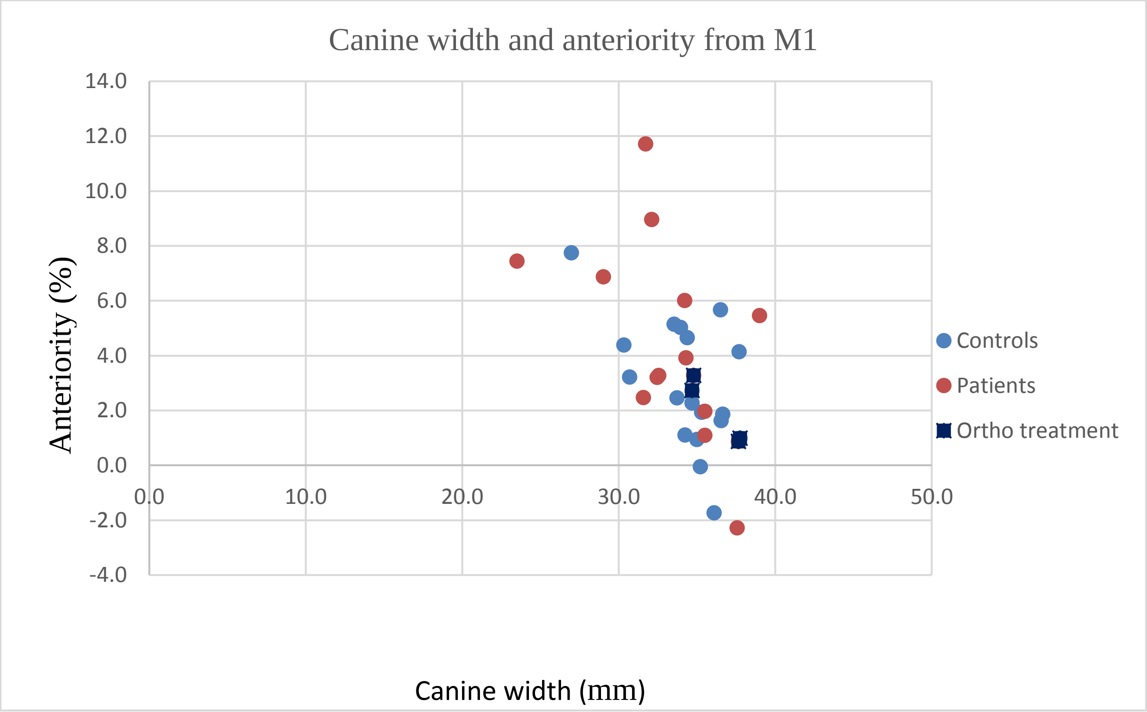
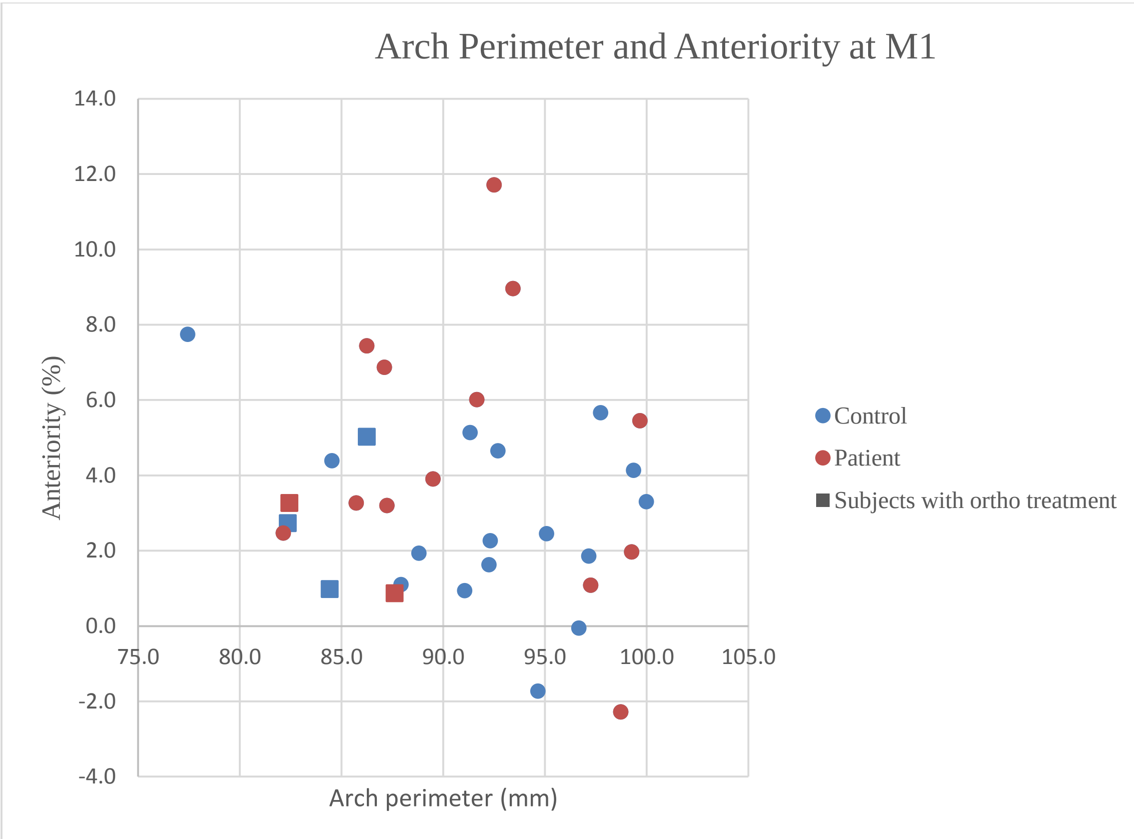


Figure 8. Scatterplot displaying arch perimeter vs. anteriority. Thiwws shows that there are no apparent relationship between arch perimeter and anteriority. However in subjects treated with orthodontics involving removal of premolars, there was a tendency towards lower arch perimeter as well as lower anteriority.

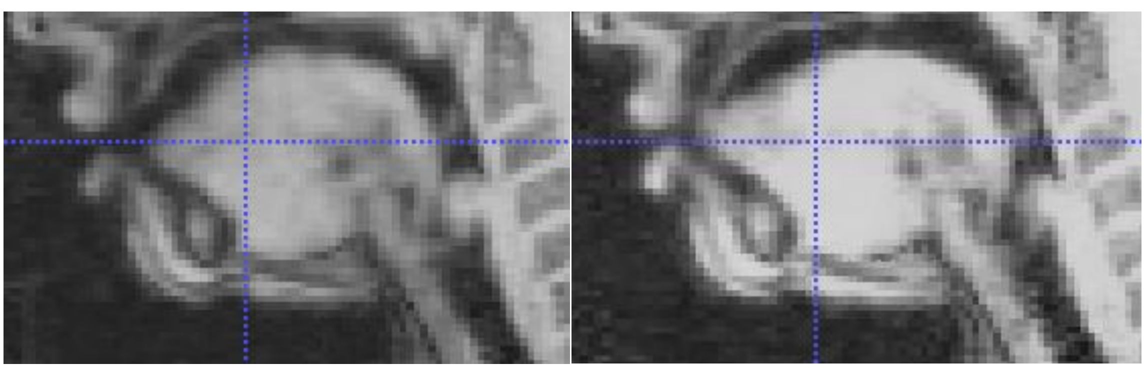


Extraction site closure did not significantly alter anteriority of tongue during speech. Mean value of 2.1% in patients with orthodontic treatment was noted with SD of 1.7 while patients without orthodontic treatment had 4.6% with SD of 3.7 (Table 5).

3.4. Negative Anteriority

Three subjects showed a negative anteriority change from /uh/ to /s/ at reference point M1. The tongue will typically take a more protruded position from /uh/ to /s/ thus resulting in a positive anteriority change. A negative anteriority change indicates that there was a decrease in anterior tongue volume from /uh/ to /s/. This implies that the anterior portion of the tongue from reference points M1 actually moved posteriorly. Upon closer examination of these particular subjects, the tongue did not move in an anterior direction as it did on most subjects. Instead, minimal movements or unusual movements were noted. For instance, in control subject 4 (see Figure 9), the tongue tip elevated into an apical /s/ but the tongue blade lowered. These two movements created virtually no anteriority change.

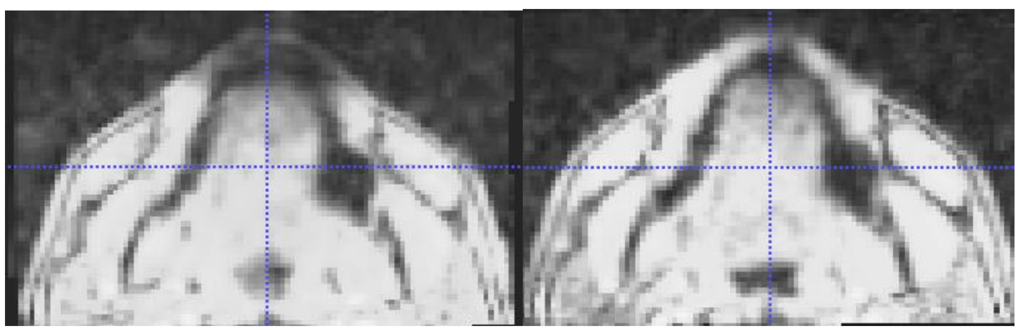
Figure 9. Cine-MRI sagittal view of subject 4 at /uh/ and /s/. Tip of the tongue simply elevates into an apical /s/ and tongue blade lowered creating little change in anteriority



In subject 26 with glossectomy, (see Figure 10), the horizontal blue line shows that the tongue has also moved upwards from /uh/ to /s/ creating virtually no change in the volume.

Figure 10. Cine-MRI axial view of subject 26 showing upward motion of tongue body rather than forward displacement of tongue from /uh/ to /s/.

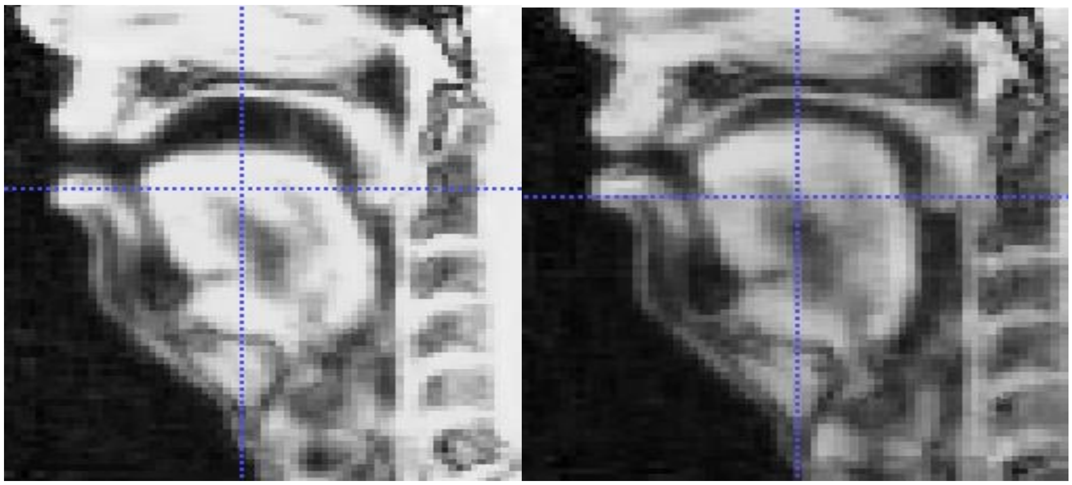
Subject 26 at /uh/ Subject 26 at /s/



In a third case, a control, high palate, laminal /s/ subject 18 with negative anteriority also showed vertical instead of anterior tongue displacement into /s/. The horizontal blue line shows that the tongue rises from /uh/ to /s/. The subject brings the tongue closer to the palate, while reducing its anteriority relative to the reference M1 (compare using vertical blue line).

Figure 11. Cine-MRI sagittal view of subject 18 showing upward motion of tongue body rather than forward displacement of tongue from /uh/ to /s/.

Subject 18 at /uh/ Subject 18 at /s/



3.5. Intelligibility Score and Arch perimeter on patients with T2 tumor

Patients with small tumors (T1) all scored 99-100% intelligible on the Sentence Intelligibility Test. Patients with moderate sized tumors (T2) scored at 94-100% (see Table 6)

Table 6. Intelligibility and Arch perimeter for patients with T1 and T2 tumors.

Subject	Tumor size/ closure	Arch perimeter	Intelligibility
Patient 1	1 primary	82.140	100
Patient 2	1 primary	85.725	100
Patient 3	1 primary	86.244	100
Patient 4	1 primary	87.228	99
Patient 5	1 primary	92.496	100
Patient 6	1 primary	99.251	100
Average		88.598	
Patient 7	2 primary	82.438	100
Patient 8	2 primary	87.617	98
Patient 9	2 primary	89.488	100
Patient 10	2 primary	91.650	94
Patient 11	2 RFFF	93.425	99
Patient 12	2 primary	99.668	95
Average		90.714	

1 =T1 tumor, 2 = T2 tumor. Primary = primary closure, RFFF = radial forearm free flap

Average arch perimeter of patients with T2 tumor was 90.7 mm. T2 patients with less than average arch perimeter appear to have higher intelligibility test scores than those with higher than average arch perimeter. Patient 11 was an exception. This patient had a radial forearm free flap closure procedure, which created a large tongue relative to the arch perimeter. Patients 7 and 8 had upper bicuspid extraction done with orthodontic closure of spaces effectively decreasing arch perimeter. T1 sized tumor resection did not appear to have a large effect on intelligibility irrespective of arch perimeter.

4. Discussion

4.1. Effects of Palate height on /s/ type and tongue anteriority

A previous study [Stone et al (2013)] looked at high versus low palate height and its relationship to /s/ type during “a souk”. The majority of the control subjects with high palate height favored laminal /s/ (N=9 of 12) while those with low palate height favored apical /s/ (N=7 of 8). The study also found that the majority of the glossectomy patients favored laminal /s/ (N=11 of 15) irrespective of palate height (Total N=35 or N=17 high, 18 low). This observation motivated the present study to measure anteriority between /uh/ and /s/ to better understand the differences between apical and laminal /s/. Table 1 shows these trends mentioned above. However, no statistical analysis could be done due to small sample size. Instead, all subjects were grouped into high and low palate as shown in table 2. Result showed that there were no significant differences in anteriority due to palate height. Insignificant difference can be attributed to several factors. Subjects with high palate may be elevating the body of the tongue to produce /s/ (i.e. figure 11) thus negligible or in some cases resulting in negative anteriority. Thus high palate height does not produce significantly greater anteriority change because the need for greater protrusive movement of tongue to produce /s/. Instead, palate height may be more closely related to the vertical movement of tongue from /uh/ to /s/ rather than anterior movement thus creating minimal differences in anteriority when comparing high vs. low palate.

4.2. Glossectomy Patients vs. Controls

Anteriority differences between control and patients were measured. All patients and controls were grouped together irrespective of palate height and /s/ types in order to increase sample size in each group. As mentioned above, in glossectomy patients, palate height did not influence /s/ type. The majority of patients, irrespective of palate height, displayed laminal /s/ (11 laminal out of 15 patients – Table 1). In controls there were 10 laminal /s/ type and 10 apical /s/ type. This is most likely due to the fact that the resected tongue has reduced volume compared to the pre-surgical tongue which required greater bodily movement. Greater bodily movement resulted in slightly greater anteriority change. However, paired t-test showed no significant difference in anteriority between patients and controls as seen in table 2. Thus this minimal differences in anteriority between subjects may be attributed the /s/ type. As patients had greater percentage of subject displaying laminal /s/, this resulted in slightly greater anteriority than controls who had equal number of laminal and apical /s/.

4.3. Effect of /s/ types, apical vs. laminal, on anteriority

As mentioned above, many patients, laminal /s/ was observed rather than an apical /s/. During surgery, the tongue tip was preserved for all patients, though its motor control was reduced due to removal of some controlling nerve fibers and only the region behind the tip is removed. Because the resected region is small, the affected tongue may not require drastic adaptation to produce sounds. However, as most patients have resected nerve fibers innervating the tongue, this loss of motor control contributes to the bodily movement of tongue during protrusion rather than controlled movement of the tip of the tongue during speech as seen in most control subjects.

In contrast, controls with high palate favored laminal /s/ while those with low palate favored apical /s/. We considered whether anteriority was linked to /s/-type in H3, but not for the two subject groups separately. When combined there was no difference in anteriority between apical and laminal /s/ (see Table 2). When comparing subject groups, controls had lower anteriority than patients. Also, when comparing the anteriority of laminal /s/ of controls vs. patients, patients' anteriority was greater. This was also the case when comparing apical /s/ in control vs. patients. From this, one must consider how the anteriority of a resected tongue would be greater than those that have not been resected. In order to compensate for the differences in tongue size, a ratio of anteriority to whole tongue was calculated so that % change of anteriority was compared. This means that greater anteriority represent greater proportion of anterior tongue movement. Thus majority of patients had greater proportion of anterior tongue movement than control. This observation indicates couple factors. Firstly, larger movement means that patients are forcibly moving tongue in anterior direction to produce /s/. Secondly, as the tongue deviates to the affected side, more posterior tongue is pulled anteriorly thus contributing to the increased in anteriority. A third possibility is that the tongue is simply getting fatter and wider during protrusion. Table 1 shows a difference in the effect of palate height on /s/ type in controls and patients. The control subjects with a low palate tended to produce mostly apical /s/ (7/8 subjects); controls with a high palate rarely produced apical /s/ (3/12). Patients with a high palate followed the same trend as controls and produced fewer apical /s/ (2/5). However, patients with a low palate did not produce the same pattern as controls. They produced very few apical /s/ (2/10). This suggested that the reduced tongue size and reduced motor control, combined with the low palate, inhibited the tongue tip elevation needed for apical /s/, and allowed instead the additional anteriority used in laminal /s/.

Although the majority of patients display laminal /s/, there were a few patients with apical /s/ in both the high and low palate categories (Table 1). If a patient had a low palate, there is a chance that they may have maintained their apical /s/ tongue motion rather than having to adapt the tongue in a more laminal /s/ to adapt to the resected tongue. Patients with high palate and apical /s/ may have greater vertical displacement of tongue maintaining apical /s/ shape as they go from /uh/ to /s/. Although results were not significantly different, it provides one explanation as to how those few patients with apical /s/ type may behave during phoneme.

4.4. The effect of arch perimeter and canine width on anteriority

Finally, arch perimeter and canine width was measured on all subjects in order to see the effects of large or small dental arch on tongue anteriority during /s/. Larger upper arch perimeter was hypothesized to produce greater anteriority during /s/, because a larger arch perimeter means more tongue would be required to move forward into /s/ position against the alveolar ridge. This parameter however, did not correlate to anteriority as predicted.

Canine width played an important role in influencing anteriority. This was the only independent variable to significantly relate to tongue anteriority during /s/. A smaller canine width required significantly greater anteriority in both controls and patients than a larger width. This difference may be due to the need for the tongue to protrude further in a narrower anterior region of the oral cavity in order to produce /s/. The fact that arch perimeter is less important than canine width on anteriority is consistent with our understanding of the criticality of the location of the tongue tip, rather than the tongue body, in producing /s/.

4.5. Non-anterior motion into /s/

Negative anteriority was reported in three subjects all showing non anterior tongue motion from /uh/ to /s/ in "a souk". These subjects showed alternative strategies to produce /s/ rather than the predicted anterior displacement of the tongue tip. One subject elevated the tip and lowered the blade creating no change in anteriority. Another started in anterior tongue during /uh/ and simply elevated the tip into /s/ without increasing anteriority. The third elevated the entire tongue including the tip to create the /s/ without increasing anteriority. It was observed that these subjects had a slightly retrognathic mandible; whether this has an effect on anteriority is a topic for future research.

4.6. Effects of Premolar Extraction on tongue anteriority

Amongst non-orthodontically treated subjects, there appeared to be a negative correlation between arch perimeter and anteriority. One explanation is that larger the arch perimeter, the greater the tongue volume. This means that the larger tongue will occupy greater space in a larger arch. As larger tongue has more muscle volumes and more likely that resection from glossectomy is less affected due to the greater number of muscle fibers remaining in larger tongue. Therefore lesser anterior movement is needed to produce /s/.

A direct relationship was observed between arch parameter and anteriority in subjects who had orthodontic treatment that involved extraction of at least 2 upper bicuspids or all four 1st bicuspids. This was true in both patients and controls. Although not significantly different, artificially decreased arch perimeter may play a role in decreasing anterior tongue movement during /s/. Most likely explanation is that because there is decreased tongue space within the oral cavity, there is less need for the tongue to traverse to produce /s/. There is also the possibility that the upper anterior teeth retracted during orthodontic movement decrease the need for the tip of tongue to travel less anteriorly to produce /s/. Although pre-orthodontic treatment models and MRI measurements could not be obtained on these subjects, the relationship between decreased anteriority and orthodontic space closure involving bicuspid extraction seem to be a common finding.

4.7. A Unique Subject

Another observation made on one subject was that with malocclusion. For instance, control subject 9, had a high palate and apical /s/ tongue movement. The majority of high palate controls had laminal /s/ (9/12), this particular subject did not. Upon examining the subject cast, their malocclusion seem to be the culprit in causing this outlier. Patient had an extremely deep bite with significant overjet. Lingually, the lower incisals were in contact with the anterior palate at the level of the incisal papilla. This indicates that the subject’s vertical dimension of occlusion is decreased along with the subjects available tongue space. Although this subject's palate was categorized as high, this experiment did not take into consideration the role the lower dentition may have on /s/ type. Thus when measuring the upper cast alone, the subject appeared to have plenty of tongue space because of the high palate. However, the significant amount of lower dentition decreased the available tongue space due to the subject's overbite. Thus, in this instance, the limiting factor for the tongue movement may have been more influenced by the lower arch than the upper arch. This would mean that as a patient bites more deeply into the palate, the tongue rests closer to the palate, and even with a high palate, the tongue may behave more like one with a low palate, in this case producing an apical /s/ movement.

4.8. Speech Intelligibility in Glossectomy Patients

Many results were not significantly different and the glossectomy tongue often behaved similarly to controls irrespective of /s/ types and palate height. Intelligibility was also very good in this group of patients who were all at least 94% intelligible, which shows the patient's adaptability to their new morphology. However, it was found that patients with less than average arch perimeter had better intelligibility test scores than those with a greater arch perimeter. This was true for the moderate sized T2 tumor patients, because the T1 patients were all 99-100% intelligible (see Table 6). Patient 11 had a different closure procedure, a radial forearm free flap was used to replace the resected tissue. The RFFF created a larger tongue and could have compensated for the resected volume of the tongue thus improving the intelligibility score even though the arch perimeter for this patient was larger than average. Thus a smaller arch perimeter may increase intelligibility for patients by giving the diminished tongue less space to maneuver in. Further investigation with more patients will be needed to determine if arch perimeter significantly affects the intelligibility of glossectomy speakers. From this study however, canine width had a significant effect on anteriority of the tongue, but arch perimeter has patient intelligibility.

Also, to note was the intelligibility testing on two patients who had previous orthodontic treatment involving four bicuspid extractions showed little differences in acoustics ranging from 98-100%. This meant that orthodontic treatment does not affect acoustics in glossectomy patients. However it is interesting to note that these two subjects had T2 tumors. When comparing the intelligibility test of other patients with T2 tumors, orthodontically treated patient appear to have higher intelligibility test than those without as well as lower than average arch perimeter due to upper bicuspid extractions.

4.9. Limitations of study

One limitation of this study was the small sample. There were not enough subjects to produce a robust statistical analysis and mostly trends had to be reported. In addition, the anteriority calculation was based on position of teeth in the de-formed high resolution MRI, the accuracy of the reference point is dependent on experimenter's experience and ability to identify and extract the molar roots. As only one experimenter was involved in selecting teeth position, consistency was observed during anteriority calculation which minimized error.

Another limitation was the categorization of /s/ types. The experimenter determining apical /s/ vs. laminal /s/ in DICOM image viewer may have misinterpreted the /s/ types in subjects as cine-images were not always clear. Thus categorization of /s/ type remains to be improved upon.

5. Conclusion

H1 was not supported and there was no significant difference between anteriority in high vs. low palate. However, high palate had a slightly higher anteriority than low palate. Minimal difference on anteriority may be attributed to the vertical movement of tongue from /uh/ to /s/ that creates minimal changes on anteriority.

H2 was not supported in this study. There was no significant difference between controls and patients on anteriority. But patients had a slightly higher anteriority than controls. This may be attributed to the higher number of patients favoring laminal /s/ than apical /s/.

H3 was also not supported in this study. No significant difference was found in anteriority between apical /s/ and laminal /s/. The two different /s/ types had minimal differences although laminal /s/ had slightly greater anteriority than apical /s/. Laminal /s/ may have slightly greater anteriority due to their bodily displacement rather than controlled tongue tip movement seen in apical /s/.

H4 arch perimeter did not significantly affect anteriority although a slightly negative correlation was seen which indicate that larger arch perimeter is associated with decreased anteriority. However canine width showed significant difference in anteriority change. Smaller canine width created significantly greater anteriority change which indicate that narrowing of the anterior region of oral cavity creates greater protrusive movement of the tongue. The fact that arch perimeter is less important than canine width on anteriority is consistent with our understanding of the criticality of the location of the tongue tip, rather than the tongue body, in producing /s/.

Subjects with orthodontically extracted teeth with space closure in general displayed decreased arch perimeter. Decreased arch perimeter in these subjects also displayed a decreased anteriority than those with larger arch perimeter. Canine width did not seem to be affected in patients with orthodontic treatment.

Intelligibility testing on patients with small TN1 had good scores regardless of arch perimeter however in patients with TN2, smaller than average arch perimeter seem to result in higher intelligibility than those with higher than average arch perimeter. TN2 patients with orthodontic extraction of upper bicuspids which resulted in lesser than average arch perimeter also had higher intelligibility scores than those without orthodontic treatment who had higher than average arch perimeter.

In summary, palate height, /s/ type, subject type, and arch perimeter did not result in significant difference in anteriority but canine width did. This shows that glossectomy tongue are able to adapt to the decreased tongue volume and compensate by having similar anteriority change as controls thus resulting in non-significant results between the two groups. This study also found that arch perimeter may be linked to intelligibility testing of patients which is a topic of future research.

6. References

Jemal, A., Siegel, R., Xu, J., Ward, E.,(2010) Cancer Statistics, 2010. CA: A Cancer Journal for Clinicians 60(5): 277-300.

Johnson N, Sandy J (1999). Tooth position and speech—is there a relationship? Angle Orthod 69:306-310.

KM Yorkston, DR Beukelman, R Tice (1996) - Sentence Intelligibility Test, Lincoln, NE: Tice Technology Services.

Lee, J., Woo, J., Xing, F., Murano, EZ, Stone, M, Prince, JL. (2014) Semi-automatic segmentation for 3D motion analysis of the tongue with dynamic MRI. Computerized Medical Imaging and Graphics.

Masaki, S., Tiede, M., Honda, K., Shimada, T., Fujimoto, I., Nakamura, Y., & Ninomiya, N. (1999). MRI-based speech production study using a synchronized sampling method. Journal of the Acoustical Society of Japan, 20, 375-379.

Nael F. Osman, William S. Kerwin, Elliot R. McVeigh, Jerry L. Prince Cardiac Motion Tracking Using CINE Harmonic Phase (HARP) Magnetic Resonance Imaging.. Magn Reson Med. Dec 1999; 42(6): 1048–1060.

National Cancer Institute: http://www.cancer.gov/cancertopics/factsheet/detection/staging, January 6, 2015

Shapiro, B.L., Redman, R.S., & Gorlin, R.J. (1963). Measurement of normal and reportedly malformed palatal vaults. I. Normal adult measurements. Journal of Dental Research, 42(4), 1039-1042.

Stone, M., Rizk, S., Woo J., Murano, EZ., Chen, H., Prince, J. (2013). Journal of Med Speech-Lang Path. 20(4): 106-111.

Yushkevich, PA., Piven, J., Hazlett, HC., Smith, RG., Ho, S., Gee, JC., Gerig, G.(2006) User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability. *Neuroimage* Jul 1;31(3):1116-28.