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Abstract

The Effect of Maxillary Features and Occlusal Parameters on “sh” Production in Control and Glossectomy Subjects

Andrew David Pedersen, Master of Science, 2017

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This study examines the process by which the tongue articulates speech in glossectomy and control subjects using high resolution structural, and cine-MRI. Maxillary features and occlusal parameters are assessed in both groups to see if any effect on the amount of tongue volume displaced when contacting the anterior palate is noted. This volume amount is termed anteriority and measured against multiple variables. The independent variables include palate height, intercanine width, arch perimeter, orthodontic bicuspid extraction, overbite and overjet. The speech task of each subject is the sound “sh” extracted from a repeated word task. Results of the study showed statistically significant ($p \leq 0.05$) differences in anteriority between glossectomy patients and controls, large versus small overbite, and an interaction between subject type and overbite. Data suggests having a larger overbite decreases the oral cavity size during “sh” sound and therefore increases tongue anteriority, especially in glossectomy subjects.

The Effect of Maxillary Features and Occlusal Parameters on "sh" Production in Control and Glossectomy Subjects

by
Andrew David Pedersen

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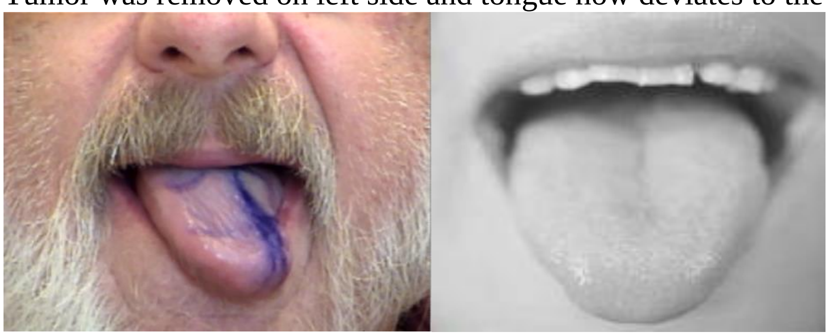
I. Introduction

I.I Tongue Cancer and Surgical Interventions

According to the CDC, the second leading cause of death is cancer (https://www.cdc.gov/nchs/fastats/leading-causes-of-death.htm). Of all cancers, oral and pharyngeal cancer combined becomes the sixth most common cancer in the world. When considering oral cancer alone, there is an estimated annual incidence of 275,000 (Warnakulasuriya, 2009). Currently reported by the American Cancer Society in 2016, there are 48,330 people in the United States that develop oral or oropharyngeal cancer each year and 9,570 will die from the cancer (Siakholak et al, 2016**).** One of the most common oral cancers is tongue cancer, which is typically located on the lateral wall of the tongue. Specifically, one of the most common oral carcinomas is oral squamous cell carcinoma (Markopolous, 2012). A common procedure for treating tongue cancers is partial or total glossectomy of the tongue. The tongue is a crucial organ to the human body allowing for taste, speech articulation, mastication, deglutition, airway protection, maintenance of oral hygiene, and enjoyment of food (Kazi, 2006). Therefore, extra care is needed when performing glossectomy surgery and repairing with primary closure or a flap procedure.

The surgery must not only excise the tumor tissue but an additional 1-1.5 cm margin of healthy tissue to ensure complete removal of the cancer. As a result, a change or distortion in speech is not unlikely and varies highly on the amount of tongue tissue that is removed (https://www.cancer.org/cancer/oral-cavity-and-oropharyngeal-cancer/treating/surgery.html). The patients in the present study had glossectomy surgery to remove oral cancers involving either the right or left lateral border of the tongue and were small-to-moderate in size (Figure 1). Using the TNM system from the National Cancer Institute, T1N0M0 and T2N0M0 tumors were excised and repaired with primary closures. One patient received a radial forearm free flap due to the larger size of the tumor. In the tongue, a T1 tumor is <2 cm in its largest dimension and T2 is 2-4 cm in its largest dimension. The other two categories represent whether lymph nodes (N), or metastasis (M) are involved. In this study, all patients were N0 and M0, meaning there was no lymph node involvement or spread of the cancer https://www.cancer.org/treatment/understanding-your-diagnosis/staging.html).

Figure 1. Photos of patient tongue after glossectomy surgery and healthy control tongue. Tumor was removed on left side and tongue now deviates to the left upon protrusion.

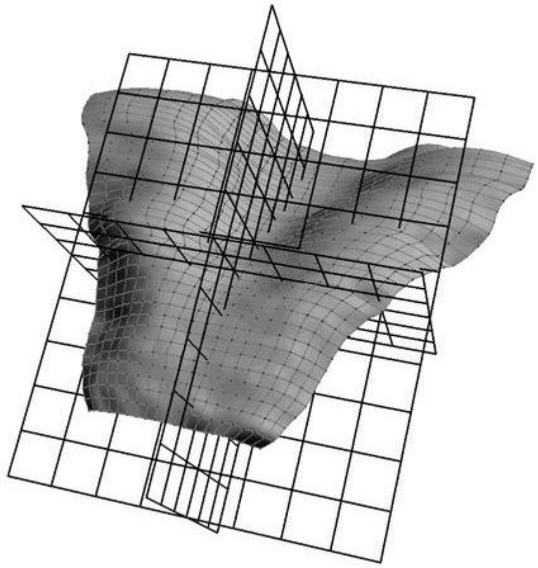


<u>I.II "Sh" and Anteriority</u>

Patients who have had a glossectomy procedure, learn to adapt to be able to articulate and pronounce speech normally again. Typically, most patients with a T1 or T2 size tongue tumor are able to speak after glossectomy surgery without a discernable audible difference than someone who did not have a glossectomy procedure. Reasons for this can be explained by altered motor control strategies (Fangxu et al, 2016). One speech sound that often sounds distorted after this surgery is "s". However, the "sh" is rarely affected. This is interesting since they are both are fricatives and produced in the same manner; the tongue approximates the palate, narrows the airway and creates friction. One question of interest in this study is whether the “sh” is unaffected because it uses a slightly more posterior part of the tongue to constrict the vocal tract and create the friction, or whether it is also altered, but the motion alterations are not audible because of the resonance differences in the vocal tract. We predict that alterations in “sh” shape occur, because the “sh” constriction requires a significant portion of the anterior part of the tongue, despite this modification not being audible. Figure 2 below shows the shape of the tongue when it is contacting the palate during “sh”.

In order to assess the differences between controls and the altered tongue morphology of patients during “sh” production, a measureable parameter needs to be standardized to all subjects. The measureable parameter used in this study is tongue anteriority. Anteriority is defined as the percentage difference of the tongue positioned in the anterior vocal tract “uh” to “sh” when viewed on cine-MRI.

Figure 2. Shape of the tongue when producing “sh” and contacting the anterior portion of the palate. The sides of the tongue contact the palate and teeth. The anterior portion is flat and the posterior grooved. Each square in the grid is 5 mm square.



I.III MRI and Software Analysis

Magnetic Resonance Imaging is a crucial device in the healthcare field used for a variety of purposes. MRI is defined as a “test that uses a magnetic pulse of radio wave energy to make pictures of organs and structures inside the body” (Healthwise, 2015). One of the great advantages of MRI is the ability to see information that other devices may not detect while not subjecting the human body to radiation exposure. The MRI machine is a composed of powerful magnets that force protons in the body to align to the magnetic field emitted. Signals from the excited hydrogen atoms of water molecules send a radio frequency that is detected by special sensors. The different types of body tissues with different hydrogen compositions have varying times for the protons to realign and thus release different amounts of energy when the radiofrequency field is shut off (NIH**)**. MRI is particularly useful for soft tissues of the body, where more hydrogen molecules can be found. Examples of soft tissues often analyzed with MRI include the brain, spinal cord and nerves, ligaments and tendons, fat and finally muscles (NIH).

In this study, one of the most unusual muscles of the body, the tongue, is studied using Magnetic resonance imaging. Cine-MRI, which is short for cinematic, is used to analyze the movement of the tongue during the given speech task. The cine-MRI collects short frames of data during a longer movement making a movie. Since the signal emitted by the hydrogen protons is weak, multiple repetitions of a motion are made and the frames are an ensemble summed across repetitions (Xing et al., 2016). With this type of MRI collection, we can track subtle differences from one subject to another when a specific sound is analyzed. As mentioned previously, the "sh" sound can be analyzed using this type of MRI when the tongue is producing the word "a shell."

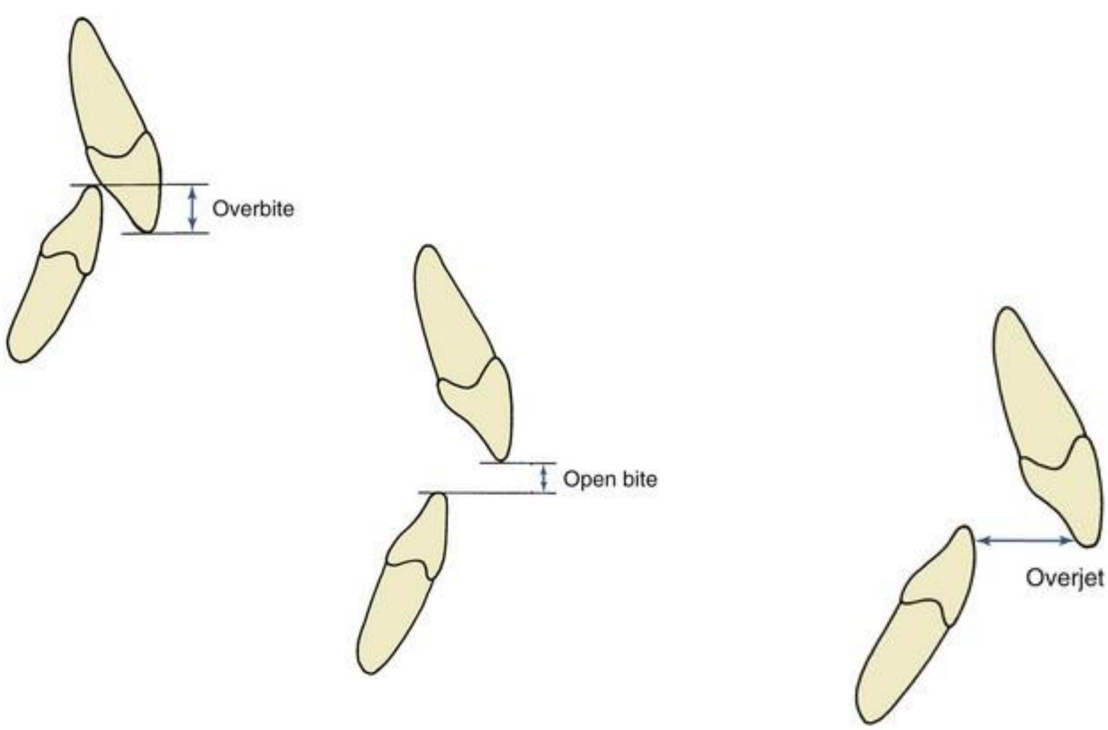
I.IV Variables assessed in the Maxilla and Mandible

In addition to glossectomy vs. control, another important variable is high palate vs. low palate patients. Having a higher palatal vault for the tongue to articulate with in the production of "sh" could possibly influence the subject's tongue behavior. Previous research and studies have been devoted to speech production in patients with clefting and abnormal depth of palate. In one specific study, speech was analyzed with a spectrograph between cleft palate speech and normal speech. The study showed that there was an increase in width and depth of the nasopharynx and pharyngeal cavity in cleft palate speech compared with normal speech. Width and depth were compared between twenty cleft patients and twenty normal speech patients on lateral cephalograms (Charan Sahoo, 2013). Repaired or unrepaired cleft palate aside, the relevance of this previous study is to show that changes in the oropharyngeal depth and palate depth can alter speech.

Intercanine width and arch perimeter are both variables of interest when analyzing speech production of “sh” because they are commonly altered during orthodontic treatment. They are also variables of interest since previous studies have shown a significant effect in the other fricative sound, “s”. Arch perimeter, also known as circumference, is crucial in orthodontic treatment planning decisions. When there is an arch length discrepancy or dental crowding, the arch perimeter can be changed by either extraction of bicuspids, proclination of the incisors, arch expansion, or other orthodontic therapies (Chung, 2015). In this study, variances in the arch perimeter are analyzed to see if there is an effect on speech production. Arch perimeter of the teeth confines the tongue to a set boundary demarcating the palate and could possibly affect the tongue’s “sh” production. Arch perimeter measured in millimeters is assessed. Also related to arch perimeter, are orthodontic bicuspid extraction patients and canine width measurements. Having orthodontic bicuspid extraction is usually indicated for either moderate to severe dental crowding or maxillary incisor protrusion where retraction is needed. In the latter, retraction of the maxillary incisors would decrease the arch perimeter and perhaps have a significant effect on speech. Maxillary canine width is a variable of interest since they lie just anterior to where the tongue articulates with the hard palate for “sh” production. In a recent study by Grimm et al, canine width was found to have a significant influence on tongue anteriority with the production of “s”. Specifically, tongue anteriority correlated negatively with canine width (Grimm, 2016).

Finally, two other related and very important variables studied are overjet and overbite. Speech production and incisal overlap relationships have been studied for many years. Average or normal overbite is considered to be 1-2 mm overlap when the lower incisal edges contact the lingual surface of the maxillary incisors (Proffit, 2013). For example, in a recent study found in the AJO-DO journal, Leavy et al. concluded open bites (no vertical overlap of the incisors) of 2 mm or greater are associated with sound production errors. Specifically, the errors involved "s" or /t/ production (Leavy, 2016). Overjet is defined as "the horizontal overlap of the incisors" and overbite is defined as "the vertical overlap of the incisors" (Proffit, 2013). Normal relationship of overjet is considered to be contact of upper and lower incisors with only their incisal edge width thickness measuring around 2-3 mm.

Figure 3. Overbite and overjet defined by Proffit et al.



In summary, the variables of this study include palate depth, arch width measured at the canines, arch perimeter, overjet, overbite, and tongue condition (glossectomy subject versus healthy control).

I.V. Hypotheses

H1: Glossectomy subjects will exhibit more anteriority than controls

Rationale: Patients that have had a portion of their tongue removed from glossectomy surgery often sound the same as those who have a normal healthy tongue. We hypothesize that this is due to an adaptation of the tongue during “sh” production, and that a larger volume will be moving more anterior in the palate. A larger portion of the tongue, not just the tip, will move more anteriorly because the tongue is more fixed and rigid due to scar tissue post-surgery. This anterior movement will thus have more tongue volume in spite of having part of the tongue removed.

H2: High palate height group will have greater anteriority than low palate height group

Rationale: The production of the phoneme “sh” arises when the tongue contacts the anterior portion of the palate. Therefore, a subject that has a high palatal vault will require more mass to be moved and possibly extended to contact the palate. More bodily movement of the tongue is required rather than just a small portion of the tongue. High palates in this study are considered to be >14mm when measured from the first molar lingual gingival margin perpendicular to the occlusal plane. The measurements will be further explained in the methods and materials section.

H3: A smaller arch perimeter and canine width will result in greater anteriority

Rationale: Subjects that have a small arch perimeter and small canine width will exhibit a greater anteriority. In a previous thesis defense by Hwang in 2015, anteriority was studied during the production of the phoneme “s”. Although a different sound than “sh”, the production of “s” is similar to “sh”. In the study, there was a negative correlation between anteriority and arch perimeter. Also, there was an inverse relationship between anteriority and canine width.

H4: Bicuspid extraction patients will have less anteriority than non-extraction controls

Rationale: When a patient has maxillary bicuspids extracted for orthodontic treatment, there is often a mesialization of the molars and a reciprocal distalization of the premolars and anterior teeth. This mesialization of the molars would then draw the anteriority measurement line more anterior relative to the base and origin of the tongue. Therefore, less anteriority volume of the tongue will be detected when producing “sh” even though the arch perimeter is decreasing.

H5: A greater overjet and overbite will result in less anteriority

Rationale: A larger overjet sometimes indicates a greater distance between the mandible and the maxilla in the anterior-posterior dimension. If the mandible is more retrusive than the average position, the patient has a larger overjet. A further distance for the tongue to move anterior due to the large overjet would allow for adaptation. Adaptation could potentially be less of an anterior movement of the tongue. Greater overbite often indicates a closer overlap of the anterior teeth and sometimes maxilla and mandible. With a greater overlap, the tongue has less distance to travel superiorly and anteriorly to produce the "sh" sound.

II. Methods and Materials

<u>II.I Subject Pool and Speech Materials</u>

The subjects consisted of 31 individuals with MRI data of the tongue during speech production. The sample size was 15 males and 16 females with the age range of 22 to 61. Control subjects totaled 17 individuals who did not have any history of tongue tumor needing glossectomy surgery. Patients consisted of individuals who underwent partial glossectomy surgery repaired primarily with primary closure and one underwent radial forearm flap closure. The surgical procedures were completed at Johns Hopkins Hospital or University of Maryland Medical System. For purposes of the study, partial glossectomy is defined as complete removal of the squamous cell carcinoma tumor while preserving one side and the tip of the tongue. Tumors for all patients were classified as T1N0M0 <2cm and T2N0M0 2-4 cm. N0 represents no active lymph nodes and M0 represents no signs of metastasis. All individuals were English speaking and resided in the greater Baltimore area and up to the state of Pennsylvania. Requirements of all subjects consisted of a normal hearing acuity, word recognition, speech reception threshold, and having all first molars and anterior teeth present (Stone et al, 2013).

Subjects with assumed orthodontic treatment

Five of the studied subjects were missing either two or four bicuspids, two from one dental arch or one from each of the 4 quadrants. Each of these individuals had no signs of chronic poor oral hygiene and other compromised teeth. Therefore, it can be assumed the four bicuspids in each individual were extracted as adjunctive therapy for orthodontic treatment. Of the five subjects, three were controls and two were patients.

Intelligibility test and speech material

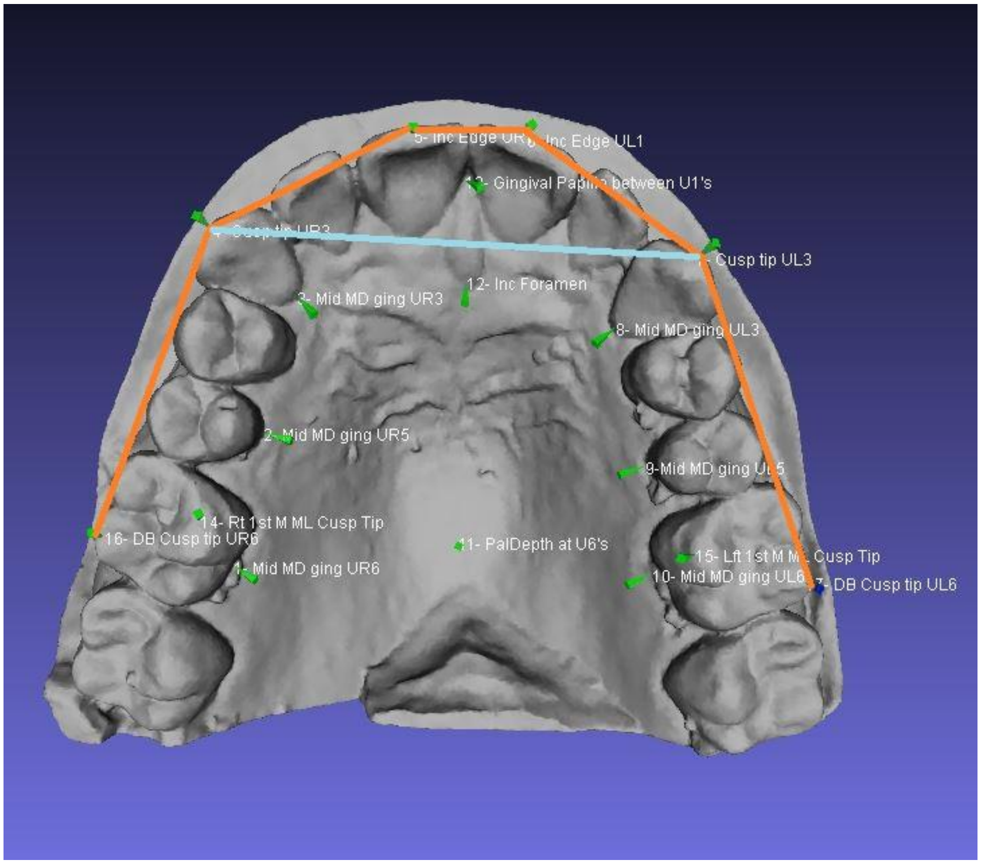
An intelligibility test known as the Sentence Intelligibility Test (Yorkstown et al, 1996) was used and scored. The results of the given patients ranged from 94 to 100 percent. The controls were only accepted if they obtained a 100 percent on the SIT. The task for each subject to perform was the sound, “a shell.” As mentioned earlier, the study focuses on “sh” production. “A shell” was used for various reasons. One of the reasons included the limited amount of mandibular jaw movement and thus, mostly tongue movement used to make the sound. Another reason is “a shell” is an easily repeatable sound for the subjects. Finally, the “uh” sound in “a shell” allows the tongue to start from a neutral position which establishes consistency in all subjects.

II.II Dental Cast Data Collection

The use of the dental casts was crucial in studying the variables of palate height, canine width, arch perimeter, overjet, and overbite and all of their effects on anteriority. They were also used extensively as reference when determining the proper locations of anteriority measurements on the MRI. The dental casts all had to be very accurate, without major blemishes, and with a clear capture of the depth of the palate. All of the casts studied had to include the maxillary first molars but most extended to second or third molar if present.

For each subject, the casts were formed from dental impressions using a mixture of alginate and water. They were later poured with either yellow or white dental stone. The models were studied previously by Jun Hwang (Hwang, 2015**)** and scanned into a 3D Ortho Insight optical scanner. The 3D renderings could then be measured and studied digitally with various set points for each subject’s dental models. Figure 3 establishes the points made to measure the needed variables. When calculating the arch perimeter, six different points from one side of the arch to the other were connected and measured. As seen in the figure the 6 points were connected with the orange lines and all together were measured in millimeters to determine the arch perimeter. The arch perimeter only included the maxillary first molars from the distobuccal tip of the right first molar all the way to the distobuccal cusp tip of the left first molar. The points were measured and saved as x, y, z coordinates in MeshLab and converted to millimeters using Microsoft Excel. Canine width was measured by measuring the distance from the cusp tip of the right canine to the cusp tip of the left canine as seen in figure 4 with the blue line. Of the 31 subjects, 29 total arch perimeters were measured. The two subjects that were excluded did not have all teeth from the right maxillary first molar around to the left maxillary first molar. Palate depth measurements were confirmed from the previous study by Grimm et al. in 2016. All subjects were grouped into either high palate or low palate groups. Two subjects' palate height could not be measured due to a palatal torus or irregularity from the alginate impression. Thus, 29 of the total 31 subjects were grouped according to palate type. The low palate group consisted of a palate depth of less than or equal to 14 millimeters and high palate was anything greater than 14 millimeters. The measurements consisted of points from the lingual gingival margin of the maxillary first molars perpendicular to the occlusal plane. 14 millimeter measurement was chosen as the dividing line between the two groups since this was average height in the subjects. Another study by Shapiro, Redman, and Gorlin in 1963 showed men to have an average palate height of 14.9 mm and women to have 12.7 mm average height.

Figure 4. Digital 3D model of the upper maxilla with arch perimeter shown with orange lines and canine width shown with a blue line.



<u>Overjet and Overbite measurements</u>

All maxillary and mandibular dental stone models were also used for overjet and overbite calculations. Maxillary and mandibular models were hand-articulated into centric occlusion using a wax bite registration created by the subject. Any subject whose models could not accurately be articulated together or centric occlusion is not clearly defined, measurements were not used for comparison. As stated by Proffit, overjet is the horizontal overlap of upper and lower incisors calculated using a millimeter ruler from the incisal edge of the upper central incisor perpendicular to facial surface of the lower central incisor when in centric occlusion. The overbite is the vertical overlap of the incisors measured by the distance between the incisal tip of the upper central incisor to the incisal tip of the lower central incisor (Proffit, 2013). All calculations are in millimeters and measured from the central incisor that has the greatest deviation from the average. For example, if the upper right central incisor is more protrusive and anterior than the left, overjet is calculated from the right central incisor. Measurements were completed using a Boley gage and measured to the tenth decimal place. Pencil marks were made on the cast on the lower central incisors where the upper centrals extended in centric occlusion. This allowed for the overbite calculation.

For future statistical analysis of overjet and overbite, all subjects were divided into two different groups. For overjet, subjects with less than 3.0 mm were considered to be small to average and any measurement ≥ 3.0 mm were considered to be large. For overbite, subjects with 2.8 mm or less were considered to be small to average and > 2.8 mm was considered to be large. These divisions were based on what is considered normal or average overjet and overbite in *Contemporary Orthondontics*, Proffit et al.

II. III. MRI Data Collection

Pre-MRI Training

In order for consistency to be preserved, all subjects were given the same repeatable speech task while in the MRI. An easily repeatable word for all subjects to produce is the word “A shell.” The “a” syllable, pronounced “uh”, starts all patients in a neutral tongue position. The tongue is neutral when it is inferior and posterior within the oral cavity. The “shell” portion of the word is a commonly used word that will allow for analysis of the “sh” sound. In regards to anteriority, the volumetric quantity of the tongue assessed at “uh” is subtracted from “sh” in all subjects. The difference between the “uh” and “sh” will be compared between all subjects given different variables

Adopted from Masaki et al., subjects were trained to reproduce a specific repetition of the desired phoneme. Over the course of fifteen minutes, subjects repeated the speech task while synchronized to a metronome of four beats. Specifically, the repeat cycle was at 0, 300, 700, and 1,400 milliseconds and repeated every two seconds. The two syllables of “uh” and “shell” were produced during the first two beats and both inhalation and exhalation were on the last two beats before repeating again. MRI data collection included the phoneme of interest and the inhalation portion of the cycle. Discontinuation of data recording occurred when the experimenter noted accurate timing after minutes of repetition for each subject. The final MRI movie was constructed from five repetitions.

Two recording types were recorded during this process. One was an acoustic recording of the phoneme in the MRI with the use of a noise-canceling fiber optic microphone (OptoAcoustics Ltd, Israel). The other recording of the desired phoneme was completed in the Vocal Tract Visualization Lab. The phoneme was produced when the subject was lying in the supine position in a dental chair while listening to the MRI audio recordings to help synchronize the speaker. The use of this recording was for the purpose of acoustic and perceptual analysis (All adopted from Hwang, 2015).

High Resolution and Cine-MRI

The MRI machine needs to have five repetitions of the word “a shell” by the subject. Each of those repetitions are combined together and form a movie per slice. The movie of the MRI images is also known as cine-MRI as stated earlier. 2.0 T Siemens Tim Trio MRI machine was used. This machine consisted of a twelve channels head coil and a four channel neck coil. The parameters used for all subjects consisted of a 26 time-frame per second with a resolution of 1.875 mm, and slice thickness of 6 mm. When evaluating the tongue and surrounding anatomical structures, a high-resolution image was needed as reference. The parameters and details of the high-resolution consisted of an in-plane resolution of 0.9 mm and slice thickness of 3 mm. The high-resolution MRI slices were used as reference within the ITK-Snap program mentioned earlier. Analyzing the teeth in the maxillary dental arch in high-resolution images aided with determining demarcation for calculating anteriority. In order to obtain these images in ITK-Snap, Lee et al. in 2014 were able to take 20-30 3 mm thick slices in the axial, sagittal, and coronal planes and combine them to form a single super-resolution 3D volume. The single super-resolution volume was 1 mm thick slice with a resolution of 0.9 mm and was known as the ‘supervolume.’

With this ‘supervolume,’ maxillary landmarks made at the first molars and second premolars to determine the anteriority line where the volume of the tongue was calculated anterior to this demarcation. When selecting the points on the molars and premolars, the teeth were viewed in various slices and points were placed at the midpoint between the mesial and distal most lingual gingival margins. For consistency, the midpoint of the first molars was determined to be about 1-2 slices away from the furcation slice for most subjects. The premolar midpoints were selected in the same plane as the ones for the molars. Anteriority was defined as a percentage. It was calculated by dividing anterior tongue volume by the total tongue volume and multiplying by 100. The change in anteriority could then be calculated by taking the percent difference between "uh" and "sh" anteriority.

As stated earlier, the cine-MRI has a poorer resolution but was needed to study the speech task of "a shell." The high-resolution 'supervolumes' were then superimposed with the cine-MRI to help measure the needed anteriority.

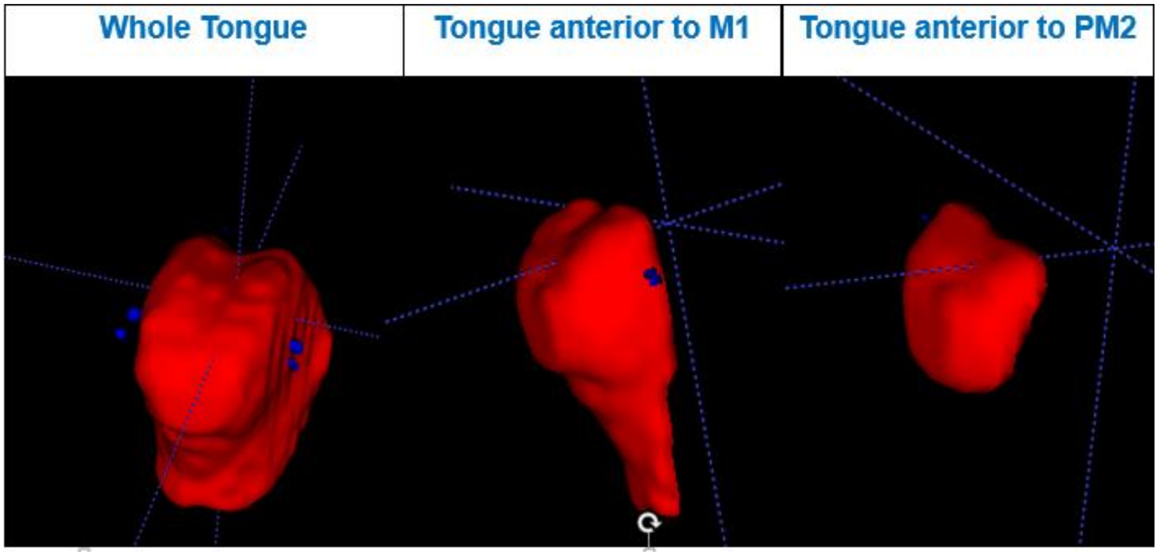
When selecting the proper time frames to be studied for anteriority, a determination of when the tongue is starting the "uh" and "sh" is needed. To determine this, the cine-MRI images were opened in DICOM-Image Viewer and played from time frame 1 to time frame 26. When detecting the time frame for "uh", the tongue was found to be in the most inferior and posterior position right before moving superior to contact the palate. Two different time frames were selected for "sh". The first time frame was initial "sh" and the second was maximum "sh". Maximum "sh" time frame was determined to be the most superior and anterior position of the tongue contacting the palate right before starting its descent to finish with the /l/. These two time frames, "uh" and max "sh" were then used for all the analyses stated above.

II.IV. Data Analysis: Tongue Segmentation and Volume Analysis

The MATLAB program is a software that is used worldwide for designing, engineer, and scientific problems. Some examples of MATLAB's use today includes automobile active safety systems, health monitoring devices, smart power grids, and many others (MATLAB**).** In this study, MATLAB was used to design a program to segment the tongue from oral cavity on the MRI images. The tongue can be segmented at the time frame containing the schwa and the "sh" sound and the volume can then be calculated to compare anteriority. The volume is calculated using the ITK-SNAP program. ITK-SNAP is a software application used to segment structures from 3D medical images such as MRI. It was developed through the efforts of Paul Yushkevich from Upenn and Guido Gerig from University of Utah. Both programs utilized in this study greatly helped analyze the anteriority of the tongue.

The tongue in each individual subject needs to be strategically demarcated from surrounding tissues in order to study its movement. The volume of the tongue can then be analyzed and studied after it is "segmented" on the cine-MRI. Segmentation of the tongue stems from selecting points within the 'supervolume' at each time frame of every subject. In total, there are 26 time frames that divide up the whole tongue during speech production of "a shell." (Lee et al, 2014). Figure 5 below shows the 3D segmented tongue volumes from the surrounding tissues. Once the tongue was segmented apart from surrounding structures, the 3D structure was loaded into the ITK-SNAP program.

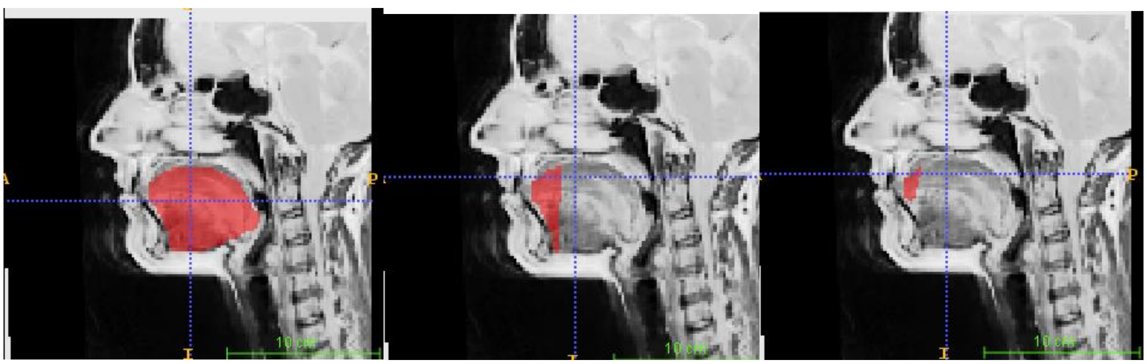
Figure 5. 3D segmented tongue from surrounding tissues. The tongue volume can be measured based on where the demarcation is made in ITK-SNAP. (Figure from Aghdam et al. poster presentation)



Through ITK-SNAP, the volume from certain selected reference points were calculated. In this study, the volume was calculated first by finding the whole volume of the tongue. Next, a reference line from gingival margin of the second premolar to second premolar on the opposite quadrant was made. A third and final reference point at the depth of the palate perpendicular to this line and occlusal plane was also made. All the pixels within this segment anterior to the reference line were added to calculate the anterior volume. This was also executed from the first molar to first molar. The reason for measuring at both the premolar and molar was because the tissue in the patient group is missing often in the molar premolar region. Therefore, a difference could be seen between the two measurements. This anterior volume change during the transition from /u/ to "sh" was then compared as a percentage of the whole tongue volume during the same transition. The percent change was chosen rather than an actual value so that various subjects with different tongue sizes could accurately be compared. Figure 6 below shows the segmentation of the tongue superimposed onto the high-resolution MRI in ITK-SNAP.

The anteriority calculated from tongue volume was then analyzed with the following variables: 1) Control vs. Patients, 2) High and low palate, 3) Arch perimeter, 4) Canine widths 5) Overjet/Overbite differences

Figure 6. Segmented volume of the tongue shown in red superimposed over the high-resolution MRI in ITK-SNAP. (Pictures from Cyrus et al. poster presentation)



Whole Tongue | Molar | Premolar

II.V. Calculations and Statistical Analyses

The study consisted of various analyses of the tongue anteriority given the multiple variables. Six independent variables were assessed: glossectomy surgery, arch perimeter, canine width, palate height, overbite and overjet. The two main statistical tests used to analyze the data were Pearson's r Correlation and ANOVA using MySTAT program. Before ANOVA tests were performed, Pearson's r Correlation tests were made to first see if molar and second premolar anteriority in patients and controls were correlated. Since a correlation was found between molar and second premolar in patients only, all other correlations studied divided the controls into molar and premolar anteriority measurements. One-way and two-way ANOVA analyses were completed. ANOVA analyses were then completed using subject type, palate height, and anteriority. Next the overjet and overbite versus subject group and anteriority were measured.

III. Results

The results of the study assessed the above mentioned independent variables and their effects on the dependent variable, anteriority. Using the statistical tests of Pearson's r Correlation and ANOVA, significant and insignificant findings are displayed in this section with a response to the proposed hypotheses. ANOVA tests were performed for the variables subject group, palate height, overjet, and overbite. The range of these variables allowed for a division of two categories to be made. For example, palate height could be divided almost evenly in groups of high or low palate. One interaction effect is noted when executing the ANOVA tests.

III.I Assessment of subject group and palate height on tongue anteriority

Molar and second premolar tongue anteriority measurements were compared for each subject group separately using Pearson's r correlations. In patients only, a significant correlation was observed between anteriority calculated at the molar and second premolar landmarks ($r = 0.73$, $p = .003$). This correlation is seen in Figure 7.

Figure 7. Correlation of molar and second premolar tongue anteriority in patients

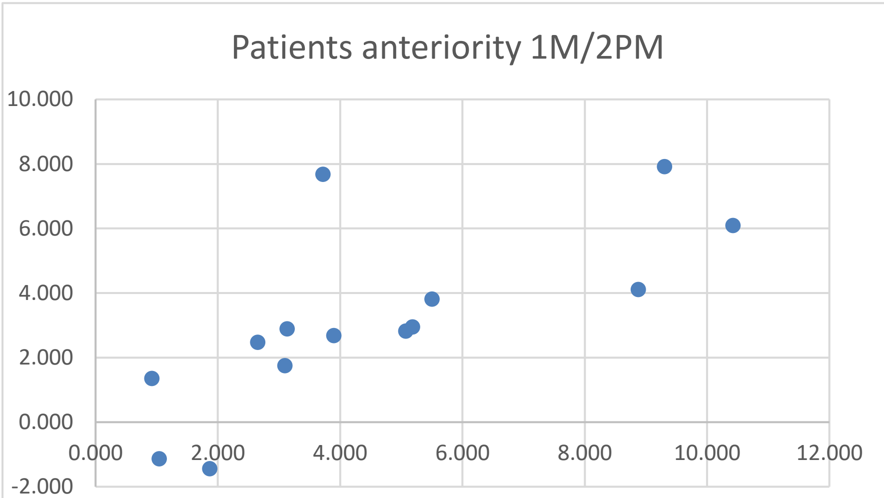


Table 1 displays the mean anteriority change from "uh" to "sh" in 29 controls and subjects within their respective palate type. The last two columns show that the mean anteriority for patients was 1.69% greater than controls at the first molar (M1), and 2.03% greater at the second premolar (PM2).

Table 1. Mean change and standard deviations in anteriority from "uh" to "sh" at M1 and PM2 for subject group and palate height. Data are percentages.

Palate type	Low		High		Both	Both
Subject type	Controls	Patients	Controls	Patients	Controls	Patients
Anteriority at M1 (% change)	3.6	4.2	2.5	5.8	2.93	4.62
Anteriority at PM2 (% change)	1.6	3.6	0.7	3.4	1.11	3.14
N	7	8	9	5	17	14
Standard Deviations for M1	3.02	2.50	1.27	3.83	2.22	3.02
Standard Deviations for PM2	0.97	3.01	1.00	1.79	1.01	2.76

The first hypothesis of a greater anteriority found in patients versus controls was supported by these data as shown in the results of a a one way ANOVA (see Table 2).

Table 2. One-way ANOVA showing significant p-value of subject type anteriority at PM2

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
Control vs. Patient	31.722	1	31.722	7.985	0.008
Error	115.215	29	3.973		

First molar measurements were insignificant after one-way ANOVA evaluation with p = 0.083 and F-ratio of 3.23.

The second hypothesis, high palate height will have greater anteriority than low palate height, was not supported statistically. ANOVA test showed no significant differences at M1 (F = 0.31, p = 0.58) or PM2 (F = 0.45, p = 0.51).

Table 3. Percent change in Anteriority of all high palate groups versus low palate group.

Anteriority	**M1 %Change**	**PM2 %Change**
Low Palate total avg	3.5	2.1
High Palate total avg	3.3	1.9

As seen in table 3 above, average anteriority changes for each palate group were about the same for both molar and premolar. Anteriority was further examined when the controls and patients were divided into high and low palate groups as seen in table 1. Within the low palate group only, there was a 0.64% difference between patients and controls at M1. However, within the high palate group, there was a 3.33% difference between patients and controls at M1. The data suggests that for high palate subjects, patients positioned their tongue differently from controls during “sh”. However, there are no statistics since when divided into these subgroups, there is too small a sample size.

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

The third hypothesis, a smaller arch perimeter and canine width will result in greater anteriority, was not statistically proven.

Two correlations were performed between anteriority and palatal features. Table 4 below shows the correlation of arch perimeter and canine width with anteriority divided into patients and controls. Molar and premolar correlation values given for the controls only. There was no relationship between anteriority and canine width or arch perimeter when producing “sh”.

Table 4. Correlation and p values of anteriority with both arch perimeter and canine width.

	Arch Perimeter Correlation	**Canine Width Correlation**
Patients	r = - 0.32, p = 0.29	r = - 0.11, p = 0.72
Controls (M1)	r = 0.24, p = 0.37	r = - 0.017, p = 0.95
Controls (PM2)	r = - 0.268, p = 0.32	r = - 0.172, p = 0.52

As stated earlier, the patients' molar and second premolar anteriority values were found to be correlated with each other. Since we are interested in the effects of glossectomy on anteriority, subsequent analyses of anteriority (when considering patients only) with other variables were assessed using the second premolar data only. One exception to this is the next section where M1 was used instead in order to compare the results more accurately with a previous study by J. Hwang et al, who also used aM1.

III.III Analysis of the effects of orthodontic bicuspid extraction on tongue anteriority

The fourth hypothesis, subjects with bicuspid extraction will have less anteriority than non-extraction controls was not proven to be true.

Five of the subjects involved in this study had either first or second maxillary premolars extracted. Each subject had the premolars extracted bilaterally and all space was closed with orthodontic treatment. Three of the five subjects were controls and two of the five were patients. As shown in figure 8 below, the arch perimeter was small for the extraction group (green triangle markers) and for four out of five had low but not extremely low anteriority. Statistical calculations could not be done since there were only five subjects.

Figure 8. Scatterplot of all 3 groups' arch perimeter by anteriority at first molar

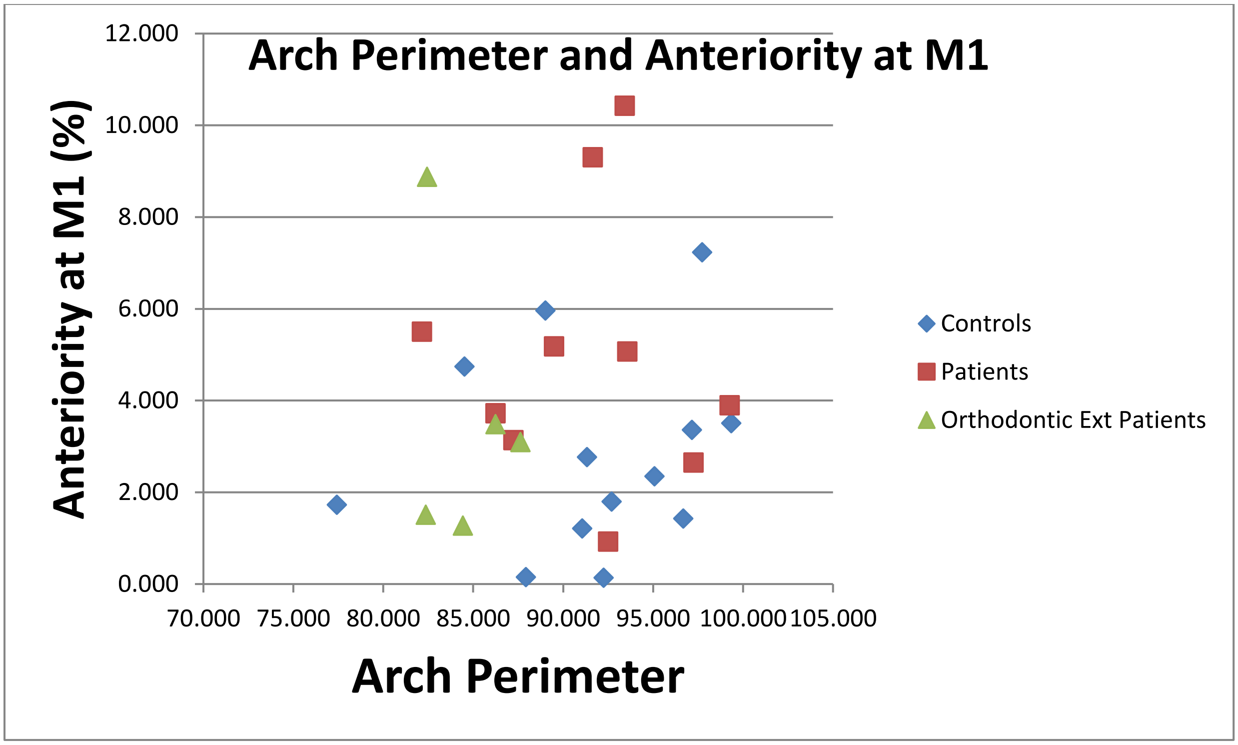
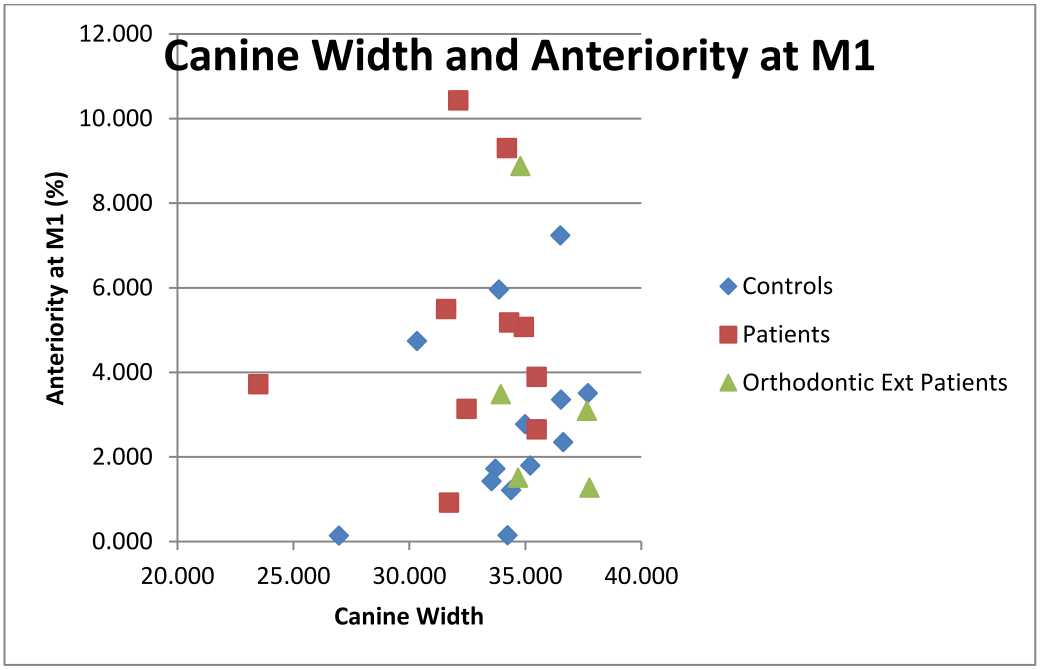


Figure 9 below also shows a scatterplot of the relationship between canine width and anteriority at first molar. Unlike the arch perimeter, canine width was not reduced in the extraction subjects and anteriority was unaffected by canine width. One of the orthodontic extraction patients has a high anteriority and the other four were evenly distributed amongst the controls and patients. It can be concluded that the arch perimeter of the orthodontic extraction patients was slightly smaller than the no treatment group, there was no difference in canine width, and anteriority was not affected by the procedure.

Figure 9. Scatterplot of all 3 groups' canine width by anteriority at first molar



<u>III.IV. Analysis of the effects of subjects' overjet and overbite on tongue anteriority</u>

The fifth hypothesis was that a greater overjet and overbite would result in less anteriority. However, it was found that a greater overbite resulted in more anteriority in subjects. Overjet did not have a statistically significant effect on anteriority.

Table 5 shows that overbite had a significant effect on anteriority. A two-way ANOVA was performed on the M1 and PM2 data. When considering the correlation of first molar and second premolar anteriority values of patients only, results are given for just second premolar. Although the main effects were significant, the interaction effect is more important as it means the main effects cannot be considered alone. Figure 10 shows the interaction between subject group and overbite on anteriority.

Table 5. ANOVA results of Overbite vs. Subject group and Anteriority at PM2

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-ratio**	**p-value**
Controls vs. Patients	16.607	1	16.607	5.937	0.022
Sm/Avg Overbite vs. Large Overbite	21.147	1	21.147	7.560	0.011
Controls vs. Patients and Sm/Avg OB vs. Lg OB	21.120	1	21.120	7.550	0.011
Error	69.932	25	2.797		

Figure 10. Interaction seen between subject group and overbite group on anteriority. Graph "1" represents small/average overbite group and Graph "2" represents large overbite group

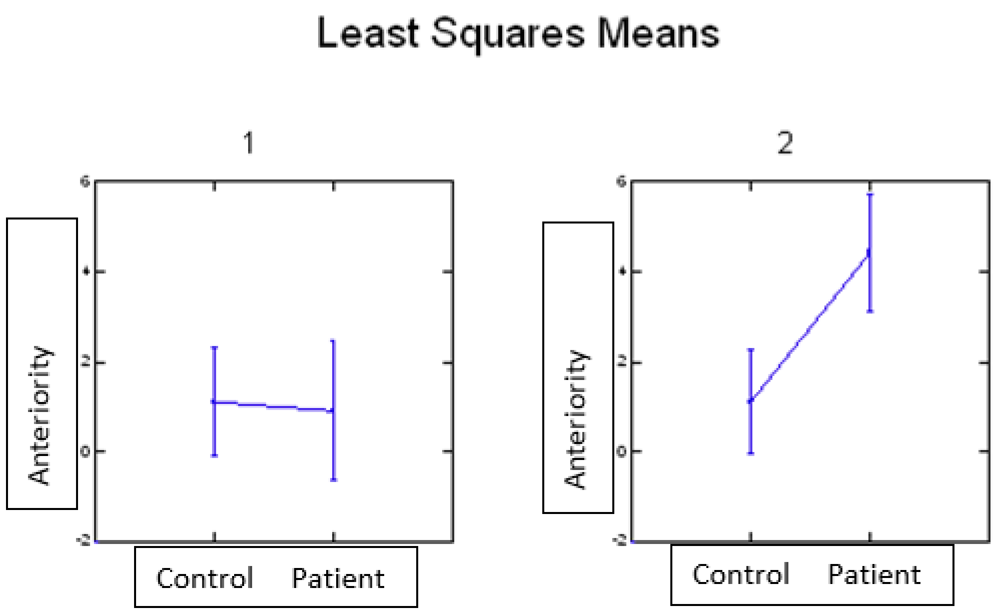
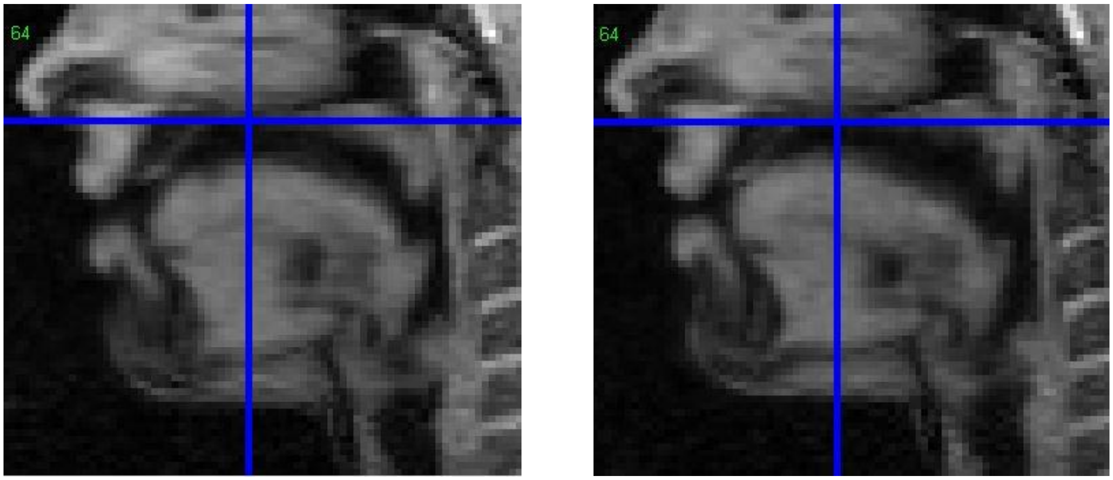


Figure 10 shows the interaction between overbite (OB) group and subject group. Graph 1 represents the small overbite group (≤ 2.8 mm OB) and no difference in anteriority is seen between controls (C1) and patients (P2) for anteriority. Graph 2 represents the large overbite group (> 2.8 mm OB), and shows much greater anteriority in the patients than the controls.

III.V. Subjects displaying negative anteriority

When subjects are speaking the word "a shell," the tongue typically moves anteriorly from "uh" to "sh". However, four subjects displayed the opposite result when analyzing anteriority at the second premolar. For these subjects the anterior portion of the tongue was more posterior during the "sh" than during "uh". When producing "sh", the tongue typically extends anterior and superior to make contact against the anterior palate. The four subjects' tongues moved slightly more posteriorly ranging from -0.12% to -1.44% when transitioning from "uh" to "sh". Two of the subjects with negative anteriority were controls and the other two were patients. In figure 11 below, the sagittal view shows what happened in these cases. Lines demarcating the same point in the image show the tongue moving more superior during "sh", rather than anterior as expected.

Figure 11. Sagittal MRI slice of the tongue showing negative anteriority. First image is "uh" and second is at "sh".

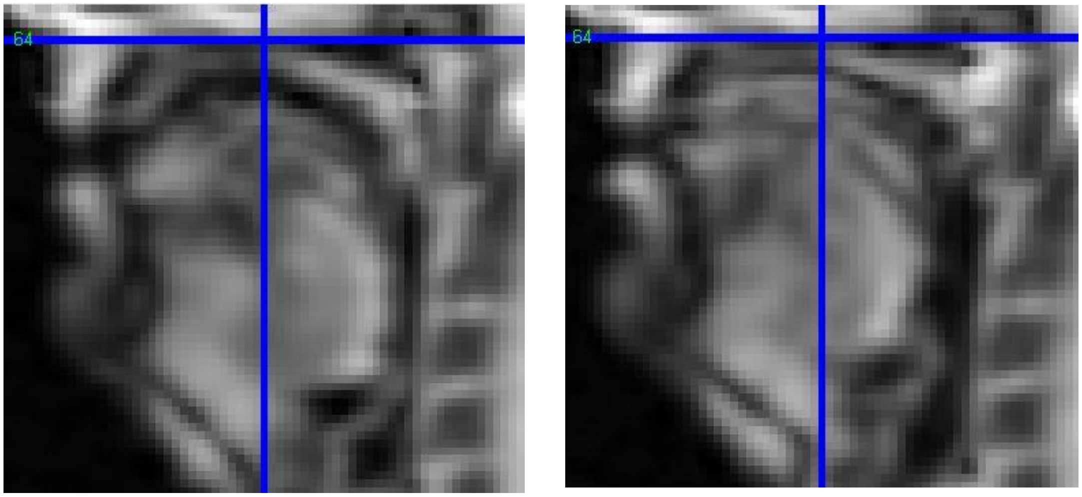


III.VI. Anteriority of Subject #12, RFFF patient.

Subject #12 was the only patient that had a radial forearm free flap repair of the tongue defect after the tumor was resected. All other patients had a primary closure. Subject #12 had a T2 tumor size, which measured in cm from anterior-posterior x mesiolingual x superior-inferior is 5.7 x 4.5 x 2.7. Calculation of total tongue volume and anteriority for this subject included the flap in the total volume of tongue.

The change in anteriority of subject #12 was 6.1%; one of the highest at the second premolar (see Figure 9). Recall that the percent change in anteriority of the patients was found to be significantly higher than the controls. Since subject #12 had a larger tumor resection area with a flap repair, the change in anteriority was higher, due to the large bulk in the middle of the tongue being moved forward during "sh". Figure 12 below shows the visual representation of the greater volume of tongue and flap to produce "sh". The flap is at the top of the tongue.

Figure 12. Subject #12 MRI sagittal view of tongue at "uh" (left picture) and "sh" (right picture).



IV. Discussion

IV.I Effects of subject type and palate height on anteriority

When assessing the subject types alone, a greater anteriority value was noted in the patient group. The mean anteriority change of the patients for the first molar and second premolar were 4.62% and 3.14% respectively. In the control group, the molar and premolar changes in anteriority were 2.93% and 1.11%. The larger anteriority value in the patient group supported hypothesis 1. In a previous study by J. Hwang, (Master's Thesis, 2015), differences in anteriority during "s" sound was studied for the same two groups. Anteriority was also found to be slightly greater on average in the patient group than the control group. Speculation as to why this may be in both “s” and “sh” production is perhaps explained by the altered anatomy of the tongue. A tongue that has more scar tissue and rigidity after glossectomy surgery will move as a solid stiff unit rather than stretching into the anterior oral cavity for sound production. A more rigid tongue moved anteriorly will move together as a unit more anteriorly to produce the same sound it once produced by stretching. Also, subject #12 had the radial forearm flap repair which would be a rigid body within the tongue. This subject was found to have one of the highest anteriority measurements.

A correlation between anteriority at M1 and PM2 was found only in the patient group and not the controls. It is predicted that the rigidity of the tongue in patients post-surgery contributes to a correlated value between the two areas of anteriority. Even patients with primary closure have increased stiffness due to scarring. Controls have a less rigid tongue and more variability between the M1 and PM2 areas may be explained by that during “sh” production.

Palate height did not have a significant effect on tongue anteriority. No statistically significant evidence was seen between anteriority and palate height. One of the reasons for this is possibly due to the small sample size of subjects. If more subjects were analyzed in each the high and low palate groups, more statistically significant results could be seen. A trend of slightly less anteriority was found in the high palate group compared to low palate group. When producing “sh”, the tongue contacts that anterior portion of the palate by moving anteriorly but also superiorly. Therefore, another reason there is no statistical difference is due to the fact the tongue may have moved more superiorly, rather than forward, and no difference in anteriority measurement was captured.

IV.II The effects of arch perimeter and canine width on anteriority

The arch perimeter and canine width were measured on all the study model casts to help determine if either contributes to “sh” anteriority changes. No correlations between arch perimeter or canine width with anteriority were noted. All Peason’s r correlation values were 0.32 or less. Most of the values were negative, such as patient arch perimeter at – 0.32. The negative correlation shows an inverse relationship between arch perimeter or canine width and anteriority. For example, when the canine width increases, the anteriority decreases. The data was not statistically significant to prove this however.

In a recent study by Grimm et al. (under review), the same dental parameters of canine width and subject group type were compared against anteriority for “s” production. Statistically significant results were found between canine width measurements and “s” anteriority. A negative correlation was found between canine width and “s” anteriority. An explanation of this was that a narrower intercanine distance forced the tongue tip to spread anteriorly. The “sh” on the other hand spreads the tongue along a larger anterior-posterior region and apparently positioning of tongue volume was not as sensitive to width between the canines as the “s".

In “sh” production however, contact with the palate is more posterior than “s” is at the alveolar ridge and specific air stream shapes are not as crucial. Therefore, alterations in the canine width will not have as much of an effect on tongue anteriority for “sh”. “Sh” anteriority may be more significantly affected if the width is different in the posterior portion of the palate. For example, a more constricted molar or premolar region. This study only assessed the effect of canine width and not molar or premolar width on anteriority. Future studies analyzing the effect of molar and premolar width on “sh” anteriority with a larger subject pool are needed.

The effects of arch perimeter on anteriority did not have a significant effect. Arch perimeter dimensions determine the confines of the palate and therefore, the area for the tongue to approximate with the palate for speech production. No trend was found could perhaps be explained by the tongue moving more superiorly in “sh” production and anteriority measurement differences were not captured.

IV.III The effects of orthodontic bicuspid extraction on tongue anteriority

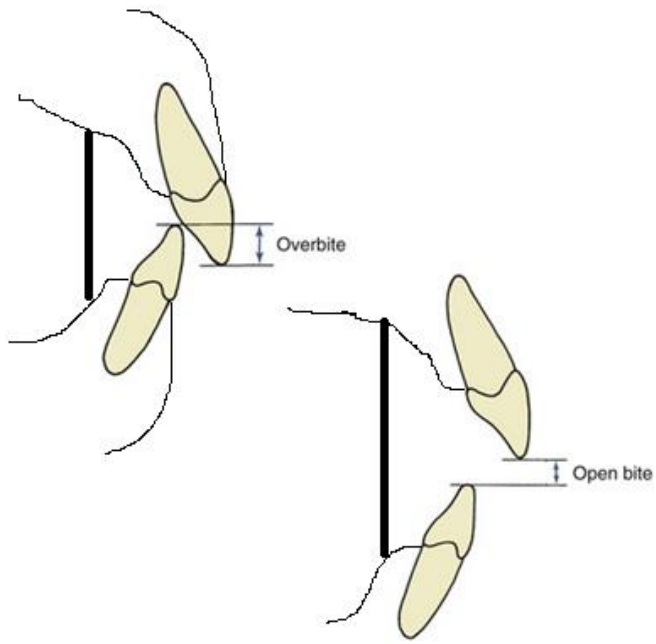
Figures 8 and 9 above displayed results for M1 instead of PM2 since comparisons are made to the study by J. Hwang et al, who also used M1. In the study by J. Hwang et al, no specific trend was found with the same five bicuspid extraction subjects but a general trend was observed. For “s” production, the bicuspid extraction cases had less arch perimeter and also showed a decrease in tongue anteriority. They proposed the smaller anteriority was due to the tongue already being positioned more anteriorly during schwa since the anterior teeth were retracted and less tongue space within the oral cavity was available**.** The same five subjects in this study of “sh” showed a wide range of tongue anteriority in spite of bicuspid extractions. As seen in figure 8, the five subjects had smaller arch perimeter as expected but tongue anteriority was scattered with most of the subjects in the lower anteriority range. “Sh” again is different than “s” by the fact that it has more posterior contact with surrounding palatal features and therefore found to be less affected by a reduced arch perimeter or canine width. The combination of both reducing arch perimeter and mesialization of the maxillary molar could cancel each other out regarding anteriority measurements and therefore, no specific trend was noted.

IV.IV Effects of overjet and overbite on tongue anteriority

The effects of overjet and overbite on anteriority were an entirely new variable that has not been assessed with this subject group before this study. Overjet, separated into small/average and large groups, was not seen to be statistically significant in altering anteriority. When analyzing the data, a determination needs to be made if the excess overjet is more from a dental origin or skeletal origin. Typically, a larger overjet discrepancy is from a skeletal discrepancy. The largest overjet value from the subject pool was found to be only 6.5 mm. There may be a skeletal contribution to this excess overjet but unfortunately this was the highest one measured. Perhaps, a significant finding could be made if more subjects with a higher range in overjet are studied in the future.

On the other hand, overbite had a significant interaction with subject group type was noted. The greater the overbite, the greater the tongue anteriority for patients. The expectation is that a greater overbite would render a smaller oral cavity in the anterior region since the teeth and part of the alveolar ridge would be overlapping with each other. One possible explanation for this is that having a more constricted anterior space in the vertical direction would force the tongue to move more anterior and towards the front teeth. A sketch over the Overbite figure from Proffit et al. illustrates this principle (see figure 13).

Figure 13. Sketch adding in the palatal walls and alveolar ridges showing a more limited oral cavity in the anterior region with a deeper overbite.



Although the illustration above is exaggerated with an open bite comparison, there are deeper bites that exist compared to the picture above. The deeper bites not depicted in the figure above sometimes display palatal impingement where the lower anterior teeth are contacting the palatal gingival when the patient is fully occluding. Clearly seen with the black lines in figure 13, there is a larger vertical height for the tongue to move more superiorly to contact the anterior palate in the open bite illustration. When the tongue is moving more superiorly, there is less anterior tongue movement.

Interestingly, this effect was seen only for patients. There was an interaction between the overbite and the subject group. Figure 10 shows that when only controls were visualized, there was not a true difference between the small and large overbite groups and anteriority. However, when the glossectomy group was visualized, the larger overbite group had a significantly higher anteriority. A reasonable explanation for the larger anteriority in the deep bite glossectomy patients could be explained in two parts. The first part for greater anteriority was explained above, the deeper/larger overbite forces the tongue to move more anterior. The second part is that the tongue is more rigid due to the scar tissue from the glossectomy surgery. Increased rigidity decreases the tongue's ability to mold and adapt to the surrounding hard oral cavity structures and thus moves more anterior as one unit.

IV.V Subjects displaying negative anteriority

Four subjects displayed a negative anteriority when producing "sh". The measurements of negative anteriority were very small, close to zero. Only speculations can be made as to why these four subjects displayed negative anteriority. The second premolar anteriority measurements were the only ones to show negative anteriority. Therefore, in the molar region, the tongue consistently moves anteriorly to produce "sh". One can speculate that the movements of the tongue anterior to the premolar region for these four subjects remains somewhat stationary in the anterior-posterior plane and the tongue instead elevates superiorly to contact the palate. As seen in Figure 11, the premolar region shows the tongue moving more superiorly to contact the palate rather than anteriorly.

IV.VI A unique subject with radial forearm free flap repair

The only patient to have a radial forearm free flap (RFFF) repair displayed one of the highest anteriority measurements. The greater anteriority is expected for two reasons. The first is that the patients in general were statistically proven to have a greater anteriority than the controls. One possible reason for this was due to the rigid nature of the tongue after glossectomy surgery. Even with a primary closure procedure, the tongue becomes more rigid from the scar tissue and thus moves more anterior in “sh” production as one rigid body. Since this subject had a RFFF procedure, the tongue is even more rigid than if it were repaired with primary closure. The second reason for a greater anteriority in this case is the added volume to the tongue with the forearm flap. Although a large portion of the tongue and tumor was removed, the radial forearm flap tissue was greater in volume. Overall, the tongue volume increased. Even though the use of percentages in the anteriority calculations normalize the differences in tongue size from one patient to another, the overall larger volume in this case is restricted by the limited oral cavity. After the tongue fills most of the oral cavity, one of the only directions to move is more anterior where more space may exist. Further studies with more patients having a RFFF procedure with varying sizes of the palate, arch perimeter, canine width, etc. is needed to find the exact reasoning behind this.

IV.VII Limitations to this study

One of the greatest limitations to this study was a small sample size of controls and glossectomy patients. Having a greater number in each group will allow for a better and more sound statistical analysis of each of the variables. For example, a larger patient or control pool would give a larger variety of palate types, arch perimeter and canine variations, possibly more bicuspid extraction cases, and larger range of overbite and overjet. As stated earlier, a larger variety of surgical repair procedures would also be helpful. For example, the RFFF repair patient had interesting results. More RFFF patients to study and draw conclusions from would produce excellent advancements in this field of speech study.

As with any study, another possible limitation is potential errors from data collection for each variable. All experimenters used the same method and specific protocol to delineate the molar and premolar regions for anteriority measurements to minimize any potential errors. Most of the measurements were collected by one experimenter and the written protocol was strictly followed so consistency between subjects can be expected. The overjet and overbite calculations were measured by two experimenters using the same protocol and measurements were confirmed. Inaccuracies could exist since they were executed manually.

V. Conclusion

The hypothesis, **H1: Glossectomy subjects will exhibit more anteriority than controls,** was statistically supported displaying a significant difference between the two groups. The glossectomy subjects had a consistently higher anteriority than the controls. This may be due to the rigid nature of the repaired tongue, whether it was a primary closure or a more extensive repair such as a RFFF.

The second hypothesis, **H2: High palate height group will have greater anteriority than low palate height group,** was not supported and no significant difference was seen. Overall, the anteriority values on average were the same between the low and high palate groups.

The third hypothesis, **H3: A smaller arch perimeter and canine width will result in greater anteriority,** was not supported statistically. The subjects had very similar anteriority measurements in spite of their differences in arch perimeter or canine width. A slight trend was seen however. For both arch perimeter and canine width, a slight inverse relationship was noted. For example, when the canine width increased, anteriority decreased. As mentioned earlier, this inverse relationship was also seen when analyzing the "s" production. The "s" production is more critically concerned with the anterior oral cavity parameters.

The fourth hypothesis, **H4: Bicuspid extraction patients will have less anteriority than non-extraction controls,** was not supported statistically. All five of the extraction subjects had a large range in variations of anteriority. No specific trends were noted.

The fifth hypothesis, **H5: A greater overjet and overbite will result in less anteriority,** was not found to be true. However, statistically significant results for overbite supporting the opposite were found. A larger overbite significantly influenced a greater anteriority in the sample pool of subjects. An interaction was also noted between overbite and subject group type. When controls only were analyzed, no difference in the overbite groups were found. However, when patients were only analyzed, the larger overbite group had a much greater anteriority measurement than the small to average group.

In summary, the variables palate height, arch perimeter, canine width, orthodontic bicuspid extraction, and overjet did not have results that were statistically significant in affecting tongue anteriority. Subject group type and overbite did show a significant difference in tongue anteriority as well as an interaction between each other. The surrounding maxillary features and occlusal parameters thus have an influence or a notable trend on “sh” production and will need to be further evaluated. Future research on this topic with a larger subject pool is crucial for further understanding the adaptations of glossectomy subjects’ speech production.

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