Hemiglossectomy tongue reconstruction: Modeling of elevation, protrusion, and functional outcome using receiver operator characteristic curve

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ABSTRACT: *Background.* The purpose of this study was to model >12 month speech and the oral phase of swallowing outcomes with the reconstructive metrics of tongue elevation and protrusion in patients reconstructed with the rectangle tongue template for a hemiglossectomy defect.

Methods. We conducted a study using 40 surviving patients (23 men, 17 women) treated between 2000 and 2012. Statistically significant correlations of elevation and protrusion with functional outcomes were modeled with receiver operator characteristic (ROC) curves to understand the performance and reliability of the rectangle tongue reconstruction.

Results. Tongue elevation (1.8–1.9 cm) reliably produces best outcomes in nutritional mode, range of liquids, and ≥4/6 for range of solids. Greater tongue elevation (2.1–2.2 cm) reliably produces best outcomes for eating and speaking in public and understandability of speech. Tongue protrusion (0.8–1.0 cm) reliably produces best scores across all assessed outcomes except ≥4/6 for range of solids and ≥4/5 understandability of speech.

Conclusion. ROC curves are useful for assessing reliability and relating reconstructive objectives to functional outcomes. © 2016 Wiley Periodicals, Inc. *Head Neck* **00**: 000–000, 2016

KEY WORDS: hemiglossectomy, tongue reconstruction, speech and swallowing function, functional outcomes, tongue squamous cell carcinoma, oral cavity cancer

INTRODUCTION

There are a number of different approaches to the reconstruction of hemiglossectomy defects.[1–4] To select a particular reconstructive approach, surgeons have few metrics to guide their decision-making. Our prior work has suggested that tongue elevation and tongue protrusion may be useful as guiding reconstructive principles.[1] In general, it is difficult for surgeons to know what metrics are important and the relative advantages and disadvantages of a particular reconstructive approach. This is partly due to the lack of a system that could model the mechanical behavior of a reconstruction in concert with the native tissue.

When surgeons choose a particular reconstructive approach, there are several components of the reconstructive choice that impact the eventual outcomes relating to speech and the oral phase of swallowing. The more straightforward components include the size of the tissue, the composition of the tissue, and the thickness of the tissue. There are more complex components, such as the elastic properties of the tissue, the stiffness, the stability, the way the tissue augments the remaining native tissue, and the effect of other treatments, such as radiation or chemotherapy.

As surgeons build their training and experience, they develop an understanding of the physical and functional performance of the transplanted tissue and the recipient native tissue. The "understanding" a surgeon has is much different than the understanding an engineer would have with respect to a device or compound. In a rigorous way, engineers evaluate the synthesis, structure, properties, and performance of compounds and devices. These processes have been applied to biological systems and have been used in many different disciplines in a variety of ways. For engineers, there is a science around assessing the physical properties and performance of a particular compound or device[5]; but for reconstructive head and neck surgeons, there is little science, rather, there are techniques that are passed from teachers and honed with personal experience. Because tissue reconstruction does not have developed metrics, different reconstructive approaches are hard to compare. If the reconstructive approaches are hard to compare, it is difficult to understand relative strengths and weaknesses of a particular approach. This article seeks to assess the strengths and weaknesses of a particular reconstruction by comparing a specific physical characteristic (such as range of motion measurements) to a functional outcome, with the overall goal of using a set of

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measurements to statistically model the functional characteristics in a standardized approach so that different reconstructive approaches can be compared.

It is reasonable to assume that a specific reconstructive approach should confer specific physical characteristics that should result in specific functional characteristics. A specific reconstructive approach may improve a particular functional characteristic while impairing another. The ideal reconstruction would improve or maintain critical physical characteristics and, as a result, maintain or improve functional characteristics. In this article, the rectangle tongue template reconstruction of the hemiglossectomy defect is being evaluated.[1] The specific physical characteristics of elevation and protrusion that this reconstructive approach produced were tabulated. These physical characteristics (elevation and protrusion), in the context of this reconstructive approach (rectangle tongue template in a hemiglossectomy defect), were evaluated with receiver operator characteristic (ROC) curves to determine the functional outcome(s) this reconstructive approach was most likely to achieve.[6]

Our goal was to assess a statistical modeling approach using ROC curves that would treat a reconstructive approach like a material that was being used to create a device. In this case, the rectangle tongue template for the hemiglossectomy defect to create a functioning tongue. The ROC curves would use the elevation or protrusion that this reconstructive approach could produce and test for a statistically relevant relationship to the functional outcomes of speech and the oral phase of swallowing. We hypothesize that there is a range of tongue elevation and protrusion that the rectangle tongue reconstruction can achieve and that these metrics can be used to model the speech and swallowing outcomes that can be obtained. In the future, this statistical approach may be used to define the relative strengths and weaknesses of other reconstructive approaches for the purposes of comparison.

TABLE 1. Patient demographics.

Characteristics	No. of patients (%)	
Age, y, mean (SD)	51.7	Range 29–81
Sex		
Male	23	(57.5)
Female	17	(42.5)
Initial BMI, mean	27.5 kg/m^2	Range 19.1–45.2
Current BMI, mean	26.8 kg/m^2	Range 20.7–47.4
T classification		
T1	4	(10)
T2	25	(62.5)
T3	7	(17.5)
T4	4	(10)
N classification		
N0	25	(62.5)
N1	7	(17.5)
N2	8	(20)
N3	0	(0)
Radiation		
Preoperative	3	(7.5)
Postoperative	22	(55)
Pre- and post-brachytherapy	1	(2.5)
None	14	(35)
Chemotherapy		
Preoperative	1	(2.5)
Preoperative induction	1	(2.5)
Postoperative	9	(22.5)
None	29	(72.5)
Donor site		
Forearm	36	(90)
Lateral arm	2	(5)
Anterolateral thigh	1	(2.5)
Rectus	1	(2.5)
Nerve graft		
Yes	21	(52.5)
No	19	(47.5)
Flap area, mean	38.8 cm^2	Range 16–80

Abbreviation: BMI, body mass index.

MATERIALS AND METHODS

Study design

This was a prospective case series of patients with hemiglossectomy defects of the oral cavity reconstructed by surgeons in the microvascular program of the Department of Otolaryngology–Head and Neck Surgery at the University of Michigan from May 2000 to January 2012.

Patient population

Patients were eligible if they had squamous cell carcinoma of the oral tongue that, after excision, resulted in a hemiglossectomy defect and that defect was reconstructed with a template-based rectangle-shaped free tissue transfer and had >12 months follow-up after completion of therapy.[1] Hemiglossectomy was defined as one-half of the oral tongue. Some patients had tongue base resection but as long as the 50% or less of the tongue base was resected and could be primarily closed to the lateral pharyngeal wall, these patients were included in this cohort.

There were 40 patients who met inclusion criteria with the baseline characteristics of the cohort shown in Table 1. There were 23 men with an average age of 51.7 years (range, 29–81 years). There were 4 T1 tumors, 25 T2 tumors, 7 T3 tumors, and 4 T4 tumors. The radial forearm autogenous transplant was used to reconstruct 90% of the defects. If the volume of the radial forearm donor site was judged to be inadequate, the rectus (2.5%), lateral arm (5%), or anterolateral thigh (2.5%) autogenous transplant was chosen. On visual inspection, all patients were able to obliterate their oral cavity when in occlusion. The mean transplant area was 38.8 cm^2. There were 26 patients (60%) who underwent radiotherapy and 11 (27.5%) who underwent chemotherapy. The overall mean follow-up duration was 49.6 months (range, 16–112 months).

Goals and principles

The goals and principles of hemiglossectomy reconstruction have been previously described.[1] Briefly, our first goal is to obliterate the volume in the oral cavity. This eliminates the dead space in the oral cavity, which improves handling of secretions and prevents food trapping. Second, we aim to maintain premaxillary contact and palatal contact of the tongue tip, which are important for articulation for a number of speech sounds. We then seek to optimize the residual "finger function" of the tongue to improve the ability to clear the buccal, labial, and alveolar sulci, and protrude past the coronal plane of the incisors. Our fourth goal is to maintain the movement of secretions from anterior to posterior in the oral cavity to improve handling of secretions. Our final goal is to optimize sensation of the remaining native tissue and the autogenous transplant. This is achieved by sparing of oncologically uninvolved sensory nerves and reinnervation of the autogenous transplant when possible.

To achieve these goals in hemiglossectomy reconstruction, we follow our previously described principles.[1] Our first principle is careful autogenous transplant selection to restore the volume of the defect. To compensate for transplant atrophy and the effects of radiation, the defect volume was "over-reconstructed." Our second principle is to reconstruct the ventral tongue and floor of mouth tissue with thin tissue, and the dorsal and lateral tongue with thicker tissue. This is achieved with careful positioning of the transplant on the donor site or customization (thinning or deepithelization) of the transplant. Our third principle is to specifically address all anatomic compartments that contribute to the volume defect, such as the mandible or muscles of the floor of mouth to prevent contraction of the transplant laterally or inferiorly. The transplant design and inset must also allow anterior and posterior excursion of the tongue to facilitate the protrusion of the tongue. Finally, our fifth principle is to obtain a smooth gutter from the anterior floor of the mouth to the posterior floor of the mouth to facilitate the clearing of secretions.

Surgical approach to the rectangle tongue template

The surgical approach to the rectangle tongue template has been previously described.[1] Briefly, the volume of the defect was estimated by evaluating 3 separate areas: the oral tongue defect, the musculature of the tongue deep to the axial plane of the floor of the mouth, and the body of the mandible. The volume to be replaced can be estimated by compressing a surgical sponge into the defect, and then compressing the same sponge into a volumetric cylinder. The flap choice (forearm, rectus, lateral arm, or anterolateral thigh) was then chosen based on the volume necessary for reconstruction and the body mass of the patient. In patients with lower body mass, an alternate donor site than the forearm is used to replace the volume of the defect.

The rectangle was sized by measuring the edges of the defect. The length was determined by measuring from the most dorsal and medial aspect of the defect to the tip of the tongue, while the tongue is gently placed on tension in the plane of the midline raphe. The width of the rectangle was determined by measuring from the tongue tip to the most anterior midline portion of the defect, while the tongue is gently placed on tension in a superior direction. The length and width are then verified by measuring the opposing defect measurements.

The template of the rectangle was placed on the donor site. The template is positioned on the donor site based on the bulk required for the tongue reconstruction. Additional subunit tabs are placed if the retromolar trigone, anterior tonsillar pillar, or floor of the mouth was resected. Additional volume was occasionally harvested when there is large volume loss on the lateral tongue or floor of the mouth.

The inset of the flap was performed with posterior inferior aspect of the flap tacked in first. Next, the posterior superior corner was tacked, followed by the anterior superior corner. At this point, a determination was made as to whether the flap was draping properly into the tongue portion of the defect and adjustments were made.

The closure was then completed with a small amount of trimming as needed to finesse the final result.

Variables under study

Oral cavity metrics were tongue tip elevation, tongue tip protrusion, and open mouth premaxillary contact. Elevation is the measurement between the tongue tip and the axial plane of the mandibular central incisors. Protrusion is the measurement between the tongue tip and the coronal plane of the mandibular central incisors. Open mouth premaxillary contact is the measurement between the central incisors when the patient is able to make contact between the tongue tip and the premaxilla. Patients were measured by the senior author (D.B.C.) in the clinic >12 months after the completion of treatment.

Speech and swallowing were assessed with an administered questionnaire the "Speech and Swallowing Assessment" and is shown in Table 2. This was administered by one of the authors (D.B.C. or M.E.S.) in the clinic. Two questions that examine a patient's ability to eat in public and their perceived understandability of speech are validated questions derived from the Performance Status Scale for Head and Neck Cancer (PSS-HN).[7] The 4 remaining questions examine a patient's mode of nutrition, speaking in public, range of liquids, and range of solids intake. The Likert scale from the PSS-HN has been altered from a 25-point incremental scale starting at 0 and ending at 100 to a 1-point incremental scale starting at 1 and ending at 5, so that all questions use a 1-point to 5-point or 1-point to 6-point Likert scale.[1] Functional outcomes were measured in all 40 patients at least 12 months after the completion of treatment.

Statistical analysis

To understand the relationship among tongue elevation, tongue protrusion, and a functional outcome measure of speech or swallowing, bubble plots (a form of scatter plots for 3 variables) were used. Tongue elevation was plotted on the y-axis and tongue protrusion was plotted on the x-axis for each patient. The location of the x y coordinate was plotted with the value of the speech or swallowing score of interest for an individual patient. Larger bubbles represented better (higher) speech and swallowing scores, and smaller bubbles represented poorer (lower) scores.

Scatter plots, such as bubble plots, are used to generate a visual cue for the distribution of data. In this study, the bubble plots were used to determine a visual cut point for the measure of tongue elevation and/or tongue protrusion that is related to higher (better) speech or swallowing score. As a visual estimate, these plots are useful, and Spearman correlations were performed to evaluate the relationship of these variables.

A linear regression was performed using elevation or protrusion as the explanatory (independent) variable to

TABLE 2. Administered questionnaire that assesses speech and swallowing function.

Nutritional mode
1. Nothing by mouth
2. Tube feeds; trial oral intake
3. Combined oral and tube feeds
4. Nutritional supplements only taken by mouth
5. Oral intake with nutritional supplements
6. Oral intake alone; no supplements

Range of liquids
1. No liquids by mouth
2. Limited quantity of liquids by mouth
3. Restricted range of liquid consistencies
4. Full range of liquids; bolus volume restriction
5. Full range of liquid consistencies; restrictions solely related to acidity, spice, and/or temperature
6. Full range of liquids; no restrictions

Range of solids
1. No solids
2. Pureed solids
3. Minced, moist, soft solids
4. Variety of solids taken, usually facilitated by increased moisture or liquid chasers
5. Minimally restricted solids with few specific exclusions
6. Full range of solids; no restrictions

Understandability of speech[7]
1. Never understandable; may use written communication
2. Difficult to understand
3. Usually understandable; face-to-face contact necessary
4. Understandable most of the time; occasional repetition necessary
5. Always understandable

Eating in public[7]
1. Always eats alone
2. Eats only at home in presence of selected persons
3. Eats only in presence of selected persons in selected places
4. No restriction of place but restricts diet when in public to less messy/difficult foods (may eat anywhere but avoids certain foods)
5. No restriction of place, food, or companion (eats out at any opportunity)

Speaking in public
1. Avoids or no spoken communication
2. Speaks only at home in presence of highly familiar partners
3. Talks only in presence of selected people in selected contexts and limits content and quantity substantially
4. No restriction of context or partner but tends to limit extent of conversation when in public; communicates with strangers
5. No restriction of context, partner, or quantity

determine if there were associations between tongue measurements and a higher (better) speech or swallowing score.

The variables that were significant from the linear regression modeled with ROC curves to understand the characteristics of the rectangle tongue reconstruction. ROC curves were chosen for this analysis to determine the inflection (cut) point for a particular measurement of tongue elevation or tongue protrusion that reliably predicts a speech or swallowing outcome. Measurements that are below this cut point would have a high sensitivity to reliably predict a functional outcome, but low specificity (high false-positive rate). Measurements above this cut point would be highly specific to reliably predict a functional outcome, but have a low sensitivity (high false-negative rate) and would not be possible to obtain in all patients.

With this statistical approach an understanding of the performance of the rectangle tongue template can be evaluated. The purpose is to model the relationship among tongue elevation, tongue protrusion, and a speech or swallowing outcome with this particular defect and reconstructive approach. The assumption is that different reconstructive approaches will have different dynamic and physical characteristics that relate to a speech or swallowing outcome. For the rectangle tongue reconstruction, we modeled the sensitivity and specificity of either elevation or protrusion at a specific speech or swallowing outcome. This analysis helps determine the statistically significant cut point (measurement) for tongue elevation or tongue protrusion at a particular outcome level of speech or swallowing. When the data become ordered at a particular level of speech or swallowing and generates a statistically significant area under the ROC curve, this result indicates that at this particular level of outcome the measurement of elevation or protrusion is the minimum required to reliably produce the speech or swallowing outcome of interest.

Written informed consent was obtained from all patients and the study was performed after institutional review board approval (HUM00050982).

RESULTS

The mean tongue tip elevation was 2.4 cm (range, 0.5–5.0 cm) and the mean tongue tip protrusion was 1.4 cm (range, 0–3.6 cm). Figure 1 shows the distribution of elevation and protrusion that was achieved in the entire cohort with this reconstructive approach.

Nutritional mode

The "nutritional mode" mean score was 5.65 of 6 and there were 30 of the 40 patients who achieved a score of 6 of 6 (Figure 2A). The nutritional mode is an assessment of the use of nutritional supplements and gastrostomy tube dependence. A score of 6 represents unrestricted oral intake and 5 represents oral intake with occasional nutritional supplements.

Range of liquids

The "range of liquids" mean score was 5.75 of 6 (Figure 2B). There were 33 of the 40 patients who achieved a full score of 6 of 6 with no restrictions and of the remaining 7 patients, there were 6 patients who had full range of liquid consistencies with restrictions solely related to acidity, spice, and/or temperature.

Range of solids

The "range of solids" mean score was 5 of 6 (Figure 2C). Of 40 patients, 18 scored a 6 had no restrictions in their solid food intake and 12 scored a 5 and were minimally restricted solids with few specific exclusions, such as bread and dry meat. There were 2 patients who scored a 3 and only ate minced, moist, or soft foods and 2 patients scored a 1 who ate no solid foods.

Eating in public

The "eating in public" median score was 4.4 of 5 (Figure 2D). Of 40 patients, there were 23 patients who had

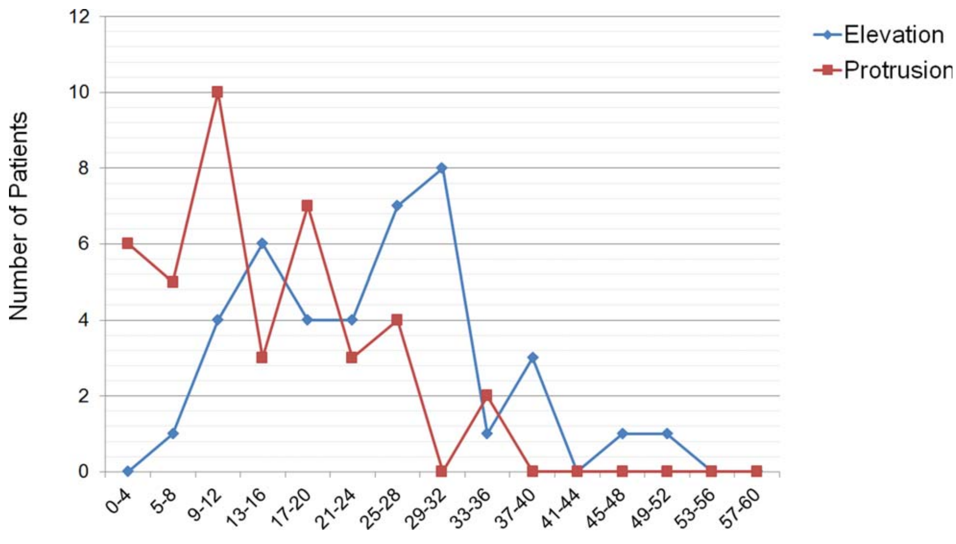

FIGURE 1. Line graph showing tongue tip elevation and protrusion scores for all patients. The mean tongue tip elevation was 2.4 cm (range, 0.5–5.0 cm) and the mean tongue tip protrusion was 1.4 cm (range, 0–3.6 cm). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

no social restrictions or restricted diet when eating in public places and 12 patients who had no restriction of place but restricted diet when in public to less "messy" foods.

Speaking in public

The "speaking in public" mean score was 4.85 of 5 (Figure 2E). Thirty-six of the 40 patients had no restriction of context, partner, or quantity when speaking in public. There were 2 patients who limited their extent of conversation when in public, and 2 patients who only talked in the presence of selected people.

Understandability of speech

The "understandability of speech" mean score was 4.45 of 5 (Figure 2F). Of 40 patients, 21 scored a 5 and were understandable all the time and 16 patients scored a 4 who were understandable most of the time but required occasional repetition. Three patients scored a 3 who were usually understandable, but required face-to-face contact.

Univariate associations with tongue elevation

A linear regression was performed using elevation as the explanatory variable and the various functional outcomes as the dependent variable. In a univariate analysis, all outcomes except speaking in public improved with increasing tongue elevation (Table 3). The linear regression showed that understandability of speech was most strongly associated with tongue elevation followed by eating in public.

Univariate associations with tongue protrusion

A linear regression was performed using protrusion as the explanatory variable and the various functional outcomes as the dependent variable. In a univariate analysis, all outcomes except range of liquids improved with increasing tongue protrusion (Table 4). The linear regression showed that eating in public was most strongly associated with tongue protrusion followed by speaking in public.

In a univariate analysis, age, sex, initial body mass index (BMI), current BMI, N classification, or the addition of chemotherapy to the treatment regimen were not associated with elevation or protrusion scores. Advanced T classification did predict a lower elevation ($r = -0.513$; $p = .001$) but not protrusion ($r = -0.270$; $p = .091$) score. The addition of radiation to the treatment regimen predicted a lower elevation ($r = -0.380$; $p = .016$) but not protrusion ($r = -0.238$; $p = .139$) score.

Receiver operator characteristic curves

We used an ROC curve analysis to model the relationship among tongue elevation, tongue protrusion, and a speech or swallowing outcome. The assumption is that different reconstructive approaches will have different dynamic and physical characteristics that relate to a speech or swallowing outcome. This analysis helps determine the statistically significant cut point (measurement) for tongue elevation or tongue protrusion at a particular outcome level of speech or swallowing.

Receiver operator characteristic curve of tongue tip elevation for nutritional mode, range of liquids, and range of solids

The elevation cut points that produced reliable outcomes for nutritional mode, range of liquids, and range of solids were similar (Table 5). When a tongue tip elevation of 1.8 to 1.9 cm was obtained, the rectangle tongue hemiglossectomy reconstruction was able to reliably produce maximum scores in nutritional mode (6/6 = oral intake alone without supplements) and range of liquids (6/6 = full range of liquids without restrictions). When assessing range of solids and tongue tip elevation of 1.8 cm, the rectangle tongue reconstruction was able to reliably produce a 4 or greater (Table 2). The Likert value of 4/6 for range of solids specifies that moisture is needed to assist in swallowing of solids. This is likely related to a radiation effect but the number of patients was too small in this cohort to assess patients with and without radiation for a particular functional outcome.

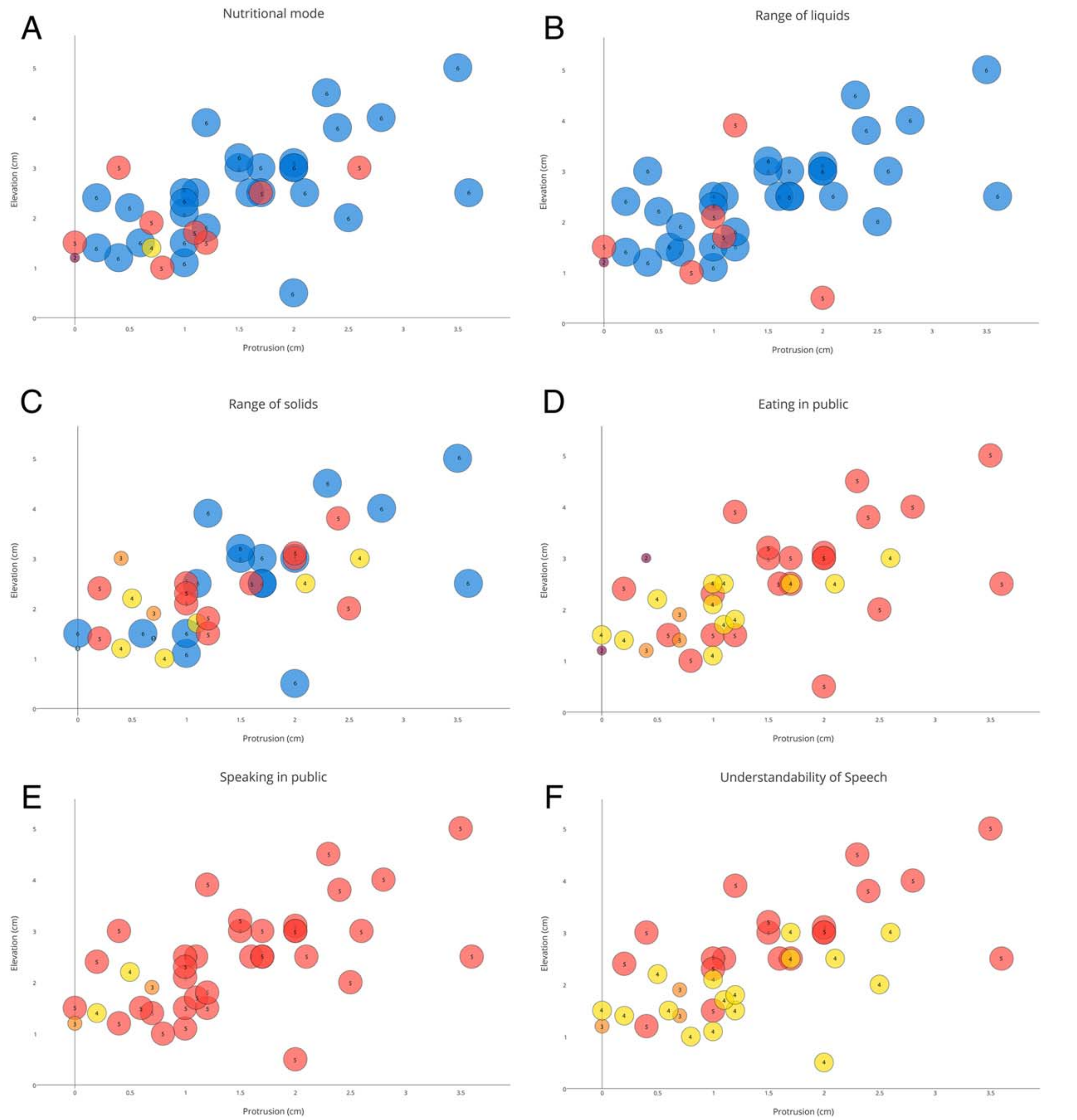

FIGURE 2. Bubble plots of a specific speech and swallowing outcome related to elevation and protrusion. For each patient, a bubble is plotted on the x-axis/y-axis coordinate of protrusion and elevation. Larger bubbles mean better (higher) scores, and the score is in the center of the bubble. (A) Nutritional mode; (B) range of liquids; (C) range of solids; (D) eating in public; (E) speaking in public; and (F) understandability of speech. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Receiver operator characteristic curve of tongue tip elevation for eating in public, speaking in public, and understandability of speech

The elevation cut points that produced reliable outcomes for eating in public, speaking in public, and understandability of speech were also similar, but required slightly higher tongue tip elevations (Table 5). When assessing eating in public, speaking in public, and understandability of speech and tongue tip elevation of 2.1 to 2.2 cm, the

TABLE 3. Correlation of elevation to oral function.

	p value	R coefficient	Mean (highest possible)	Mode
Nutritional mode	.029	0.346	5.65 (6)	6
Range of liquids	.023	0.359	5.75 (6)	6
Range of solids	.027	0.349	5 (6)	6
Eating in public	.008	0.413	4.4 (5)	5
Speaking in public	.068	0.292	4.85 (5)	5
Understandability	.0001	0.644	4.45 (5)	5

TABLE 4. Correlation of protrusion to oral function.

	p value	R coefficient	Mean (highest possible)	Mode
Nutritional mode	.027	0.360	5.65 (6)	6
Range of liquids	.071	0.288	5.75 (6)	6
Range of solids	.010	0.403	5 (6)	6
Eating in public	.0001	0.551	4.4 (5)	5
Speaking in public	.005	0.437	4.85 (5)	5
Understandability	.031	0.342	4.45 (5)	5

rectangle tongue hemiglossectomy reconstruction was able to reliably produce maximum scores (Table 2).

Receiver operator characteristic curve of tongue tip protrusion

The protrusion cut points that produced reliable outcomes for nutritional mode, range of liquids, range of solids, eating in public, speaking in public, and understandability of speech were similar (Table 5). When a tongue tip protrusion of 0.8 to 1.0 cm was obtained, the rectangle tongue hemiglossectomy reconstruction was able to reliably produce maximum scores in nutritional mode, range of liquids, eating in public, and speaking in public. At this same level of protrusion, this reconstructive approach can reliably produce scores of 4 or greater for range of solids and understandability of speech (Table 2). As with tongue elevation, these findings relating to range of solids may be related to radiation but the number of patients was too small in this cohort to assess patients with and without radiation for a particular functional outcome.

DISCUSSION

We hypothesized that there is a range of tongue elevation and protrusion that the rectangle tongue reconstruction can achieve and that these metrics can be used to model the speech and swallowing outcomes that result from this reconstructive approach. We were able to demonstrate that rectangle tongue hemiglossectomy reconstruction was able to reliably produce the majority of our speech and swallowing outcomes, and hope that this statistical approach could be used in the future to guide surgeons to compare different reconstructive techniques.

The linear regression analysis showed that greater elevation and protrusion measurement was associated with higher scores in the majority of speech and swallowing outcomes (Tables 3 and 4). Elevation of the tongue was most strongly correlated to understandability of speech. It is possible that understandability is related to elevation because patients with higher elevations are able to obtain premaxillary contact that would aid in the production of alveolar consonant and affricate sounds.

Protrusion of the tongue was most strongly correlated with eating in public. It is also likely that eating in public is related to protrusion because greater protrusion helps with the "finger function" of the tongue. The "finger function" is a function of the tip of the tongue that helps bring food into the oral cavity, helps manipulate food during the oral phase of swallowing to form a bolus, and helps clear the oral sulci of residual food. These "finger functions" likely make patients more comfortable in public situations.

We were able to use a novel statistical modeling approach using ROC curves to treat a reconstructive approach like a material that was being used to create a device. Modeling with ROC curves using the elevation or protrusion metrics allows us to statistically relate metrics to the functional outcomes of speech and swallowing. By virtue of obtaining a statistically significant result, it shows that elevation and protrusion are related to the consistency of food, understandability of speech, speaking, and eating in public. This approach validates using these metrics as guiding principles in oral cavity reconstruction. Using the ROC curves allowed us to determine the statistically significant cut points that could reliably produce the speech or swallowing outcome of interest for this reconstructive approach. These cut points are important

TABLE 5. Receiver operating characteristic model: Elevation and protrusion cutpoints that are reliably associated with a functional outcome.

Functional outcome	Value reliably obtained	Sensitivity	Specificity	AUC	ROC curve *p* value
Elevation cutpoint of 1.8–1.9 cm					
Nutritional mode	6/6	77%	70%	0.707	.04
Range of liquids	6/6	78%	71%	0.763	.03
Range of solids	≥4/6	72%	60%	0.698	.05
Elevation cutpoint of 2.1–2.2 cm					
Eating in public	5/5	73%	65%	0.721	.02
Speaking in public	5/5	69%	75%	0.771	.08*
Understandability	5/5	90%	79%	0.858	.001
Protrusion cutpoint of 0.8–1.0 cm					
Nutritional mode	6/6	83%	60%	0.714	.04
Range of liquids	6/6	64%	63%	0.701	.09*
Range of solids	≥4/6	83%	100%	0.724	.03
Eating in public	5/5	85%	100%	0.782	.003
Speaking in public	5/5	83%	100%	0.918	.007
Understandability	≥4/5	81%	100%	0.866	.04

Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.
* Most patients scored 5.

because they can both guide the surgeon on what metrics to obtain for the reconstruction and to be used to inform patients with respect to their expected functional outcome.

It is important to understand that the ROC curve informs the surgeon about the reproducibility and reliability of the reconstructive approach. A statistically significant curve cannot be generated if the outcomes of the reconstruction are inconsistent. In many scientific fields, this is an important application of the ROC curve. The ROC curve is used to understand an expected outcome relating to a material after repeated trials or experiments.

Although 2 of the 6 functional outcome measures have been validated (PSS-HN), the remaining 4 questions measuring patient's mode of nutrition, speaking in public, range of liquids, and range of solids have not been validated. These questions are shown in Table 2 for the readers to make their own assessment.

Whereas there are a number of different approaches to reconstruction of hemiglossectomy defects, there continues to be a lack of metrics for reconstruction that relate to functional outcomes. Previously described techniques include the bilobed,[2] lambdoid,[3] and conical[4] reconstructions. Comparisons across these studies are currently difficult. First, these studies evaluate varying defects, including patients who underwent soft tissue resections with those who underwent soft tissue resections and mandibulectomy. The different defects would change the principles of reconstruction and make comparison difficult to a selected cohort of patients with a hemiglossectomy defect. Second, the speech and swallowing outcomes of interest are reported but with no associated metrics, therefore, direct comparison to this study is difficult.

Comparisons between functional outcomes in hemiglossectomy reconstructions has been performed by Tarsitano et al.[8] They compared 12 hemiglossectomy defects reconstructed with a radial forearm transplant to 14 hemiglossectomy defects reconstructed with anterolateral thigh transplants. Although they do not comment on the volume of reconstruction, they showed slightly better swallowing outcomes in the anterolateral thigh flap group. This type of study is very useful. If there were metrics that were related to the functional outcome, then direct comparison between different reconstructive techniques would be simpler and would allow us to determine reproducibility of techniques.

CONCLUSION

Rectangle tongue reconstruction was effective at achieving sufficient tongue tip elevation (range, 1. 8–1.9 cm) to optimize the assessed functional outcomes except range of solids (required moisture). Slightly higher elevation (range, 2.1–2.2 cm) optimized speaking and eating in public. This reconstruction was effective at achieving tongue tip protrusion (range, 0.8–1.0 cm) to maximize all functional outcomes except range of solids and understandability of speech in which the functional outcome reliably achieved was greater than 4. Other reconstructive approaches should be evaluated using this statistical approach to compare the relative strengths and weaknesses to demonstrate the reliability of a particular reconstruction and to work toward improving on the functional outcomes for patients.

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