EFFICACY OF SPEECH AID PROSTHESES FOR ACQUIRED DEFECTS OF THE SOFT PALATE AND VELOPHARYNGEAL INADEQUACY—CLINICAL ASSESSMENTS AND CEPHALOMETRIC ANALYSIS: A MEMORIAL SLOAN-KETTERING STUDY

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Abstract: *Background.* Restoration of speech after surgical resection for oropharyngeal cancer traditionally includes maxillofacial prosthetic intervention. Relatively few publications with objective speech outcomes exist. The purpose of this study was to evaluate speech outcome relative to the size of the surgical defect, the type of speech prosthesis, and the height and position of the speech bulb in relation to the posterior pharyngeal wall in the nasopharynx.

Methods. Fifty-five patients treated at the Memorial Sloan-Kettering Cancer Center Dental Service who underwent ablative cancer therapy were evaluated. All patients were 4 months or longer after surgery and were using a speech aid or obturator prosthesis at the time of the study. Speech samples for percent intelligibility and perceptual evaluation were collected and analyzed, in addition to aeromechanical measurements of palatopharyngeal function. Lateral cephalograms were taken while wearing the prosthesis using a radiopaque marker placed on the posterior aspect of the prosthesis for evaluating the height and position of the prosthesis obturator–speech bulb component.

Results. After adjustment for the differences between listeners, findings revealed that as the percentage of resection of palate or tongue increased, the intelligibility of speech decreased. Aeromechanical assessment of speech was the only outcome measure sensitive to the type of speech prosthesis. The position of the speech bulb component, as well as the angle measured, was correlated with the percent intelligibility. The amount of the prosthesis physically contacting the posterior pharyngeal wall was not significantly associated with any of the functional outcome measures.

Conclusions. Speech aid and obturator prostheses contribute to a higher percentage of intelligible speech. A difference in intelligibility exists in relationship to the position of the prosthesis and the anterior tubercle of the atlas vertebrae (C1), both statistically and clinically. The position for optimal speech could not be specifically located mathematically (ie, 3 mm or 3 degrees inferior to the anterior tubercle of the atlas vertebrae) from the analysis. Subjective ratings of the efficacy of the obturator–speech bulbs by the clinicians did not correspond to the percent

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intelligibility. A strong statistical and clinical correlation exists supporting the efficacy of speech bulb–obturator intervention after velopharyngeal insufficiency for improved intelligibility of both words and sentences. © 2005 Wiley Periodicals, Inc. *Head Neck* **27:** 195–207, 2005

Keywords: speech aid prosthesis; cephalometric angle; velopharyngeal inadequacy; acquired defects of the soft palate; maxillofacial prosthodontics

Intelligibility of speech is usually altered after ablative surgical resection for many oropharyngeal cancers. Several methods of restoring patients to near presurgical speaking ability have been used throughout the years, including speech aids and obturator prosthetic appliances. Most recently, microvascular free-flap tissue transfers have also been attempted for optimal restoration of speech for acquired defects.

Palatopharyngeal insufficiency is usually managed prosthetically by fabrication of an obturator, a speech aid, or an obturator combined with a speech aid–component prosthesis. Obturators alone are customarily used to restore an acquired hard palate opening and/or contiguous alveolar structures.[1] Speech aid prostheses are removable prostheses usually required to restore an acquired or congenital defect of the soft palate with the central component extending into the pharynx to separate the oropharynx and nasopharynx, thereby allowing completion of the palatopharyngeal sphincter.[1]

Ablative cancer surgeries of the head and neck encompassing more than two anatomic sites (ie, hard palate, soft palate, tonsil, lateral pharyngeal wall, base of tongue) most often require an obturator with a speech aid component to adequately restore the patient's speech to a functional level. This additional speech aid component to the obturator is usually placed superiorly to any remaining soft palate and contacts the lateral and posterior pharyngeal wall, thus closing the anterior defect of the hard palate in addition to the posterior defect of the soft palate, ultimately aiding in speech intelligibility and preventing foods and liquids from leaking through and out of the nasal cavity.

The purpose of this study was to answer the following: (1) Does the size of the surgical defect (percentage of soft palate, hard palate, and tongue removed) affect functional speech outcome? (2) Does the total height of the posterior aspect of the prosthesis contacting the posterior pharyngeal wall affect functional speech outcome? (3) Does the position of the speech aid component in relationship to the anterior tubercle of C1 and the palatal plane, as measured by cephalometric angles and linear measurements, affect functional speech outcome? (4) Is the overall subjective rating of the speech prosthesis by the maxillofacial prosthodontist consistent with ratings of the patient's intelligibility?

MATERIALS AND METHODS

Patients. The Memorial Sloan-Kettering Cancer Center (MSKCC) Dental Service database of patients treated from January 1990 to March 2001 was used to generate a list using ICD-9 codes of patients who underwent soft palate resection as part of ablative cancer therapy and the types of prostheses delivered. Two hundred forty-one patients were identified as having a total or partial soft palate resection and fitted with an obturator prosthesis alone, an obturator combined with a speech bulb component, and/or a speech bulb prosthesis alone. Patients were at least 4 months after surgery. Patients were excluded from this study for reasons of geographic limitations (ie, living overseas), if English was not their primary language, or if they were deceased. After revising the list using these exclusion criteria, 132 patients remained. Starting at the beginning of the alphabetical list, the first 55 patients who met the requirements and consented to participate were appointed for the study. Before involvement in the study, the patients gave informed consent for the investigators' evaluation of their medical and surgical data, speech evaluation, and cephalometric analysis.

The biographical, medical, and surgical data collected for each patient included the hospital identifying number (used throughout the study to blind the evaluators for speech and cephalometric evaluation), age, diagnosis, TNM classification and stage, date of surgical procedure, anatomic regions resected, radiation dosage with number of fractions, tobacco use history, whether or not trismus was present (defined by evaluators as interincisal or ridge-ridge opening < 20 mm), type of prosthesis (speech aid, obturator, obturator with speech aid component), type of reconstructive surgery if applicable (rectus abdominus, radial forearm flap, radius, fibula scapula, latissimus dorsi, iliac, or temporalis, microvascular free flap), and a rendering of a subjective overall rating of the efficacy of the prosthesis using a 5-point Likert scale (1, best; 3, acceptable; 5, not acceptable by the maxillofacial prosthodontist who fabricated the prosthesis). The anatomic areas involved in the ablative surgery were also documented on a schematic design (Figure 1). The biographical, medical, and surgical data are presented in Table 1.

The number of anatomic regions that were involved in the surgery was collected (Figure 2) and summarized (Table 2). Every patient had some portion of the soft palate removed.

Functional Speech Measures and Evaluations. The speech evaluations consisted of both aeromechanical and perceptual assessments, completed both with and without the patient's prosthesis in place. A speech-language pathologist from an outside (non-MSKCC) medical facility collected data using a standard protocol. The PERCI-SARS (Microtronics Corporation, 1999) was used to collect the aeromechanical data (oral and nasal air pressure and nasal air flow) necessary for the estimation of palatopharyngeal orifice area during speech (Figure 3).[2] Oral air pressure was collected by a polyethylene catheter placed on top of the tongue, posterior to the maxillary incisors, and nasal air pressure was collected by a polyethylene catheter suspended in a foam cork designed to fit one nare of the patient. Nasal air flow was collected by a polyethylene tube sized to fit securely in the other nare. Patients were asked to produce repeated

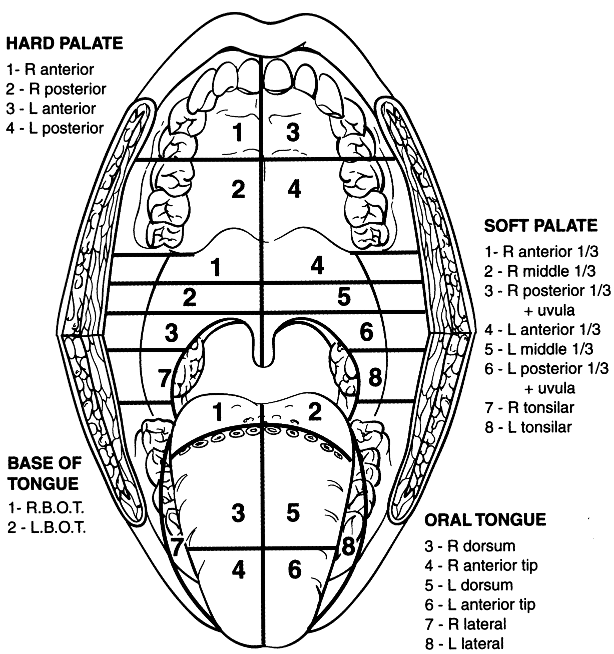

FIGURE 1. Diagram of anatomic areas possibly resected for individual patient. © MSKCC Medical Illustration 2004.

Table 1. Biographical data of patients who participated in the study.

	Obturator (n = 12)	Obturator w/ speech aid (n = 24)	Speech aid (n = 19)	Total (n = 55)
Sex				
Male	5	13	11	29
Female	7	11	8	26
Age, y				
Range	13–82	44–81	30–80	13–82
Mean	64	64	57	62
Tobacco use				
No. pts, yes	3	9	11	23
Tobacco use history, y				
11–15	1	2	6	9
16–20	0	3	1	4
21–25	1	1	0	2
26–30	1	2	1	4
36–40	0	1	1	2
46–50	0	0	2	2
T classification—initial				
T1	0	0	0	0
T2	1	1	4	6
T3	2	2	6	10
T4	5	12	5	22
Not reported	4	9	4	17
Initial stage				
II	1	1	2	4
III	2	2	5	9
IV	5	12	8	25
Not reported	4	9	4	17
Surgical reconstruction				
Fibula free flap	0	1	0	1
Radial forearm flap	0	0	5	5
Radial free flap	0	0	1	1
Temporalis flap	0	1	1	2
Pectoralis flap	0	0	1	1
Irradiation				
No. pts, yes	6	18	15	39
Range, Gy	40–66	63–72	50–70	40–70
Mean, Gy	60	66	65	64
Trismus				
No. pts, yes	0	2	2	4

utterances of two stimulus words (papa; hamper). With the PERCI-SARS software, the palatopharyngeal orifice area was calculated by placing cursors on the pressure peaks for the /p/ sounds in both words.

In addition to the palatopharyngeal area, the nasal cross-sectional area during quiet breathing was calculated for each patient using the PERCI-SARS.[3] The measures required for calculation of nasal cross-sectional area were gathered in the following manner: (1) oral air pressure collected by a polyethylene catheter placed on top of the

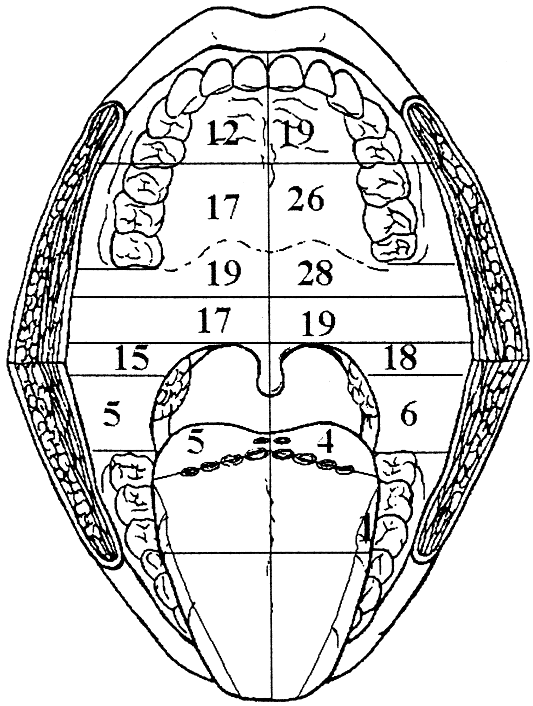

FIGURE 2. Anatomic resection sites and the number of patients with that area removed. Numbers will add up to more than 55, because patients can have multiple resection areas. © MSKCC Medical Illustration 2004.

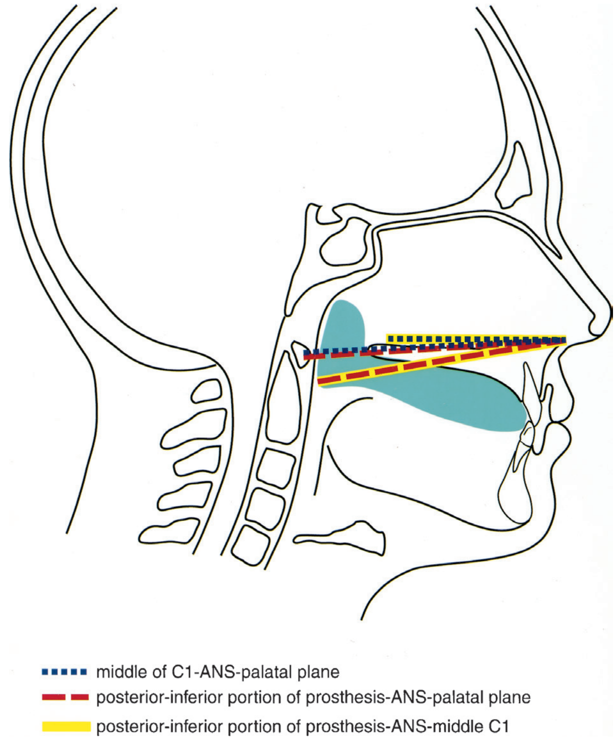

FIGURE 3. Diagram of lateral cephalometric radiograph with prosthesis in place for individual measurements. © MSKCC Medical Illustration 2004. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

tongue, just posterior to the maxillary incisors; (2) nasal air pressure collected by a polyethylene catheter suspended in a nasal mask that fit securely around the nose; and (3) nasal air flow collected by a heated pneumotachograph that was connected to the same nasal mask in the suspended polyethylene tube. With the PERCI-SARS software, the nasal cross-sectional area was calculated by placing cursors on the pressure peaks for five inspiratory and expiratory gestures for each patient.

Table 2. Number of patients in each group with percentage of hard and soft palate removed as determined by examiners. Please refer to Figure 2.

	Obturator (n = 12)	Obturator with speech aid (n = 24)	Speech aid (n = 19)	Total (n = 55)
% of hard palate resected				
4/4 (100) (bilateral maxillectomy)	1	1	0	2
3/4 (75)	0	2	0	2
2/4 (50)	8	20	1	29
1/4 (25)	2	0	4	6
None resected	1	1	14	16
% of soft palate resected				
6/6 (100)	0	1	1	2
5/6 (83)	0	0	0	0
4/6 (67)	0	0	7	7
3/6 (50)	0	4	5	9
2/6 (33)	2	7	3	12
1/6 (17)	10	12	3	25

Speech samples for intelligibility measures and perceptual evaluations were collected in a quiet, but not sound-proofed, room using a portable cassette recorder (Sony TCM-5000EV), with an external microphone (Sony ECM-MS907) at a standardized distance of 2 feet from the patient. For intelligibility purposes, speech stimuli included 50 words and 22 sentences that were randomly generated by the Computerized Assessment of Intelligibility of Dysarthric Speech (CAIDS) (Pro-Ed, Austin, TX).[4] Patients read one set of stimuli while wearing their prosthesis and a different set without the prosthesis. Most of the 39 irradiated patients reported xerostomia; however, water was not provided during the speech analysis. Percent intelligibility was calculated using four "naive" listeners who transcribed what they perceived each patient to be saying. Two attending

MSKCC maxillofacial prosthodontists (JMH, IMZ), an MSKCC maxillofacial prosthodontic fellow (GCB), and an untrained layperson, who had no prior patient contact, transcribed the speech samples. The samples were played on the same portable cassette recorder as the recordings were made, and the listeners were allowed to listen to each sentence twice, whereas the individual words could only be listened to once. All four listeners used a headset. Each listener chose a comfortable level of loudness with the headsets in place. These transcriptions were compared with a key stored in each patient's file, so that a percentage of correctly identified words could be calculated. Each listener retranscribed approximately 10% of the recordings so that intrajudge measurement reliability could be assessed. The patients and the evaluators all spoke English as their first language.

For perceptual analysis purposes, each patient was asked to read the Zoo Passage, which is a non-nasal reading passage that is used routinely for assessment of nasality in North America.[5] One speech-language pathologist, who was blinded to each patient's identity as well as whether the patient was speaking with or without the prosthesis, rated each sample of speech using a 5-point Likert scale for each of the following parameters: vocal quality, vocal pitch, vocal intensity, resonance, and intelligibility. The points on the scale for each of these five parameters were defined and based on other reports of perceptual assessment of intelligibility,[6] voice,[7] and resonance.[8]

Cephalometrics. A lateral cephalogram was taken (Gendex Orthoralix SD Ceph) with the prosthesis in place. The prosthesis posterior component of the speech bulb and/or obturator had a strip of tin foil (Buffalo Tin Foil, .0005 thickness, Item # 82192, Buffalo, NY) placed on the most posterior extent of the prosthesis, from the most inferior to superior portion that appeared radiopaque on the radiograph for measurement purposes. The maxillofacial prosthetic fellow took all the lateral cephalograms. The Department of Diagnostic Radiology digitized the radiographs in the standardized manner by the same technician with measurements completed using radiologic analysis software (GE PathSpeed Web 8.1, GE PACS Web Server Image and Information Gateway). The maxillofacial prosthetic fellow transferred all of the measurements from pixels to millimeters, with 10% of the lateral cephalographs selected at random measured again for reliability purposes. The angle formed by the most posteroinferior portion of the prosthesis to the anterior nasal spine (ANS) through the anatomic hard palate was recorded (Figure 3). The angle formed from the same line from the most posteroinferior portion of the prosthesis to the ANS to the middle of the anterior tubercle of C1 was also recorded (Figure 3), in addition to the angle made from the middle of C1 to the ANS to the hard palate (Figure 3).

The most posteroinferior point was measured to the most superior position for the maximum height of the prosthesis. In addition, the total height of the posterior wall of the prosthesis making contact with the anterior tubercle and the total height of C1 were measured and recorded. The amount of the prosthesis superior, parallel, and inferior to C1 was measured and reported. If the overall prosthesis was either inferior or superior to the anterior tubercle, the distance from the middle of the tubercle was then measured and recorded. Finally, the distance of the inferior portion of the external auditory meatus ring marker to the middle of C1 was measured and recorded.

Statistical Methods. When comparing assessments measured both with and without the prosthesis in place, one of two tests was used. For continuous assessments, a paired *t* test was used; for categorical assessments, a test for marginal homogeneity (an extension of McNemar's test) was used. Both tests take into account the paired nature of the data. The former tests for differences in the mean values of the assessments, whereas the latter tests whether the distributions of the data collected both with and without the prosthesis in place are the same.

When testing for associations between independent groups of patients (where the ordering of the groups was of no interest, ie, type of prosthesis), and a continuous assessment, the Kruskal-Wallis test, was used. This test is a nonparametric test of the null hypothesis that the distribution of the continuous data collected is the same in all of the independent groups. Associations between independent groups of patients and speech evaluation data, in which the assessments data were recorded in categories (ie, on a 5-point Likert scale) and in which no inherent ordering of the values of the group and the assessment exists, were tested using the Pearson chi-square test. The null hypothesis was no association; the alternative hypothesis was general association. Comparisons between the speech outcome assessments measured as continuous data (ie, palatopharyngeal and nasal cross-sectional area) to assess correlation were analyzed using the Pearson correlation coefficient test statistic. When the objective was to compare a continuous speech outcome assessment (ie, palatopharyngeal area) to an assessment recorded in categories (ie, intelligibility), in which inherent ordering exists for both assessments, the Mantel-Haenszel chi-square test was used. Both tests test the null hypothesis of no association against the alternative of a linear association. All tests used a significance level of .05. All p values reported are from two-sided tests.

RESULTS

Patient Characteristics. Associations between patient variables and intelligibility measures were investigated with a general linear model using least-squares methodology while controlling for listener. While wearing the prosthesis, the percentage of hard and soft palate surgically resected was associated with percent intelligibility for words (p = .03); however, it was not associated with percent intelligibility for sentences (p = .83). The percentage of the tongue resected was associated with percent intelligibility for both words and sentences (p < .0001). Regarding the direction of the associations, the data indicated the presence of a negative slope; therefore, as the percentage of palate or tongue resected increased, the percent of words (and/or sentences) understood decreased. The percentage of palate resected was not associated with the aeromechanical or perceptual rating measures. On the other hand, the percentage of tongue resected was associated with perceptual judgments of vocal quality (p = .0008), vocal pitch (p = .0019), and degree of speech impairment (p = .0036). These associations were positive, so that as the percentage of tongue resected increased, the ratings of vocal tenseness and vocal pitch increased, as did the degree of speech impairment. Patients wearing their prosthesis with tongue involvement had a mean word intelligibility of 57% (p < .001) compared with patients with no tongue involvement (81%). Patients wearing their prosthesis with tongue involvement had a mean sentence intelligibility of 79% (p < .001) compared with patients with no tongue involvement (93%). The four listeners, trained and untrained, reported a range of percent intelligibility of sentences with the prosthesis from 86% to 98%. This included all three types of prostheses (median, 94%). Prosthetic intervention of the nine patients who had both palatal insufficiency and base of tongue resection had an overall percent intelligibility of sentences of statistical significance compared with overall percent intelligibility of sentences without prosthetic intervention (mean, 55%). The range of the four listeners of rating percent intelligibility of sentences without a prosthesis was 32% to 77%.

Functional Speech Outcomes. All the patients rehabilitated with obturators were able to participate in the PERCI measurements both with and without their obturator. In the group of individuals with an obturator and speech aid, 23 were evaluated with the PERCI, with one patient not being measured because of severe maxillary lip contracture that did not enable him to form the seal required for measurement. The PERCI measurements were attempted on 19 patients in the speech aid only group, with one patient unable to complete the PERCI without her prosthesis because of a psychological problem at the time of recording. The results for the PERCI measurements are shown in Table 3.

The speech recording transcriptions were graded and reported as percent intelligibility (Table 4). Listeners 1 and 2 were the two attending maxillofacial prosthodontists, listener 3 was the maxillofacial prosthetic fellow, and listener 4 was the untrained participant who had no prior patient contact. Statistical analysis revealed that when comparing the assessments of the percent of words understood and sentences understood between the four listeners, there was a difference (p = .002 and p < .0001, respectively). Listeners 1 and 4 and listeners 2 and 3 were strongly associated. The existence of these correlations does not contradict the statistical differences between the listeners, because the correlation might be that listeners are evaluating the same parameter, but they might be evaluating it differently.

When testing whether any of the functional speech measures were correlated with one another, the degree of speech impairment (measured on the Likert scale) was associated with percent intelligibility (measured by the C-AIDS), with p < .0001. The direction of the association was negative; therefore, as the degree of speech impairment increased, the percent of words and sentences understood by listeners decreased. Perceptual ratings of the degree of speech impairment

Table 3. Palatopharyngeal orifice area with and without a prosthesis: mean, number (*n*), range, and standard deviation (SD).

	PERCI with prosthesis /papa/ (mm^2)			PERCI with prosthesis /hamper/ (mm^2)			PERCI without prosthesis /papa/ (mm^2)			PERCI without prosthesis /hamper/ (mm^2)		
	Mean (*n*)	Range	SD	Mean (*n*)	Range	SD	Mean (*n*)	Range	SD	Mean (*n*)	Range	SD
Obturator	1.13 (11)	0.06–4.44	1.7	1.46 (11)	0.111–4.11	1.3	52.83 (11)	0.08–80	27.0	57.33 (11)	0.51–80	28.3
Obturator + aid	3.38 (22)	0.01–13.99	4.0	4.46 (22)	0–23.75	5.7	52.94 (22)	1.19–80	27.5	52.75 (22)	0.04–80	30.0
Aid	4.26 (19)	0.08–19.08	5.9	5.49 (19)	0.11–16.35	5.1	53.04 (18)	10.72–80	27.3	57.73 (18)	11.18–80	26.6

were not associated with nasal cross-sectional area but were marginally associated with palatopharyngeal area as measured by saying "papa" (p = .09) and associated with palatopharyngeal area as measured by saying "hamper" (p = .05). These associations were positive; thus, as the degree of speech impairment increased, the palatopharyngeal area increased as well. Perceptual ratings of vocal quality were associated with percent intelligibility assessed using words (p = .01) and sentences (p < .0001), with more abnormal vocal quality being associated with lower intelligibility. Perceptual ratings of pitch were also associated with percent intelligibility assessed using words (p = .01) and sentences (p = .005), with more abnormal vocal pitch being associated with lower intelligibility. Perceptual ratings of intensity were marginally associated with percent intelligibility assessed using words (p = .14) and associated more so with sentences (p = .03). The trends indicate that increased intensity was associated with poorer intelligibility. Perceptual ratings of resonance were associated with percent intelligibility of words and sentences (p < .0001), palatopharyngeal area during the production of the words "papa" (p = .04) and "hamper" (p = .002), and nasal cross-sectional area (p = .06). The data indicate that perceptual ratings of resonance indicative of increased hypernasality were associated with poorer intelligibility, larger palatopharyngeal areas during speech, and larger nasal cross-sectional areas during breathing.

Table 4. Median percent of words and sentences understood by the four listeners relative to the position of the speech aid–obturator prostheses.

Position	Median % words understood*	Median % sentences understood
Below C1		
Listener 1	74.0	92.2
Listener 2	80.0	99.1
Listener 3	82.0	95.5
Listener 4	66.0	87.0
Overall	74.0	93.1
At C1		
Listener 1	68.0	88.0
Listener 2	78.0	97.7
Listener 3	76.0	96.4
Listener 4	72.0	91.0
Overall	75.0	93.8
Above C1		
Listener 1	84.0	94.0
Listener 2	92.0	98.6
Listener 3	88.0	97.7
Listener 4	80.0	91.0
Overall	86.0	95.4

*p < .0001.

The different types of prostheses (speech aid, speech aid plus obturator, obturator) were tested to distinguish whether or not there was an effect on intelligibility; nasal cross-sectional area; remaining palatopharyngeal area; and perceptual assessments of vocal quality, vocal pitch, vocal intensity, and resonance. Only remaining palatopharyngeal area as measured by saying "hamper" was found to be statistically associated with type of prosthesis (p = .03). The trends indicated in the analysis suggest that the remaining palatopharyngeal area was smallest in patients wearing obturators, largest in patients wearing speech aids, and between these two in patients wearing a combination of obturator plus speech aid appliance.

The analysis of the subjective ratings by the maxillofacial prosthodontists of the efficacy of the prosthesis was found to be inconsistent with the subjective ratings of speech by the speech pathologist while the prosthesis was being worn. (The difference [p = .04] between the measures leads to the conclusion that the evaluation of what constitutes a good speech prosthesis as judged clinically includes aesthetics, stability, and comfort, and does not necessarily agree with clinical impressions of speaking function.) Generally, the maxillofacial prosthodontists "underestimated" the efficacy of speech outcome of the prostheses compared with the evaluation by the speech pathologist.

Cephalometrics. The cephalometric analysis was successfully completed on 10 of the patients (83.3%) in the obturator group. Two patients were excluded because of positioning errors as a result of kyphosis, thus resulting in inaccurate and unreliable analysis. In the obturator-with-speech-aid group, the cephalometric analysis was completed on 23 (96%) of the 24 patients, with one exclusion because of kyphosis and unreliable data. The angle measured from the most posteroinferior position of the prosthesis to the ANS through the hard palate was completed for 16 patients in this group; seven of 23 patients were excluded from this analysis because the hard palate was not clearly visible on the radiograph, thus rendering the data unreliable. The angle produced from the most posteroinferior portion of the prosthesis to the ANS to the middle of C1 was available for 20 patients; measurements on three patients in this group were not attainable because the ANS was not clearly visible on radiograph. With respect to the group of individuals rehabilitated with a speech aid, the cephalometric analysis was completed on all 19 patients. The position of C1 in relationship to the hard palate was assessed by measuring the angle made from the middle of C1 to the ANS through the hard palate. The angles across all groups ranged from 0.1° to 8.9°, with the mean angle formed being 3.2° (95% CI, 2.6°–4.0°).

Cephalometric angles and the overall height of the prosthesis and the height of the posterior wall of the prosthesis contacting the posterior pharyngeal wall for each patient in all three groups were measured (Table 5). The results showed no associations between the angle from ANS to HP and percent intelligibility using words ($p = .26$) or sentences ($p = .38$) nor between the angle from C1 to ANS and percent intelligibility using words ($p = .27$) or sentences ($p = .15$). Finally, no other speech evaluation measures (ie, PERCI and subjective assessments) were associated with cephalometric angles.

The height of the posterior wall of the prosthesis contacting the posterior pharyngeal wall was measured in relation to the amount below, at, and above C1. In the obturator group, one patient had 3.26 mm of the prosthesis below C1. Seven of the patients had a portion of the prosthesis at C1, ranging from 0.19 mm to 5.49 mm (average, 3.36 mm; median, 3.91 mm). Eleven of the patients had a portion of the prosthesis above C1, ranging from 3.26 mm to 17.67 mm (average, 8.56 mm; median, 8.93 mm). Of these 11, five of the patients did not have any amount of the prosthesis at C1, and the distance the prosthesis was above C1 ranged from 0 mm to 10.23 mm (average, 3.68 mm; median, 2.42 mm).

In the obturator-plus-speech-aid group, four patients (17%) had 0.65 mm to 7.07 mm (average, 3.09 mm; median, 2.33 mm) below C1. Seventeen (71%) patients had 1.02 mm to 9.95 mm (average, 5.76 mm; median, 5.67 mm) of the posterior wall of the prosthesis at C1. Twenty-two (92%) of the patients had from 1.21 mm to 27.99 mm (average, 8.27 mm; median, 8.00 mm) of the prosthesis above C1. Of these 22 patients, five (23%) of them did not have any amount of the prosthesis at C1, and the distance the most inferior portion of the prosthesis was above C1 ranged from 2.42 mm to 11.25 mm (average, 6.15 mm; median, 4.98 mm).

In the speech aid group, six of the patients (32%) had a portion of the prosthesis below C1, ranging from 1.86 mm to 12.28 mm (average, 6.26 mm; median, 5.58 mm). Eighteen (95%) of the patients had a portion of the prosthesis at C1, ranging from 1.40 mm to 10.51 mm (average, 5.88 mm; median, 5.49 mm). Fourteen (74%) of the patients had a portion of the prosthesis above C1, ranging from 0.37 mm to 8.56 mm (average, 3.24 mm; median, 2.74 mm). None of the patients in this group had their prosthesis completely above C1.

The aeromechanical, intelligibility, and perceptual assessments of speech were investigated with respect to position of the speech prosthesis. Because of the differences in intelligibility scores between listeners, adjustments for the listeners were made when analyzing whether the position of the prosthesis affected percent intelligibility. The speech evaluation assessments that were analyzed were the nasal cross-sectional area; palatopharyngeal area; percent intelligibility; and perceptual judgments of vocal quality, vocal pitch, vocal intensity, and resonance. Of these evaluation assessments, only percent of word intelligibility, after adjusting for the listener difference, was associated with the position of the speech aid obturator prostheses, as demonstrated in Table 4 ($p < .0001$).

Throughout the three groups, the amount of the prosthesis contacting the posterior pharyngeal wall was marginally associated with the percent

Table 5. Summary of literature review of investigations describing surgical reconstruction.

Author	No. patients	Reconstruction procedure	Evaluated by speech pathologist	Results
Gillespie et al[9]	18	11 uvulopalatal flap alone 7 uvuloplatal flap + flap	No	73% normal speech as evaluated by the examiner.
Zeitels et al[11]	10	Myomucosal SCARF	No	3/10 were noted by the examiner to have resonance change that was mild in nature.
Zohar et al[13]	5	Uvulopalatal flap	No	Postoperative rhinolalia was unremarkable as evaluated by the examiner.
Brown et al[10]	18	Radial forearm free flap + superiorly based pharyngeal flap	Yes	1/4 resections: normal speech; 1/2 resections: 3 of 4 normal speech; >3/4 resection: normal speech as evaluated by medical staff, speech pathologist, and untrained listeners.
Yoshida et al[12]	10	Radial forearm free flap	No	Obturator pts (n = 4), 89% intelligibility preoperative 29% postoperative, w/o obturator 68% w/ obturator Flap pts (n = 6) 87% intelligibility preoperative 58% postoperative

intelligibility of words understood (p = .13) and less associated with the sentences understood (p = .25), controlling for the listeners. In this case, the direction of the association was negative. Thus, as the amount of the prosthesis contacting the posterior pharyngeal wall increased, the percent of words and sentences understood decreased. There were no associations noted between the cephalometric measures and the aeromechanical and the remaining perceptual speech outcome measures.

DISCUSSION

Our study included multiple parameters regarding outcome assessments of speech intelligibility with and without a speech prosthesis. The diagnosis, tumor size, anatomic sites resected, type of prosthesis, percent intelligibility using individual words and sentences as perceived by one untrained listener and three trained listeners with and without the prosthesis, and formal speech evaluation (including both aeromechanical and perceptual measures) by an independent speech pathologist were all used with univariate and multivariate analyses.

The diagnosis, staging, and surgical resection areas were included and recorded in such detail as an attempt to compare our speech outcomes with patients in other studies who received microvascular flaps for similar surgeries. Most other studies report that most patients reconstructed with free flaps had tumors ranging from T1 to T3.[9–15] Most of this study population had tumors ranging from T3 to T4. Our results indicated that when wearing a prosthesis, patients with larger surgically acquired defects (more anatomic regions in the ablative surgery) tended to receive lower percent intelligibility of speech scores, especially for single-word utterances, than did the patients with smaller defects. However, overall percentages of correctly interpreted sentences had an overall excellent high intelligibility score. Several investigations and reports (Table 5), including this study, attempt to relay this information diagrammatically. Many of these reports are difficult to interpret, with limited diagrams to quantify the surgical defects and reconstructive efforts by labeling with fractions or percentages, our study included.[9–15] Other reports attempt to quantify the surgical defects and reconstructive efforts by labeling with fractions or percents.[10,11]

Unlike other studies that have tried to recreate a functional velopharynx using surgical flaps,[10] the flaps used in the patients in this study were not intended to reconstruct the soft palate to a functional form but were used primarily for protection and lining of the lateral and posterior pharyngeal walls, therefore allowing access into the nasopharynx for prosthetic rehabilitation. Our study used a percentage of the actual words transcribed correctly from patient readings and not a visual scale converted to a percentage. In this study, all words and sentences that the patients read were randomly generated to prevent such a learning effect. In addition, the C-AIDS test provides a quantitative objective rating of intelligibility rather than a visual analog scale. Regardless, whereas the two percent intelligibility scores from both studies were measured in different manners, both measure the same end point (ie, the higher the percentage, the more intelligible the speech) and can be interpreted in relation to one another with these previous issues in mind.

The ratings of patients' readings of the Rainbow Passage in the Brown study by five untrained listeners and a speech pathologist resulted in an average score of 81% for the pharyngeal plus radial forearm flap patients and 62% for the radial forearm flaps alone by the untrained listeners. The speech pathologist scored 94% for the pharyngeal plus radial forearm flap group and 89% for the radial forearm flap alone group on average. In the current MSKCC study, the untrained listener, who had no prior patient contact, averaged 87% for patients wearing their prosthesis and 53% without the prosthesis. The averages of the three trained listener scores with and without the prosthesis were 93% and 67%, respectively. Therefore, if it were assumed that the patient cohorts in the two studies are similar, it would seem that results with a speech aid prosthesis are comparable or even more favorable for reconstruction with a pharyngeal plus radial forearm free flap. However, caution is warranted when comparing the results of these two studies because of the different methods in which speech intelligibility was measured.

The results of this study also revealed that the percentage of base of tongue resected had an impact on the percent intelligibility of both word and sentence intelligibility, which has been previously described in the literature.[16] These patients experienced a change in their articulation pattern that might have influenced the intelligibility scores.

The cephalometric analysis required that the original films be digitized so that they could be analyzed with the computer software. Once digitized, the software used reported length measurements in pixels. A cephalogram was then taken with an 11-mm ball bearing held under the upper lip, measured three times in pixels, and thus enhancing a conversion from pixels to millimeters. The angle measurements were evaluated to investigate whether a reliable intraoral reference point exists to use when fabricating the prostheses for maximum functional outcome.

The cleft palate literature, which typically reports on congenital defects of children, debates over using the palatal plane (a line drawn from ANS to PNS) or the anterior tubercle of C1 as reference points for placement of the inferior border of the speech aid prosthesis.[17–21] The findings of our study suggest that the angle formed by measuring from the most posteroinferior portion of the velopharyngeal portion of the speech aid obturator to ANS to either the hard palate or the middle of C1 did not have any affect on speech outcomes. Our study population differs from suggested regions of placement of the speech bulb in the patient with cleft palate with palatal insufficiency in regard to age of the patients, and all of our defects were acquired. An important factor in speech outcomes in this study was the amount of the speech aid–obturator prosthesis inferior, at, and superior to C1. Although the results of our study support that changing the position of the speech aid–obturator prosthesis does influence the percent intelligibility only, the data are not conclusive as to where the optimal position is mathematically (ie, 3 mm or 3° superior to C1). In our study, intelligibility of words seemed to be influenced most by the height of the prosthesis, with intelligibility scores being highest when the prosthesis was positioned above C1. For sentence intelligibility, which is the essence of verbal communication, the height of the prosthesis seemed to have little influence on intelligibility results. It is noteworthy that both perceptual ratings of speech impairment and aeromechanical assessment of velopharyngeal function were not sensitive to the position of the prosthesis with respect to C1.

Conclusions regarding the amount of the speech aid–obturator prosthesis actually contacting the posterior pharyngeal wall during function (speech) to produce superior intelligibility also could not be drawn. Our data showed marginal association between contact height and percent intelligibility for words, and even less for sentences. The nasopharyngeal extension of the prosthesis should be functionally developed and modified to the confines of the muscles of the lateral and posterior pharyngeal walls.[17–21] The proportion of the speech aid–obturator prosthesis in our study contacting the posterior pharyngeal wall ranged from 3.44 mm to 36.83 mm overall, and again, did not associate with percent intelligibility. Therefore, we can conclude by our study that obturating acquired defects is similar to the findings of other cleft palate investigations.

The aeromechanical evaluations within this study reveal a trend in the data that suggests defects requiring a speech aid will be harder to resolve than those requiring an obturator (or an obturator plus a speech aid). In addition, perceptual ratings by the speech-language pathologist of increased degree of speech impairment were associated with the aeromechanical findings of larger palatopharyngeal orifice areas. Although the aeromechanical measurements were sensitive to the defect and to subjective ratings of speech impairment, they were not sensitive to cephalometric measures. That the aeromechanical measures were not sensitive to angle, position, or height of prosthesis contacting the posterior pharyngeal wall is not surprising, because the estimations for orifice area are made with respect to a point of constriction, regardless of the placement of that constriction.

The results of the subjective evaluations of visual ratings of the speech aid–obturator prostheses differed in regard to speech intelligibility as defined by the maxillofacial prosthodontists and the speech pathologist. The attending maxillofacial prosthodontists' overall rating of the prosthesis included aesthetics, comfort, and stability on one Likert scale, whereas the speech pathologist had separate scales for specific vocal quality measurements and intelligibility. Witt et al[22] reported expert raters (plastic surgeon, otolaryngologist, and prosthodontist) were sensitive to differences in resonance and intelligibility but not to other aspects of voice quality. This fact led the "expert evaluators" to recommend further speech evaluation of the patients with cleft palate more often than the speech pathologist.[22] One Likert scale, which considered more variables overall, compared with another evaluating only one variable could account for the differences.

Several studies self-evaluate flap reconstructions in terms of speech without the use of independent specialists or intelligibility tests, which might or might not support their findings (Table 5). Assessment bias can result from leading to unfounded conclusions being drawn of one treatment modality being superior to another. Podol and Salvia[23] examined the evaluations of trained observers (speech pathologists) in relationship to the patients with cleft palate they were treating. They showed that knowledge of a repaired cleft affected the interpretation of nasal speech, increasing the perception of hypernasality and the recommendation for speech therapy. Consequently, assessment bias and the need for objective measurements should be considered before rendering any conclusions.

The need for independent, trained, and naive observers using an array of equipment and tests has been documented throughout the literature to draw clinical and statistical conclusions that are significant.[22,23] The use of cinefluorography, nasoendoscopy, cephalometric radiographs, and PERCI measurements of air flow and nasal area in combination with one another have been reported to contribute in optimal results.[21,24–29] It has been reported that the subjective evaluations of resonance by a speech pathologist are associated with nasal cross-sectional area, palatopharyngeal area, and percent intelligibility. Thus, a highly trained listener is likely to be sensitive to speech issues that dominate most patients included in this study. Bagnall et al[30] suggested that untrained listener assessments should also be considered to add validity to the subjective evaluations of the trained listeners. Witt et al[22] agree that "It is the perceptual speech results as judged by a patient's peer group that are crucial to patients' social function." Thus, in our study, we included both trained and untrained listeners, as well as more objective measures of speech, to complete a thorough investigation in which we could attempt to compare our results with reported results of other studies.

Our results also suggest that investigators should be cautious about the interaction of extraneous vocal quality attributes in the assessment of intelligibility. Other investigators have found that the perception of one speaking attribute might influence the perception of another dimension of speech.[31] In our study, the data revealed that perception of vocal quality, pitch, and intensity was associated with percent intelligibility outcome. Thus, in this group of patients, vocal quality, pitch, and intensity might play a role in the final assessment of a patient's intelligibility.

CONCLUSIONS

Speech intelligibility is enhanced by use of obturator–speech aid prostheses. Using the cephalometric analysis, a specific mathematical landmark could not be identified as to the position of the prosthesis that would produce optimal results. The anatomic landmark investigated in this study was the palatal plane and the anterior tubercle of C1. As a general area for an appropriate position of the prosthesis for maximum function, the palatal plane should be considered and used. After the velopharyngeal extension is developed, its relationship to C1 should be considered and ultimately evaluated by the multiple means discussed earlier. Whether or not the prosthesis should be moved superiorly or inferiorly will be dictated by the experience of the maxillofacial prosthodontist and the voice quality of the patient. Herein lies the artistic component provided by the maxillofacial prosthodontist rendering treatment.

Intelligibility scores of speech with the maxillofacial prosthesis in place were shown to be superior compared with not wearing a speech aid–obturator prosthesis. Many of the studies available for comparison of speech aids/obturators and free flap reconstruction, including the present, are retrospective and contain information that makes it difficult to directly compare one with another. Future studies should (ideally) prospectively evaluate the patient's speech before surgery, and status after surgery, at different periods of time (ie, 3 months postoperatively, 1 year postoperatively), with multiple tests being used for trending purposes. In the era of microvascular reconstructive surgery in head and neck cancer, a role exists for speech aid–obturator prosthetic intervention for maximum functional outcomes regarding restoration of speech. Speech aid or obturator prostheses intervention should be considered as an integral component of soft palate resection resulting in excellent restoration of velopharyngeal insufficiency, thus providing patients an acceptable and functional speech outcome.

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