IMPACT OF TONGUE BASE AND POSTERIOR PHARYNGEAL WALL BIOMECHANICS ON PHARYNGEAL CLEARANCE IN IRRADIATED POSTSURGICAL ORAL AND OROPHARYNGEAL CANCER PATIENTS

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Abstract: *Background.* Postsurgical oral and oropharyngeal cancer patients may experience pharyngeal clearance problems after completion of postoperative radiotherapy.

Methods. Swallowing was examined in six patients using videofluoroscopy for up to 1 year after surgery. Biomechanical analysis was used to mark movement of the tongue base and posterior pharyngeal wall during swallowing.

Results. The majority of patients experienced increased problems with pharyngeal clearance at or after their 6 month posthealing evaluation, generally 18 to 22 weeks after completion of radiotherapy. Pharyngeal residue was associated with a disruption in either tongue base or posterior pharyngeal wall movement.

Conclusions. Increased fibrosis of the pharyngeal musculature after completion of radiotherapy may have a negative impact on pharyngeal clearance in addition to any pharyngeal clearance problems resulting from surgical resection. Tongue base to posterior pharyngeal wall contact is essential but not sufficient for effective pharyngeal clearance. Sufficient duration of tongue base to posterior pharyngeal wall contact is also needed to provide adequate pharyngeal bolus driving pressure. © 2000 John Wiley & Sons, Inc. *Head Neck* **22:** 120–131, 2000.

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Surgically treated head and neck cancer patients may experience disordered swallowing function postoperatively.[1–5] Swallowing function in these patients may be affected by the degree of resection and the nature of reconstruction.[6–8] Although the oral stage of the swallow is generally more severely impaired, the pharyngeal stage of the swallow may be affected if resection includes the tongue base.[9,10] Postoperative radiation therapy is usually included as a standard part of treatment to control the spread of cancer in patients with more advanced disease. Although effective in preventing the proliferation of disease, postoperative radiation therapy to the head and neck may contribute to additional swallow dys-

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function. In a previous investigation,[11] the effects of postoperative radiotherapy on speech and swallowing function were investigated in a number of patients with resections of the oral cavity and oropharynx. Compared to nonirradiated patients matched on surgical variables, the irradiated patients had significantly reduced oral and pharyngeal swallowing performance; specifically, longer oral transit times on paste boluses, lower oropharyngeal swallow efficiency, increased pharyngeal residue, and reduced cricopharyngeal opening duration. Difficulty with the transport of more viscous consistencies may be the result of pain from mucositis during radiation treatment as well as increased fibrosis of the oropharyngeal musculature after completion of radiotherapy causing a disruption in the ability of the tongue to produce sufficient bolus driving pressure. Increased pharyngeal residue and shortened cricopharyngeal opening duration in the irradiated patients also are indications of a reduction in pharyngeal bolus driving pressure, perhaps resulting from reduced tongue base retraction. Movement of the tongue base and posterior pharyngeal wall toward each other until full contact is achieved is a key element in producing adequate pharyngeal bolus driving pressure.[12, 13] A deficit in either tongue base retraction or posterior pharyngeal wall bulging would be expected, therefore, to have an impact on movement of the bolus through the pharynx. This preliminary study used biomechanical analysis to examine tongue base and posterior pharyngeal wall movements during the swallow and their relationship to pharyngeal residue in six irradiated postsurgical patients.

MATERIALS AND METHODS

This study protocol was approved for use with human subjects by the Institutional Review Board of Northwestern University. Tongue base and posterior pharyngeal wall movements during swallows of liquid and paste boluses were analyzed from archived videofluoroscopic studies of swallow for six patients with resections of the oral cavity or oropharynx. At the time of surgery, diagrams of the amount of excised tissue were made by the patient's surgeon on standard drawings with measurement in centimeters being recorded at the maximum length, width, and depth of the excision. These dimensions were used to calculate the estimated resection volume. An assessment of the percentage of oral tongue and tongue base resected for each patient was also determined from the standard diagrams. The oral tongue was divided into two anterior quadrants and two posterior quadrants, each with a maximum possible resection of 25% for each quadrant. The percentage of oral tongue resected was the sum of percentage resected in each quadrant. The tongue base was assessed with a maximum possible resection of 100%. Each patient also received postoperative radiotherapy between 1 and 3 months after surgery. Data concerning the total amount of radiotherapy, dates of treatment, and whether the treatment field included the neck were collected.

Swallowing performance was assessed with videofluoroscopy preoperatively and at 1, 3, 6, and 12 months posthealing. Posthealing assessments were performed within a 2-week window on either side of the actual planned evaluation date. The swallow study protocol included two trials each of 1-ml liquid barium and 1-ml barium paste. These bolus types are part of the standard clinical protocol for assessing patient behavior with various food consistencies.[14] Fluoroscopic studies of swallowing in the lateral plane were recorded on 3/4 inch videotape at 30 frames per second.

Biomechanical analysis was used to mark the movements of the tongue base and posterior pharyngeal wall over time. Each video frame (1/30 s intervals) from the first swallow on each liquid and paste bolus was digitized, utilizing a Gateway 2000 80486 computer equipped with a Data Translation Image Digitizing Board (model DT2861) with interactive software.[15] The following points, lines, and angles were marked on each digitized video frame (Figure 1).

1. a point on the anterior-inferior corner of C4 that served as an "anchor point," the origin of the *x–y* coordinate system against which movement of the other structures was measured
2. a line along the vertical length of C3 from the anterior-superior corner to the anterior-inferior corner, to serve as the reference distance from which absolute movement was measured and to compensate for radiographic magnification
3. the angle of the subject's head tilt from true vertical, measured from the anterior-inferior aspect of C4 to the anterior-inferior corner of C2
4. a line from the anterior-inferior corner of C2 to a point on the posterior pharyngeal wall and a point on the tongue base at that level to measure posterior tongue base movement and an-

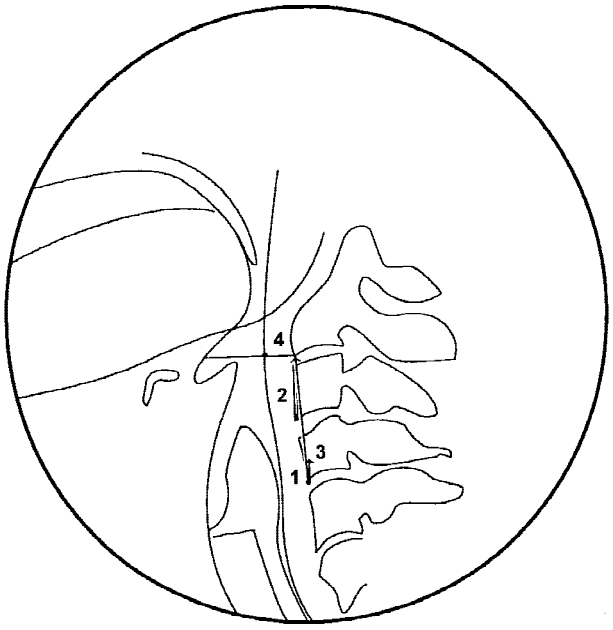

FIGURE 1. Lateral view from videofluoroscopy of swallow study with marked points and lines identified including: (1) anchor point marked at the anterior-inferior corner of C4; (2) reference distance line drawn on C3 from the anterior-superior corner to the anterior-inferior corner; (3) postural angle; and (4) line from anterior-inferior corner of C2 to a point on the posterior pharyngeal wall and a point on the tongue base at that level.

terior movement of the posterior pharyngeal wall.

The reference distance was used to correct for fluoroscopic magnification across digitized images and as an index of movement of oropharyngeal structures. To adjust for size among the patients, the vertical length of the third cervical vertebra was used as the reference distance for all studies and assigned a value of 15 units. This value was derived from calculations of the average length of C3 (15 mm), based upon our measurements of several cervical vertebrae from skeletons in our anatomy laboratory and of cervical vertebrae from videofluorographic studies in which a known reference distance was available.

Plots of structural movement over time were generated from the digitized and marked images of each subject's swallows (Figure 2). From the graphs of each subject's swallows, the following outcome measures were made:

1. distance between tongue base and posterior pharyngeal wall while at rest (units);
2. extent of tongue base retraction relative to its most anterior position prior to onset of swallow (units);
3. extent of anterior bulging of the posterior pharyngeal wall relative to rest position (units); and
4. duration of tongue base contact to posterior pharyngeal wall (s).

The extent of tongue base posterior movement was measured from its most anterior position before the onset of the swallow rather than its rest position, because the tongue base always moved anteriorly from its rest position as the oral tongue collected the bolus for transport to the pharynx. It was determined that measuring the extent of posterior movement from this anterior position better characterized tongue base movement during the swallow and its contribution to bolus propulsion than it would have if measured from its more posterior rest position.

Not all the archived videotapes were of sufficient quality for digitization. Criteria for videotape quality included visualization of the structures of interest in the lateral plane throughout the entire swallow and sufficient radiographic contrast to view areas of both high and low density. Therefore, data were not available for all six patients at each of the evaluation points.

Multiple trials from the same bolus type were averaged at each evaluation point for each patient. Because of the small number of patients and missing data at some evaluation points, statistical analyses were not performed. Average values for the duration of tongue base to posterior pharyngeal wall contact, extent of tongue base retraction, and extent of posterior pharyngeal wall bulging, as well as approximate percentage of oral and pharyngeal residue on the first swallow attempt for each bolus are graphed for each patient, who are discussed in case study format. Schematics of each patient's surgical resection are included in Figure 3; patient demographics and treatment characteristics are summarized in Table 1.

RESULTS

Patient 1. Swallow data for Patient 1 are illustrated in Figure 4. Patient 1 had analyzable archived videotapes for his 1, 6, and 12 month posthealing swallow evaluations. The distance between his tongue base and posterior pharyngeal wall at rest was 15 units. Although this patient had a relatively small surgical resection in the anterior oral cavity, he demonstrated difficulty with pharyngeal clearance as indicated by pharyngeal residue of nearly 50% on both liquid

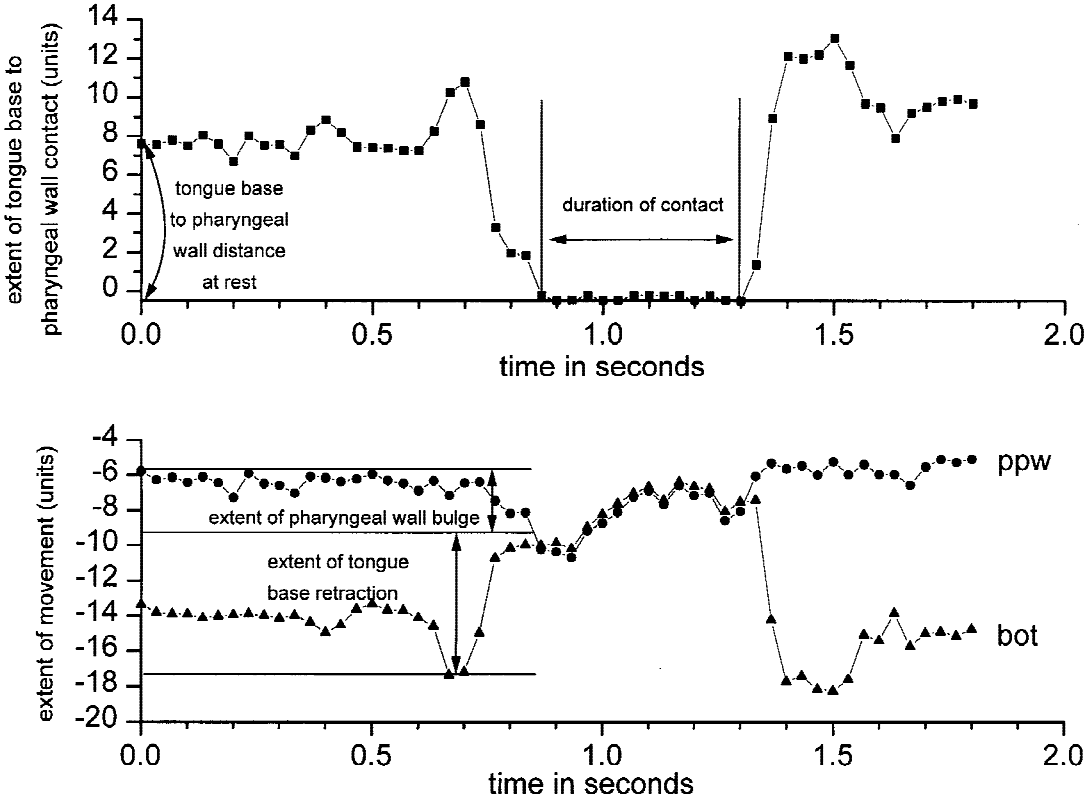

FIGURE 2. Graphs of movement in units of pharyngeal structures over time during a paste swallow of one patient. The first point on each graph indicates the structures at rest. Top graph plots the extent of tongue base to posterior pharyngeal wall contact over time (filled square). The duration of tongue base to posterior pharyngeal wall contact is measured between the two vertical lines. Bottom graph plots the extent of posterior pharyngeal wall bulge (filled circle) and extent of tongue base retraction (filled triangle) over time. Extent of movement data for each variable is measured between the horizontal lines.

and paste boluses after completing his radiotherapy. The residue increase seemed to be associated with a reduction in both tongue base retraction and posterior pharyngeal wall bulging. This pharyngeal swallow dysfunction may be the result of the effects of the patient's radiotherapy, focused not only at the area of the primary but also at both the left and right neck, which would inevitably have an impact on the pharyngeal musculature.

Patient 2. Swallow data for Patient 2 are illustrated in Figure 5. Patient 2 had analyzable archived videotapes for her 3, 6, and 12 month posthealing swallow evaluations. The distance between her tongue base and posterior pharyngeal wall at rest was 14 units. Although Patient 2 had difficulty primarily with transporting the bolus out of the oral cavity, some evidence of a pharyngeal clearance problem is apparent on liquid. Pharyngeal residue on liquid boluses increased to approximately 23% at the 6 month posthealing evaluation, which was approximately 18 weeks after completion of radiation therapy. This increase in pharyngeal residue is associated with no movement in the posterior pharyngeal wall at the 6-month assessment. The lack of movement in the posterior pharyngeal wall seemed to have an impact on pharyngeal clearance despite adequate tongue base contact to the posterior pharyngeal wall. When the posterior pharyngeal wall was able to move again at the 12-month posthealing assessment, pharyngeal residue on liquid boluses dropped. Because of the large amount of oral residue on the paste bolus, it is difficult to determine the impact of posterior pharyngeal wall movement on pharyngeal residue with the paste bolus.

Patient 3. Swallow data for Patient 3 are illustrated in Figure 6. Patient 3 had analyzable archived videotapes for his preoperative swallow study as well as his 1, 3, 6, and 12 month posthealing swallow evaluations. Patient 3 demonstrated a pharyngeal dimension between the tongue base and posterior pharyngeal wall at rest of 6.25 units preoperatively. After surgery, this

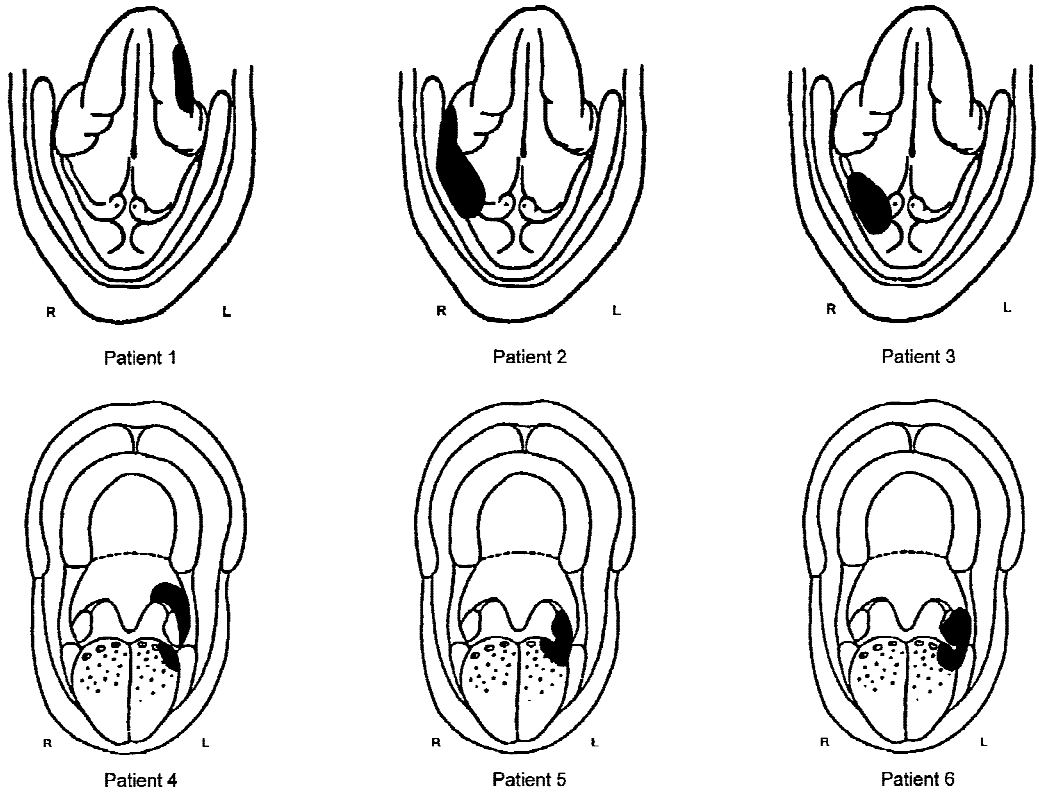

FIGURE 3. Drawings of structures resected for each patient. The dark portion of each figure indicates the extent of surgical resection.

dimension increased to 10 units probably as a result of reconfiguration of the oral and pharyngeal cavities after resection and reconstruction. Patient 3 demonstrated minimal problems with bolus transit and pharyngeal clearance on the liquid bolus. This subject's oral swallow problems are more evident on the paste bolus. Posthealing oral residue reached nearly 100%, indicating that the patient was unable to transport the bolus out of the oral cavity on the first attempt. This dysfunction is not unexpected, because this patient had an anterior oral cavity resection and was reconstructed with a pectoralis major myocutaneous flap. Problems with oral transit and clearance of the bolus from the oral cavity have been reported previously in this patient population.[9] Because of the patient's severe problems with oral transit on the paste bolus, it is difficult to determine what if any pharyngeal clearance problem this patient would have with paste.

Patient 4. Swallow data for Patient 4 are illustrated in Figure 7. Patient 4 had analyzable archived videotapes for his preoperative study as well as his 1, 3, 6, and 12 month posthealing swallow evaluations. The distance between his tongue base and posterior pharyngeal wall at rest prior to surgery was 6.5 units; after resection and primary closure, this dimension increased to 8 units at the 1-month posthealing assessment. By 12 months posthealing, the distance between the tongue base and posterior pharyngeal wall had gradually reduced to 7 units.

This patient demonstrated few problems with bolus clearance on liquids. For the paste consistency, pharyngeal residue was greatest at the 6-month posthealing evaluation, which occurred 22 weeks after completion of radiotherapy. Although the extent of both tongue base retraction and posterior pharyngeal wall bulging were at preoperative levels, the duration of tongue base to posterior pharyngeal wall contact was half that of its pretreatment duration, suggesting that the reduced duration of contact had a negative impact on pharyngeal clearance.

Patient 5. Swallow data for Patient 5 are illustrated in Figure 8. Patient 5 had analyzable archived videotapes for her 1, 3, 6, and 12 month posthealing swallow evaluations. She demonstrated a pharyngeal dimension between the tongue base and posterior pharyngeal wall at rest

Table 1. Summary of patient demographics and treatment characteristics.

Patient	Gender	Age	Tumor stage	Volume resected (cc)	% Oral tongue resected	% Tongue base resected	Other structures resected	Surgical closure type	No. days RT started after surgery	RT dose (cGy)	Field(s)	Neck dissection?
1	M	59	T2N3bM0	3	12	0	None	Primary	33	6400	Primary, left neck, right neck	Bilateral radical
2	F	64	T2N0M0	63	6	0	Rt. lateral FOM; mandible	Primary	27	6000	Left neck, right neck, anterior neck	Right radical
3	M	69	T2N2bM0	37	1	0	Ant. FOM	PMMF	25	5580	Right neck	Right radical
4	M	45	T2N0M0	10	3	1	Lt. tonsil; soft palate	Primary	25	6000	Primary	Left modified radical
5	F	62	T2N0M0	35	6	12	Lt. tonsil	Skin graft	54	6000	Left neck	Left radical
6	F	66	T3N2aM0	119	5	12	Lt. tonsil; soft palate; pharyngeal wall; mandible	Primary	21	6000	Left neck, right neck, anterior neck	Left modified radical

Abbreviations: RT, radiotherapy; FOM, floor of mouth; PMMF, pectoralis major myocutaneous flap.

of 7 units after resection and reconstruction. Patient 5 had mild to moderate problems with oral residue but did not demonstrate any difficulty with pharyngeal clearance during or after her radiotherapy. The duration of tongue base to posterior pharyngeal wall contact remained consistent across the posthealing evaluations, varying by no more than 0.05 s.

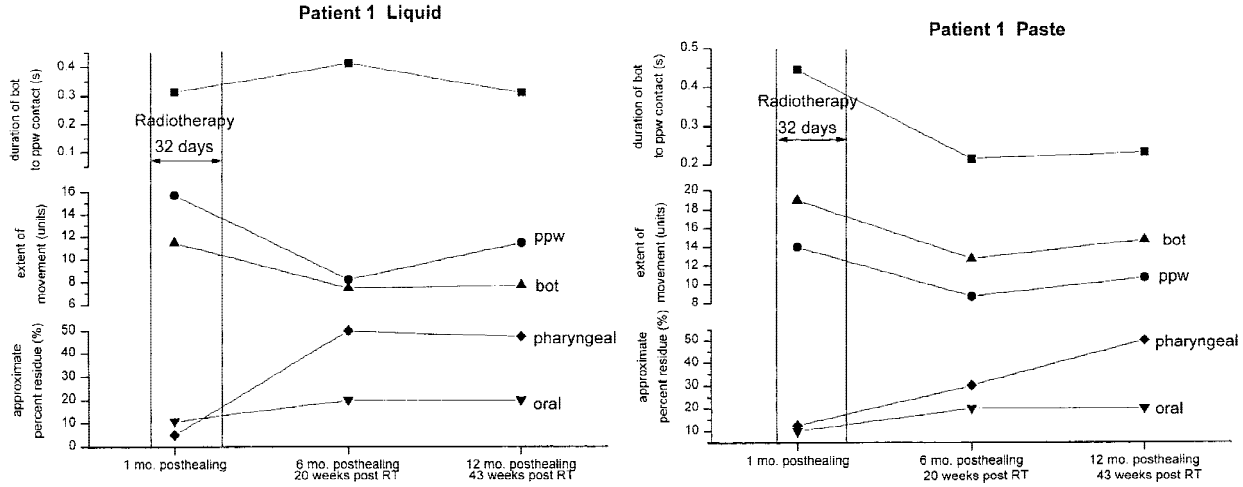

FIGURE 4. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 1. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

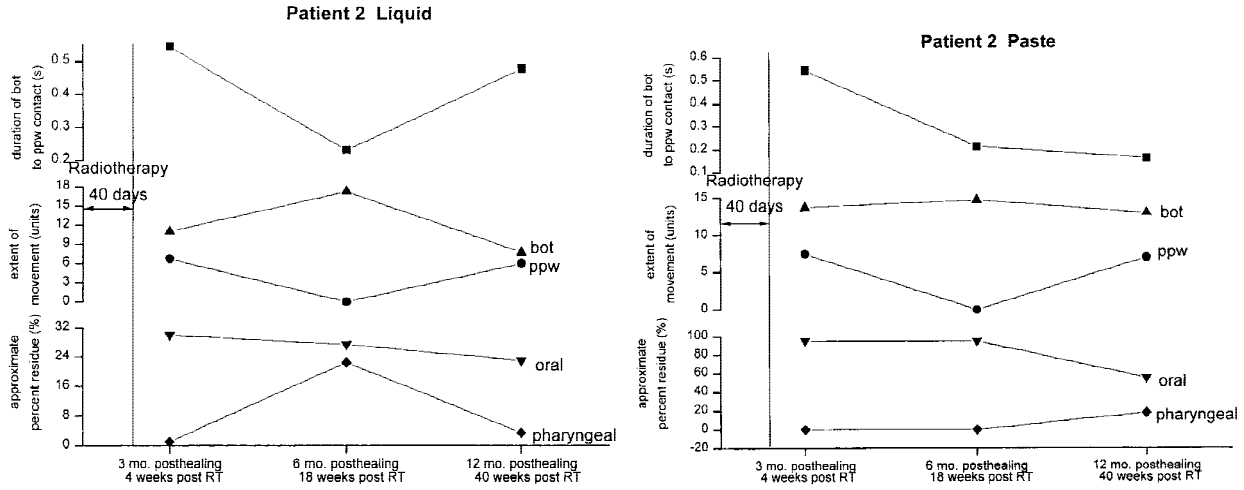

FIGURE 5. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 2. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

Patient 6. Swallow data for Patient 6 are illustrated in Figure 9. Patient 6 had analyzable archived videotapes for her 3, 6, and 12 month posthealing swallow evaluations. The distance between her tongue base and posterior pharyngeal wall at rest before surgery was 15 units; after resection of the base of tongue and primary closure, this dimension increased to 21 units at the 3-month posthealing assessment. By the 6-month posthealing assessment, the distance between the tongue base and posterior pharyngeal wall had stabilized at 19.5 units and remained there at the 12-month posthealing evaluation.

On liquid boluses, Patient 6 demonstrated more problems with oral residue that pharyngeal residue. Residue from the liquid bolus tended to pool in the anterior oral cavity where the patient had difficulty collecting the bolus. Primary closure of the oropharyngeal defect may have reduced the patient's ability to move the oral tongue anteriorly for clearing the bolus from the oral cavity. Pharyngeal residue on liquids was less of a problem for this patient, even at the 12- month posthealing assessment, when she could not achieve tongue base to posterior pharyngeal wall contact, because she used a head-back posture to

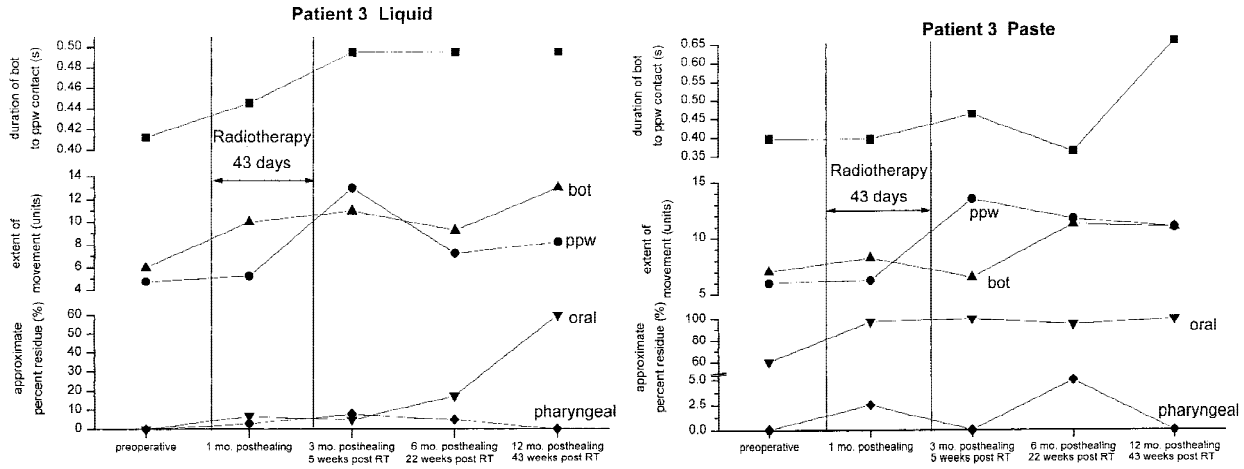

FIGURE 6. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 3. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

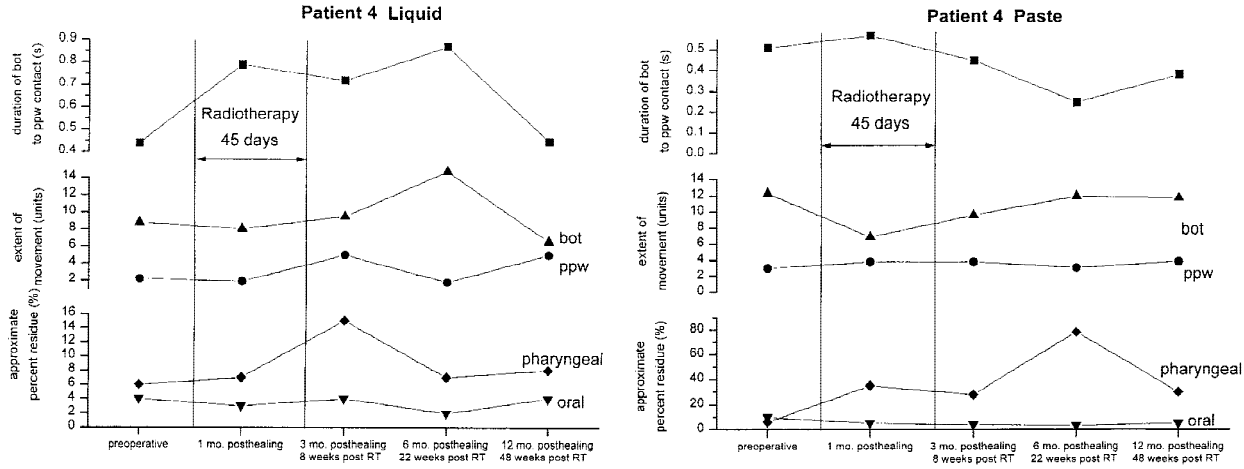

FIGURE 7. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 4. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

aid in pharyngeal transit. For the paste consistency, problems with clearance of oral residue were also evident; however, pharyngeal residue on the paste consistency became more of a problem at the 12-month posthealing assessment, which occurred 45 weeks after completion of radiotherapy. The patient was unable to achieve tongue base to posterior pharyngeal wall contact, resulting in the clearance of none of the bolus that entered the pharynx.

DISCUSSION

This preliminary study used biomechanical analysis to examine tongue base and posterior pharyngeal wall dynamics in relation to pharyngeal clearance in patients with oral and oropharyngeal resections who also received postoperative radiotherapy. Although the number of subjects in this study is small, these preliminary data reveal some interesting patterns and identify areas for future research.

Although each patient differed in the extent and nature of surgery as well as the data available for biomechanical analysis, some general trends were observed. Four of the six patients (Patients 1, 2, 4, and 6) experienced increased problems with pharyngeal clearance on at least one bolus consistency at or after their 6 month

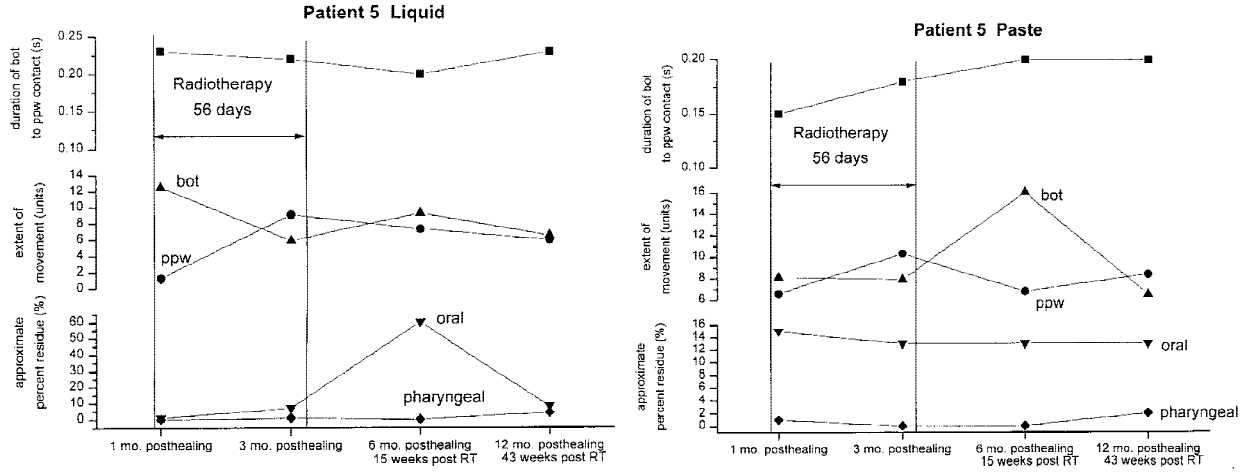

FIGURE 8. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 5. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

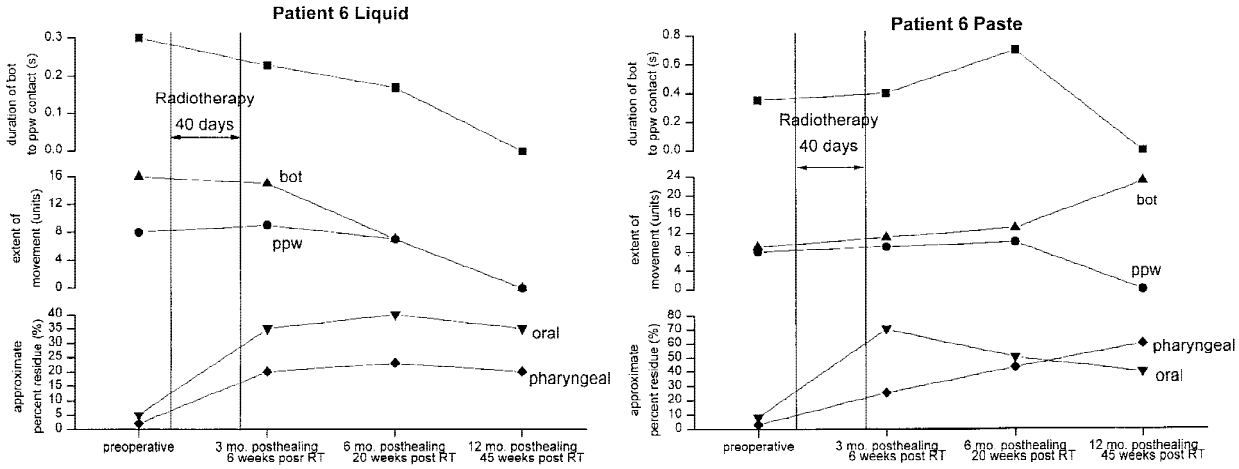

FIGURE 9. Plots over evaluation point of duration of tongue base (bot) to posterior pharyngeal wall (ppw) contact in seconds (filled square), extent of tongue base retraction in units (filled upright triangle), extent of posterior pharyngeal wall movement in units (filled circle), approximate percentage pharyngeal residue (filled diamond), and approximate percentage oral residue (filled inverted triangle) for Patient 6. Top graph summarizes data for liquid boluses; bottom graph summarizes data for paste boluses.

posthealing swallow evaluation, generally 18 to 22 weeks after completion of radiation therapy. Because of his severe problems with transporting the bolus through the oral cavity, it was not possible to assess any potential pharyngeal clearance problem in Patient 3. Patient 5 did not demonstrate any difficulty with pharyngeal clearance across her posthealing evaluation studies.

Patients who receive both surgical intervention and postoperative radiotherapy for treatment of their disease will first experience the impact of the surgical procedure on swallowing function and later the additional effects of postoperative radiotherapy. Patients 1, 2, and 5 demonstrated little or no difficulty with pharyngeal clearance of the bolus in their initial postoperative evaluations (1 and 3 months posthealing) as indicated by less than 15% pharyngeal residue after the swallow (pharyngeal clearance in Patient 3 cannot be assessed adequately because of his problems with oral clearance). Patients 4 and 6 experienced slightly more difficulty with pharyngeal clearance of the paste bolus at their 1 and 3 month posthealing evaluations with pharyngeal residues between 20% and 40%. Any swallow dysfunction at the 1-month posthealing evaluation represents primarily the effect of the surgical procedure, because most of the patients had not completed their radiotherapy at the time of that evaluation. Swallowing problems at the 3-month posthealing evaluation may reflect the impact of both the surgical procedure and the early effects of radiotherapy, such as mucositis and the beginning of xerostomia, because the 3-month evaluation occurred generally between 4 and 8 weeks after completion of radiotherapy. In this study, however, patients with evaluations at both 1 and 3 months posthealing (Patients 3, 4, and 5) did not demonstrate an increase in pharyngeal clearance problems between the two assessment points, suggesting that the early effects of radiotherapy did not have an impact on pharyngeal clearance over that caused by the surgical procedure.

It is later that the effects of radiotherapy seem to have an impact on pharyngeal clearance. Patients 1, 2, 4, and 6 demonstrated increased problems with pharyngeal clearance on at least one bolus consistency after their 6-month posthealing swallow evaluation, generally 18 to 22 weeks after completion of radiation therapy. These patients had increases of up to 50% in the amount of pharyngeal residue remaining after the swallow. Because it is unlikely that changes to swallowing function at 6 months posthealing would result from the surgical procedure, this decrement in pharyngeal clearance is probably attributable to such longer-term effects of radiotherapy as fibrosis of the pharyngeal musculature.

Movement of the tongue base and posterior pharyngeal wall toward each other until full contact is achieved is the key element in producing pharyngeal bolus driving pressure and effective bolus clearance through the pharynx.[12, 13, 16] When the field of postoperative radiotherapy includes the oropharynx or neck, the pharyngeal constrictors and tongue base will be included in the treatment volume. Increased fibrosis[17] of the

pharyngeal musculature after completion of radiotherapy may be expected to have a negative impact on pharyngeal bolus clearance, even in patients whose resections are limited to the anterior oral cavity. Three of the four patients in this study who demonstrated a marked increase in pharyngeal residue after the 6-month posthealing evaluation received postoperative radiotherapy to both the right and left neck (Patients 1, 2, and 6). Patients 2 and 6 also received radiotherapy to the anterior neck, and Patient 1 received additional radiotherapy to the site of his primary tumor. The fourth patient, Patient 4, received postoperative radiotherapy to the site of his primary tumor, which was situated in the oropharynx. Given that the tongue base and pharyngeal musculature bilaterally would have been included in the irradiated field in these four patients, it seems clear that fibrosis of the irradiated tissue had an impact on pharyngeal clearance by 18 to 22 weeks after completion of treatment, as evidenced by an increase in pharyngeal residue in these patients. Patient 5, who demonstrated no changes in the amount of pharyngeal residue across her postoperative evaluations, received postoperative radiotherapy only to her left neck. Although the pharyngeal musculature would have been included in this field, perhaps that fact that the radiotherapy was only unilateral spared this patient from the effects of fibrosis on pharyngeal clearance. Patient 3 also received unilateral postoperative radiotherapy to his right neck; however, because of his severe problems with clearing the bolus from the oral cavity, it is not possible to determine the impact of either the surgical procedure or radiotherapy on pharyngeal function in this patient.

The locus and extent of resection did not seem to be related to an increase in problems with pharyngeal clearance after the 6-month posthealing assessment. Patient 1 had his resection limited to the antereolateral oral tongue; in addition to a portion of the oral tongue, Patient 2 had resection of floor of mouth musculature; whereas, Patients 4 and 6 had more extensive surgery including the tongue base, tonsil, and soft palate. Despite the differences in their extent and locus of surgery, each of these patients experienced worse pharyngeal clearance on at least one bolus consistency 18 to 22 weeks after completing radiotherapy.

The four patients who demonstrated pharyngeal clearance problems each had primary closure of their resection sites. In patients with resections in the anterior oral cavity, primary closure may result in an anterior tethering of the tongue, thereby reducing its ability to move posteriorly to aid in bolus clearance. With a posterior site of resection, primary closure may pull the tongue base laterally toward the side of the resection, again interfering with normal tongue base retraction during the swallow. Earlier biomechanical analyses of patients with resections of the anterior oral cavity have indicated that in the presence of reduced tongue base movement, the other component of pressure generation, the pharyngeal walls, seemed to compensate and maintain bolus propulsion through the pharynx by bulging anteriorly to a greater extent than normal.[18, 19] In this study, movement of the posterior pharyngeal wall, which might have been able to compensate for a reduction in tongue base retraction as a result of primary closure, may have been disrupted by increased fibrosis after the completion of radiation therapy, contributing additionally to an increase in pharyngeal residue after the 6-month posthealing evaluation.

The fact that the four patients who experienced increased difficulty with pharyngeal clearance after their 6-month posthealing assessment all had primary closure may be a coincidence. Patient 3, who was reconstructed with a pectoralis major myocutaneous flap, had such severe difficulties with clearance of the bolus from the oral cavity that any pharyngeal problem could not be assessed; in such a case, it is not accurate to suggest that the patient with flap reconstruction did not have a problem with pharyngeal clearance. Patient 5 did not demonstrate any problems with pharyngeal clearance after either her surgery or postoperative radiotherapy; she was reconstructed with a skin graft. It is possible that this patient maintained greater mobility of the oropharyngeal musculature, because the skin graft did not tether her remaining tongue base laterally, as might happen with primary closure. However, as discussed previously, this patient also received only unilateral postoperative radiotherapy to her left neck; as compared to patients who experienced increased pharyngeal clearance problems after their 6- month posthealing evaluation, this patient had less of the pharyngeal musculature involved in her field of radiotherapy. It is just as likely that her pattern of radiotherapy rather than her closure type prevented her from experiencing increased problems with pharyngeal clearance after her 6- month posthealing assessment.

Tongue base to posterior pharyngeal wall contact seems to be essential but not necessarily suf-

ficient for effective pharyngeal clearance. The duration of tongue base to posterior pharyngeal wall contact as well as the extent of both tongue base retraction and posterior pharyngeal wall bulge interact to provide adequate pharyngeal bolus driving pressure. Although four of the six patients experienced increased pharyngeal residue after the 6-month posthealing evaluation, the breakdown in the pharyngeal clearance mechanism differed for each subject. Increased pharyngeal residue for Patient 1 was associated primarily with a reduction in the extent of both tongue base retraction and posterior pharyngeal wall bulge. Despite adequate tongue base retraction on liquid boluses, Patient 2's pharyngeal clearance problems seemed to be related to both reduced posterior pharyngeal wall bulging and a decrease in the duration of tongue base to posterior pharyngeal wall contact. Patient 4 demonstrated increased paste residue at 6 months posthealing, although the degree of tongue base retraction and posterior pharyngeal wall bulging was fairly consistent across the evaluation points and at preoperative levels; his pharyngeal clearance problem was associated with a reduction in the duration of tongue base to posterior pharyngeal wall contact. Although Patient 6 demonstrated extensive tongue base retraction on paste boluses at 12 months posthealing, he had no posterior pharyngeal wall movement and was unable to attain tongue base to posterior pharyngeal wall contact. Thus, the extent of tongue base retraction, degree of posterior pharyngeal wall bulging, and the duration of tongue base to posterior pharyngeal wall contact need to interact to provide sufficient bolus driving pressure. Increased posterior movement of the tongue base or increased anterior bulging of the posterior pharyngeal wall may be able to compensate for diminished movement in the opposite structure, but without sufficient duration of tongue base to pharyngeal wall contact to produce adequate pressure generation, pharyngeal clearance will be problematic. Manometric studies combined with biomechanical analysis of pharyngeal clearance in irradiated postsurgical oral and oropharyngeal cancer patients would be useful in defining the relative contributions of tongue base retraction, pharyngeal wall movement, and the duration of contact of these structures. Such studies are underway in our laboratories. This type of information would be valuable in developing exercises and planning treatment strategies for all patients with inadequate pharyngeal clearance.

Because we are limited in this study to observing movement of the posterior pharyngeal wall in the lateral plane, we are unable to assess lateral pharyngeal wall movement and contact to the tongue base. Patients with increased pharyngeal residue after radiotherapy in the presence of apparently adequate tongue base retraction and posterior pharyngeal wall bulging may be experiencing diminished lateral pharyngeal wall movement. Patients who do not have pharyngeal clearance problems despite diminished movement of the tongue base and posterior pharyngeal wall may be benefiting from exceptional lateral pharyngeal wall movement. Biplane fluoroscopy would be useful in illustrating the multidimensional functioning of the pharyngeal constrictors in treated head and neck cancer patients.

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