Journal of Speech and Hearing Research, Volume 37, 314–325, April 1994

Oropharyngeal Swallow Efficiency as a Representative Measure of Swallowing Function

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The purpose of this investigation was to correlate oropharyngeal swallow efficiency (OPSE), a summary measure of swallowing function, with its component variables. Videofluorographic assessment of oropharyngeal swallow resulted in the measurement of multiple measures of swallow function in five patient populations and a group of normal volunteers. In total, 759 swallows were studied in 149 persons. Specific dimensions of impairment were identified in the patient groups. Multiple regression analyses were used to relate multiple component variables to OPSE. In patient groups with distinct swallow impairments, OPSE was shown to be representative of the dimensions of impairment. In patient groups with limited impairment and in normal volunteers, the strongest correlates of OPSE were bolus transit times. In all groups, at least four variables were significantly related to OPSE and the squared multiple correlation coefficients ranged from 76% to 89%. We conclude that oropharyngeal swallow efficiency is a representative summary measure of swallowing function across populations characterized by a wide range of swallowing impairment.

KEY WORDS: head and neck cancer, swallowing rehabilitation, validation study, videofluoroscopic assessment of swallow

Many research studies in the areas of swallowing, speech, and hearing are characterized by the measurement of several outcome variables on the same person under the same experimental conditions (Logemann, 1987; Metz, Schiavetti, Samar, & Sitler, 1990; Pauloski et al., 1993; Perlman, Grayhack, & Booth, 1992). Variables can be analyzed separately or in combination (Pauloski et al., 1993). Several approaches have been taken to deal with the statistical analysis of multiple variables. Factor analysis or principal components analysis may be used to reduce a large set of variables to a few meaningful factors (Henderson, Fisher, Cohen, Waltzman, & Weber, 1990; Metz, Schiavetti, Samar, & Sitler, 1990). Multivariate regression procedures can be used to assess correlations among two or more variables, accounting for other variables (Perlman, Grayhack, & Booth, 1992). Or, a new summary measure can be defined that is based on the multiple variables (Logemann, Kahrilas, Kobara, & Vikal, 1989; Perlman, Grayhack, & Booth, 1992). More than one of the above approaches may be used in the same study (Metz, Schiavetti, Samar, & Sitler, 1990; Perlman, Grayhack, & Booth, 1992).

In this study, we propose to investigate the validity of a summary measure of oropharyngeal swallowing function. The basis of this investigation is multivariate data obtained from the videofluorographic assessment of swallowing function. Oropharyngeal swallow efficiency (OPSE) is a measure developed by Logemann, Kahrilas, Kobara, & Vikal (1989) to quantify the ability of the oral cavity and pharynx to move food efficiently and safely into the esophagus. Specific measures of bolus transit times, approximate percent of bolus residues and aspiration are used to calculate OPSE. As swallowing is a serially ordered sequence of motor events designed to

0022-4685/94/3702-0314$01.00/0

TABLE 1. Number of swallows by study group and bolus consistency.

Study group	Liquid	Paste	Cookie	Total
Oral/oropharyngeal cancer:				
Anterior locus	63	67	43	173
Posterior locus	93	84	63	240
Laryngeal cancer:				
Non-functional	57	22	18	97
Functional	20	32	8	60
Stroke patients:	63	16	15	94
Normal volunteers:	63	16	16	95

direct food safely and efficiently from the mouth to the stomach, oropharyngeal swallow efficiency has been conceived as a global measure, potentially sensitive to both the safety and degree of clearance of food from the mouth through the pharynx.

The purpose of this investigation is threefold. First, distinct patient groups with varying degrees of swallowing disability are compared to normal volunteers to determine the nature of any oropharyngeal swallowing impairment. Second, within each study group, the nature of the correlation of multiple swallowing variables with OPSE is examined. Finally, we investigate whether variables indicating impairment are those most strongly correlated with OPSE in each patient group.

Our rationale for this approach was as follows. For OPSE to be a valid summary measure of swallowing function, the dimensions of impairment in each patient group should correlate highly with OPSE in these patients. In populations of mild or no impairment, OPSE should correlate highly with oropharyngeal transit times, which are the main components of OPSE in uncompromised swallows. In all groups, several swallow variables should be independently related to OPSE, and the percent of OPSE variance explained by these variables should be high. This would indicate that OPSE represents a spectrum of swallowing variables, rather than duplicating the information of only one or two of these variables.

Once OPSE is determined to be a valid measure, then OPSE could be used clinically to monitor progress in the rehabilitation of swallowing function. In research studies where multiple patient subgroups are being compared, the use of a summary measure that is both statistically representative and clinically meaningful can reduce the number of statistical comparisons and simplify the interpretation of the results.

Methods

Subject Groups

Six groups of subjects were studied. The first group consisted of 36 patients who had one of 12 surgical procedures for anterior oral cancer. There were 27 males and 9 females. Mean age of patients was 61 years (range: 30 to 79 years). A videofluoroscopic study was done 3 months postoperatively and two swallows were examined for each of three bolus consistencies (liquid, paste, cookie). Since not all swallows were observed in all patients, analyses were restricted to 173 swallows that had complete data on all the swallow measures described below.

The second group of subjects consisted of 53 patients who had one of 11 surgical procedures for posterior oropharyngeal cancer. There were 43 males and 10 females. Mean age of patients was 57 years (range: 27 to 81 years). Patients were observed according to the protocol described above for the anterior oral patients. Analyses were restricted to 240 swallows with complete data.

The third group consisted of 37 laryngeal cancer patients who had a supraglottic laryngectomy or extended supraglottic laryngectomy. There were 29 males and 8 females. Mean age of patients was 59 years (range: 38 to 81 years). A videofluoroscopic study was done within 2 weeks of surgery. The protocol specified that two swallows of each of three bolus consistencies (liquid, paste, cookie) were to be ob-

TABLE 2. Mean (range) oral transit time(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	0.6 (0.2–2.7)	1.8 (0.1–12.5)	2.2 (0.1–9.0)
Posterior locus	0.6 (0.1–2.5)	1.6 (0.1–11.9)	1.9 (0.2–32.0)
Laryngeal cancer:			
Non-functional	0.6 (0.1–2.3)	0.5 (0.1–1.8)	2.2 (0.3–11.1)
Functional	0.7 (0.2–2.1)	0.8 (0.1–2.5)	1.5 (0.1–4.9)
Stroke patients:	0.7 (0.1–3.6)	1.1 (0.3–3.0)	1.6 (0.3–5.2)
Normal volunteers:	0.4 (0.1–1.0)	0.5 (0.3–1.0)	0.9 (0.2–3.1)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	1.48 (0.10–12.47)[1]
Posterior locus	1.27 (0.03–32.01)
Laryngeal cancer:	
Non-functional	0.85 (0.10–11.07)
Functional	0.87 (0.13–4.87)
Stroke patients:	0.93 (0.12–5.15)
Normal volunteers:	0.52 (0.07–3.11)

[1]Different from normal volunteers by Dunnett's test.

TABLE 3. Mean (range) pharyngeal delay time(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	0 (−2.2–3.6)	.5 (−2.0–23.0)	.6 (−1.2–9.3)
Posterior locus	.1 (−1.3–5.8)	.4 (−3.3–17.6)	.2 (−2.5–11.1)
Laryngeal cancer:			
Non-functional	−.2 (−1.9–4.7)	−.3 (−1.9–.4)	.3 (−3.2–6.0)
Functional	−.4 (−1.6–.4)	0 (−1.2–4.3)	−.2 (−.5–0.0)
Stroke patients:	.1 (−1.0–2.8)	1.3 (−0.2–5.9)	2.0 (−.4–6.6)
Normal volunteers:	0 (−1.1–1.9)	−.1 (−.7–.7)	.3 (.7–3.2)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	0.34 (−2.17–23.00)
Posterior locus	0.24 (−3.28–17.60)
Laryngeal cancer:	
Non-functional	−0.16 (−3.17–6.00)
Functional	−0.17 (−1.60–4.27)
Stroke patients:	0.62 (−0.98–6.58)
Normal volunteers:	0.00 (−1.10–3.16)

Note. No groups different from normal volunteers by Dunnett's test.

served. Patients in this group were severely swallowing-impaired and were considered non-functional swallowers. A total of 97 swallows with complete data was observed.

The fourth patient group consisted of 17 patients with laryngeal cancer who had a supraglottic laryngectomy or extended supraglottic laryngectomy and were observed according to a protocol similar to that employed with the third group. However, patients in this group were able to swallow the bolus and were considered functional swallowers. There were 13 males and 4 females. Mean age was 56 years (range: 38 to 75 years). Sixty swallows with complete data were observed. Ten patients in this group also had nonfunctional swallows that were included in the third group.

The fifth group of subjects included 8 patients who suffered a single left basal ganglion infarct (stroke) and were observed 3 weeks post ictus. There were 4 males and 4 females. Mean age was 59 years (range: 36 to 84 years). Two swallows of each of six bolus consistencies were assessed. The consistencies were liquid (1 mL, 3 mL, 5 mL, 10 mL), paste, and cookie. Data for all liquid consistencies were combined for analysis. Ninety-four swallows with complete data were analyzed.

The sixth group included 8 normal volunteers (1 male and 7 females). This group was selected as having no neurological diagnosis and no history of dysphagia. Again, two swallows of each of six bolus consistencies were observed. Ninety-five swallows with complete data were analyzed.

Observation of Swallow Variables

For each study participant in each group, a videofluoroscopic assessment of oropharyngeal swallow was accomplished, as

TABLE 4. Mean (range) pharyngeal response time(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	1.1 (.5–2.9)	1.2 (.4–2.9)	1.3 (.6–14.4)
Posterior locus	1.1 (.3–2.3)	1.2 (.2–4.9)	1.1 (.5–3.0)
Laryngeal cancer:			
Non-functional	1.1 (−.3–6.2)	1.2 (.7–2.3)	1.1 (.6–3.7)
Functional	1.0 (.5–1.8)	1.1 (.5–2.4)	.9 (.5–1.4)
Stroke patients:	.9 (.5–1.9)	.8 (.6–1.2)	.8 (.1–1.1)
Normal volunteers:	.9 (.2–1.9)	1.0 (.7–1.9)	.9 (.7–1.4)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	1.16 (0.43–14.40)
Posterior locus	1.12 (0.17–4.85)
Laryngeal cancer:	
Non-functional	1.10 (−0.33–6.21)
Functional	1.02 (0.53–2.38)
Stroke patients:	0.84 (0.11–1.88)
Normal volunteers:	0.91 (0.15–1.92)

Note. No groups different from normal volunteers by Dunnett's test.

TABLE 5. Mean (range) pharyngeal transit time(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	1.1 (0.2–5.3)	1.7 (0.3–24.1)	1.9 (0.2–14.4)
Posterior locus	1.2 (0.3–7.1)	1.6 (0.2–19.2)	1.3 (0.3–11.9)
Laryngeal cancer:			
Non-functional	0.8 (0.0–5.4)	0.8 (0.4–1.7)	1.4 (0.4–6.9)
Functional	0.6 (0.2–1.1)	1.0 (0.2–5.0)	0.7 (0.3–1.1)
Stroke patients:	1.0 (0.4–3.5)	2.1 (0.5–6.7)	2.8 (0.5–7.4)
Normal volunteers:	0.8 (0.4–2.6)	0.9 (0.5–1.7)	1.2 (0.6–4.0)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	1.50 (0.17–24.13)
Posterior locus	1.36 (0.17–19.22)
Laryngeal cancer:	
Non-functional	0.94 (0.00–6.93)
Functional	0.84 (0.23–4.97)
Stroke patients:	1.45 (0.41–7.43)
Normal volunteers:	0.92 (0.43–4.03)

Note. No groups different from normal volunteers by Dunnett's test.

described by Logemann (1983). All swallows were observed in the lateral plane. The oropharyngeal region was viewed from the lips anteriorly to the cervical area posteriorly, and from the soft palate superiorly to the 7th cervical vertebra inferiorly. A videotimer was used to encode timing information onto each video field in order to facilitate slow motion and frame-by-frame analysis. All study participants were to perform two swallows each of 1 mL thin liquid, 1 mL paste barium, and 1/4 of a Lorna Doone cookie. In addition, stroke patients and normal volunteers were to perform two swallows each of 3 mL, 5 mL, and 10 mL thin liquid.

Each swallow was analyzed frame by frame to determine the following measures: (a) oral transit time (OTT), the time (in seconds) from the onset of bolus movement in the mouth until the head of the bolus reached the point where the lower rim of the mandible crosses the tongue base; (b) pharyngeal delay time (PDT), the time (in seconds) from the arrival of the bolus head at the point where the lower rim of the mandible crosses the tongue base until first laryngeal elevation; (c) pharyngeal response time (PRT), the time (in seconds) from first laryngeal elevation until the bolus tail passes through the cricopharyngeal region; (d) pharyngeal transit time (PTT), the sum of the pharyngeal delay and response times; (e) cricopharyngeal opening duration (CPO), the time (in seconds) from the first to last opening of the cricopharyngeal opening (Jacob, Kahrilas, Logemann, Shah, & Ha, 1989); (f) laryngeal closure duration (LAC), the time (in seconds) from the first to last closure of the laryngeal vestibule (Logemann et al., 1992); (g) residue, the approximate percent of the bolus remaining in the oral cavity (ORES) and pharynx (PRES) after completion of the first swallow of a bolus; (h) aspiration, the approximate percent of bolus aspirated before

TABLE 6. Mean (range) duration of cricopharyngeal opening(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	.4 (.1–.7)	.4 (.1–.7)	.4 (.1–.8)
Posterior locus	.4 (.1–1.0)	.3 (.1–.7)	.3 (.1–1.1)
Laryngeal cancer:			
Non-functional	.4 (.0–3.8)	.4 (.2–.9)	.4 (.2–.7)
Functional	.3 (.2–.6)	.4 (.1–.8)	.5 (.2–1.1)
Stroke patients:	.5 (.1–.9)	.5 (.3–.9)	.4 (.2–.6)
Normal volunteers:	.5 (.2–.7)	.5 (.4–.7)	.4 (.3–.9)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	0.37 (0.07–0.78)[1]
Posterior locus	0.34 (0.07–1.05)[1]
Laryngeal cancer:	
Non-functional	0.41 (0.00–3.77)
Functional	0.38 (0.07–1.08)
Stroke patients:	0.46 (0.14–0.88)
Normal volunteers:	0.48 (0.24–0.89)

[1]Different from normal volunteers by Dunnett's test.

TABLE 7. Mean (range) duration of laryngeal closure(sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	.4 (0–1.48)	.4 (0–1.7)	.3 (0–.7)
Posterior locus	.6 (.1–3.54)	.4 (.1–1.6)	.4 (0–1.8)
Laryngeal cancer:			
Non-functional	.9 (0–11.7)	.7 (0–2.1)	.7 (0–2.2)
Functional	.7 (0–2.0)	.8 (0–5.5)	.6 (.1–1.5)
Stroke patients:	.5 (.3–1.7)	.5 (.4–.6)	.4 (.3–.7)
Normal volunteers:	.5 (.4–1.5)	.5 (.4–.9)	.5 (.3–.8)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	0.36 (0.00–1.65)
Posterior locus	0.49 (0.04–3.54)
Laryngeal cancer:	
Non-functional	0.82 (0.00–11.73)
Functional	0.73 (0.00–5.50)
Stroke patients:	0.51 (0.29–1.67)
Normal volunteers:	0.53 (0.33–1.46)

Note. No groups different from normal volunteers by Dunnett's test.

(ASPB) and during (ASPD) a swallow. Aspiration after the swallow occurs on residue which has already been defined.

Ten percent of all swallows were reanalyzed by the same observer as well as by a different observer to determine intrajudge and interjudge reliability. For the 54 variable-group combinations (nine distinct variables and six groups), Pearson correlation coefficients of intrajudge and interjudge reliability averaged .98 (range: .81–1.00) and .93 (range: .72–1.00) respectively.

Oropharyngeal swallow efficiency (OPSE) is a measure developed by Logemann, Kahrilas, Kobara, & Vakil (1989) to quantify the ability of the oral cavity and pharynx to move food efficiently and safely into the esophagus. OPSE is the ratio of the percent swallowed to the total swallowing time in the oral and pharyngeal stages. More specifically,

$$OPSE = \frac{100 - (ORES + PRES + ASPB + ASPD)}{OTT + PDT + PRT}$$

This formula defines OPSE as a function of multiple component measures typically obtained from the videofluorographic assessment. If percent of the bolus swallowed decreases, if aspiration increases, or if transit times increase, then OPSE is lowered.

Statistical Analysis

Inter-group differences were analyzed using nested repeated measures analysis of variance (Winer, 1971). The five patient groups were then compared to normal volunteers

TABLE 8. Mean (range) percent oral residue by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	17.7 (0–100)	31.9 (0–100)	36.5 (0–100)
Posterior locus	19.7 (0–95)	32.8 (0–100)	36.7 (0–100)
Laryngeal cancer:			
Non-functional	4.5 (0–30)	8.5 (0–30)	19.1 (0–90)
Functional	8.4 (0–60)	12.8 (0–80)	24.3 (2–90)
Stroke patients:	3.8 (0–50)	4.7 (0–15)	8.7 (0–75)
Normal volunteers:	2.6 (0–15)	3.8 (0–10)	12.8 (0–50)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	27.9 (0–100)[1]
Posterior locus	28.7 (0–100)[1]
Laryngeal cancer:	
Non-functional	8.1 (0–90)
Functional	12.9 (0–90)
Stroke patients:	4.7 (0–75)
Normal volunteers:	4.5 (0–50)

[1]Different from normal volunteers by Dunnett's test.

TABLE 9. Mean (range) percent pharyngeal residue by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	9.9 (0–100)	11.9 (0–95)	13.2 (0–50)
Posterior locus	14.4 (0–100)	15.9 (0–95)	14.1 (0–70)
Laryngeal cancer:			
Non-functional	13.3 (0–65)	13.6 (0–90)	13.1 (0–80)
Functional	6.8 (0–40)	11.9 (0–90)	3.9 (0–15)
Stroke patients:	1.0 (0–10)	2.1 (0–5)	1.3 (0–5)
Normal volunteers:	0.9 (0–5)	1.5 (0–5)	0.6 (0–5)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	11.5 (0–100)[1]
Posterior locus	14.8 (0–100)[1]
Laryngeal cancer:	
Non-functional	13.2 (0–90)[1]
Functional	9.1 (0–90)
Stroke patients:	1.3 (0–10)
Normal volunteers:	0.9 (0–5)

[1]Different from normal volunteers by Dunnett's test.

on all parameters (except ASPB and ASPD) using Dunnett's multiple comparison procedure at the .05 level (Winer, 1971). A single pairwise comparison was done to compare ASPB and ASPD between nonfunctional and functional laryngeal cancer patients. Within each of the six groups, stepwise multiple regression analysis (Kleinbaum, Kupper, & Muller, 1987) was then performed with OPSE as the dependent variable. The swallow variables described above were candidate independent variables considered for entry into the regression model. Since aspiration occurred primarily in the nonfunctional and functional supraglottic laryngectomy groups, ASPB and ASPD were candidate variables only for those two groups. PTT, which is the sum of PDT and PRT, was not a candidate variable in any regression analysis. Variables entered at the $p < .05$ level comprised the final regression model for a group. The square of the multiple correlation coefficient (R^2) gives the proportion of the total variance of OPSE explained by the significant variables. The impact of deleting each variable from the final model is assessed by two measures: (a) the partial R^2, which is the reduction in R^2 that occurs by deleting a variable, and (b) the partial F, which is the statistic used to test the significance of the deletion. After the final model had been determined, the extent of the nonsignificance of the remaining variables was assessed by the F to enter. For the regression analyses, group specific data from the different consistencies were pooled by subtracting the consistency specific mean from the raw data before analysis. Statistical analyses were done using the REG procedure of the SAS software (SAS, 1989).

TABLE 10. Mean (range) percent bolus aspirated before swallow by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus		No bolus aspiration before swallow	
Posterior locus	0.2 (0–10)	0.2 (0–20)	0
Laryngeal cancer:			
Non-functional	2.3 (0–90)	0	0.6 (0–5)
Functional	0	0.3 (0–10)	0
Stroke patients:		No bolus aspiration before swallow	
Normal volunteers:	0.03 (0–2)	0	0

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	No aspiration
Posterior locus	.2 (0–20)
Laryngeal cancer:	
Non-functional	1.5 (0–90)
Functional	.2 (0–10)
Stroke patients:	No aspiration
Normal volunteers:	.02 (0–2)

Note. Non-functional and functional laryngeal cancer patients are comparable on aspiration before swallow.

TABLE 11. Mean (range) percent bolus aspirated during swallow by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus		No bolus aspiration during swallow	
Posterior locus		No bolus aspiration during swallow	
Laryngeal cancer:			
Non-functional	23.1 (0–90)	9.1 (0–80)	4.3 (0–30)
Functional	0.6 (0–5)	1.3 (0–25)	0
Stroke patients:		No bolus aspiration during swallow	
Normal volunteers:		No bolus aspiration during swallow	

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	No aspiration
Posterior locus	No aspiration
Laryngeal cancer:	
Non-functional	16.5 (0–90)[1]
Functional	0.9 (0–25)
Stroke patients:	No aspiration
Normal volunteers:	No aspiration

[1]$p < .01$ comparing non-functional with functional laryngeal cancer patients.

Results

Group Characteristics and Comparison With Normal Volunteers

In the first part of the analysis, the five patient groups were compared to normal volunteers to determine the nature and extent of any swallowing impairment in the patient groups. The normal volunteers exhibited similar levels of oropharyngeal swallow efficiency (mean = 79) as a different group of normals reported by Logemann, Kahrilas, Kobara, & Vikal (1989), with a mean OPSE of 78. Table 1 gives the number of swallows for each study group, by consistency. Tables 2 to 12 give the means and ranges by consistency and group for the ten swallow variables described in the Methods section, and for OPSE. These tables also give the comparisons of each group to normal volunteers for all parameters except ASPB and ASPD, which are compared only between non-functional and functional laryngeal cancer patients.

The following results may be highlighted from these tables. Oral transit time is significantly increased in the anterior locus oropharyngeal cancer patients (Table 2). Although not statistically significant, increased pharyngeal delay time for the stroke patients (Table 3) and increased pharyngeal response time for the oropharyngeal cancer patients (Table 4) result in pharyngeal transit times that are higher than normal in oropharyngeal cancer patients and in stroke patients (Table 5).

For the oropharyngeal cancer patients, the duration of cricopharyngeal opening is significantly lower than normal

TABLE 12. Mean (range) oropharyngeal swallow efficiency (%/sec) by study group and bolus consistency.

Study group	Liquid	Paste	Cookie
Oropharyngeal cancer:			
Anterior locus	56 (0–116)	34 (0–131)	25 (0–110)
Posterior locus	47 (0–146)	31 (0–125)	29 (0–125)
Laryngeal cancer:			
Non-functional	52 (0–148)	57 (0–123)	46 (1–113)
Functional	80 (0–213)	61 (2–177)	64 (1–202)
Stroke patients:	68 (8–146)	35 (12–76)	43 (5–107)
Normal volunteers:	85 (35–167)	72 (48–108)	61 (12–115)

Study group	All Consistencies
Oropharyngeal cancer:	
Anterior locus	40 (0–131)[1]
Posterior locus	37 (0–146)[1]
Laryngeal cancer:	
Non-functional	52 (0–148)[1]
Functional	68 (0–213)
Stroke patients:	59 (0–146)[1]
Normal volunteers:	79 (0–167)

[1]Different from normal volunteers by Dunnett's test.

TABLE 13. Regression analysis of OPSE, oropharyngeal cancer patients, anterior locus.

Variables	Partial R^2	*F* (*p*-value) to Remove From 6 Variable Model[a]
In Model		
Oral residue	.364	457.5 ($p < .0001$)
Pharyngeal residue	.208	262.1 ($p < .0001$)
Oral transit time	.100	125.1 ($p < .0001$)
Pharyngeal delay time	.015	19.4 ($p < .0001$)
Cricopharyngeal opening duration	.014	18.0 ($p < .0001$)
Pharyngeal response time	.007	9.2 ($p = .003$)
		F (*p*-value) to Enter 6 Variable Model[b]
Not in Model		
Laryngeal closure duration		3.87 ($p = .051$)

Note. $R^2 = .868$
[a]Critical value for $F_{1,166} = 3.90$
[b]Critical value for $F_{1,165} = 3.90$

(Table 6). The duration of laryngeal closure is lower than normal for oropharyngeal cancer patients and higher than normal for laryngeal cancer patients, but these differences are not statistically significant (Table 7). Oral and pharyngeal residue are significantly higher than normal for oropharyngeal cancer patients (Tables 8 and 9). In non-functional and functional laryngeal cancer patients, aspiration before swallow is similar (Table 10) while aspiration during swallow is significantly higher in the nonfunctional group (Table 11). Finally, OPSE is significantly impaired to varying degrees across all groups except functional swallowers (Table 12). Oropharyngeal cancer patients with a posterior locus of resection have the lowest mean OPSE at 37, whereas functional laryngeal cancer patients have near-normal OPSE levels averaging 68.

Figure 1 provides a graphic representation of the variability of most of these factors across groups. In the upper panel, the total height of all bars for any group (subtracting any negative PDT) is the denominator of OPSE. In the middle panel, the total height of all bars for any group is the quantity subtracted from 100 in the numerator of OPSE.

TABLE 14. Regression analysis of OPSE, oropharyngeal cancer patients, posterior locus.

Variables	Partial R^2	F (*p*-value) to Remove From 5 Variable Model[a]
In Model		
Oral residue	.439	495.2 ($p < .0001$)
Pharyngeal residue	.191	215.4 ($p < .0001$)
Oral transit time	.052	59.0 ($p < .0001$)
Pharyngeal delay time	.024	26.8 ($p < .0001$)
Pharyngeal response time	.017	19.0 ($p < .0001$)
		F (*p*-value) to Enter 5 Variable Model[b]
Not in Model		
Cricopharyngeal opening duration		0.47 ($p = .49$)
Laryngeal closure duration		0.35 ($p = .56$)

Note. $R^2 = .793$
[a]Critical value for $F_{1,234} = 3.88$
[b]Critical value for $F_{1,233} = 3.88$

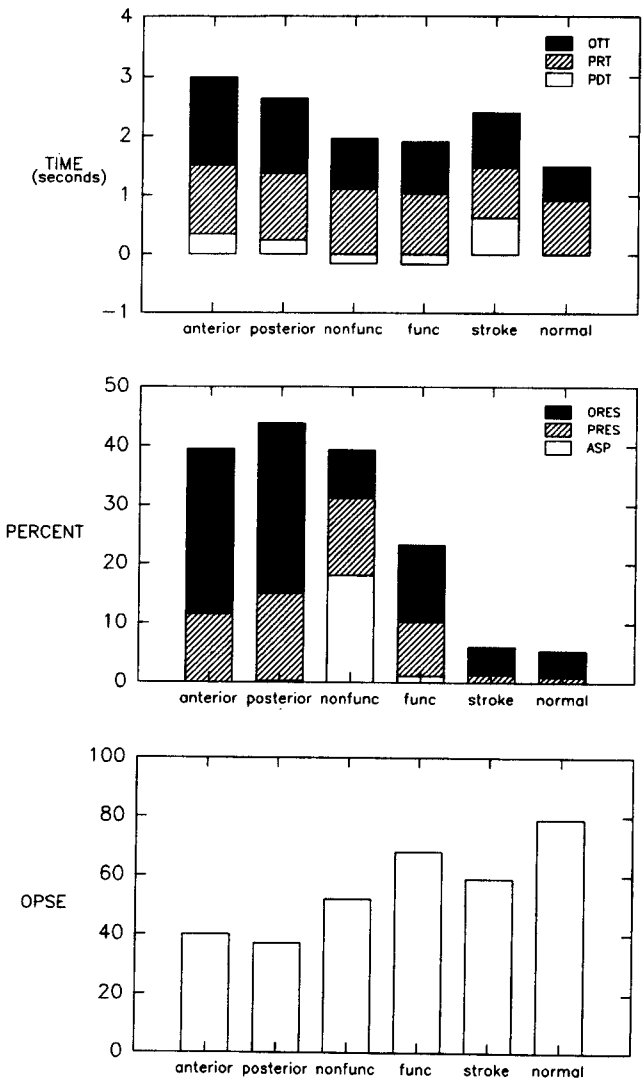

FIGURE 1. Oral transit time (OTT), pharyngeal response time (PRT) and pharyngeal delay time (PDT), in seconds, by group (upper panel); oral residue (ORES), pharyngeal residue (PRES) and aspiration before and during swallow (ASP), in percent, by group (middle panel); and oropharyngeal swallow efficiency (OPSE), by group (lower panel). Anterior = anterior locus oral cancer patients, posterior = posterior locus oropharyngeal cancer patients, nonfunc = laryngeal cancer nonfunctional swallowers, func = laryngeal cancer functional swallowers, stroke = stroke patients, normal = normal volunteers.

Multivariate Correlations of Swallow Variables With OPSE

Next, individual swallow variables were correlated with OPSE to determine which swallow dimensions were represented by OPSE. Separate analyses were done for each study group. Results of the stepwise regression analyses for the six groups are given in Tables 13 to 18. Each of these tables ranks the swallow variables from most to least impor-

TABLE 15. Regression analysis of OPSE, non-functional laryngeal cancer patients.

Variables	Partial R^2	F (*p*-value) to Remove From 7 Variable Model[a]
In Model		
Aspiration during swallow	.355	242.5 ($p < .0001$)
Pharyngeal residue	.182	124.2 ($p < .0001$)
Aspiration before swallow	.116	79.5 ($p < .0001$)
Oral residue	.065	44.4 ($p < .0001$)
Oral transit time	.044	30.3 ($p < .0001$)
Pharyngeal delay time	.034	23.3 ($p < .0001$)
Pharyngeal response time	.019	13.0 ($p = .0005$)
		F (*p*-value) to Enter 7 Variable Model[b]
Not in Model		
Laryngeal closure duration		3.32 ($p = .07$)
Cricopharyngeal opening duration		0.63 ($p = .43$)

Note. $R^2 = .870$
[a]Critical value for $F_{1,89} = 3.95$
[b]Critical value for $F_{1,88} = 3.95$

tant in terms of their correlation with OPSE. The higher the partial R^2 and the F to remove for a variable, the more important that variable is to OPSE. Oral residue and pharyngeal residue are the most important correlates of OPSE in the oropharyngeal cancer patients, both for anterior resections (Table 13) and for posterior resections (Table 14). Aspiration during swallow relates most strongly to OPSE for non-functional laryngeal cancer patients with supraglottic laryngectomies (Table 15). Oral transit time and pharyngeal delay time are the best correlates of OPSE for the functional laryngeal cancer patients (Table 16), stroke patients (Table 17), and the normal volunteers (Table 18). For all study groups, pharyngeal response time is secondary to the variables mentioned above, ranking third in normal volunteers

TABLE 16. Regression analysis of OPSE, functional laryngeal cancer patients.

Variables	Partial R^2	F (*p*-value) to Remove From 6 Variable Model[a]
In Model		
Oral transit time	.206	98.7 ($p < .0001$)
Pharyngeal delay time	.140	67.0 ($p < .0001$)
Pharyngeal residue	.139	66.4 ($p < .0001$)
Oral residue	.124	59.4 ($p < .0001$)
Pharyngeal response time	.083	39.7 ($p < .0001$)
Aspiration before swallow	.056	27.5 ($p < .0001$)
		F (*p*-value) to Enter 6 Variable Model[b]
Not in Model		
Cricopharyngeal opening duration		1.08 ($p = .30$)
Laryngeal closure duration		0.84 ($p = .36$)
Aspiration during swallow		0.30 ($p = .59$)

Note. $R^2 = .889$
[a]Critical value for $F_{1,53} = 4.02$
[b]Critical value for $F_{1,52} = 4.03$

TABLE 17. Regression analysis of OPSE, stroke patients.

Variables	Partial R^2	F (*p*-value) to Remove From 4 Variable Model[a]
In Model		
Oral transit time	.213	80.5 ($p < .0001$)
Pharyngeal delay time	.190	71.8 ($p < .0001$)
Oral residue	.065	24.5 ($p < .0001$)
Laryngeal closure duration	.027	10.0 ($p = .002$)
		F (*p*-value) to Enter 4 Variable Model[b]
Not in Model		
Pharyngeal response time		3.74 ($p = .056$)
Cricopharyngeal opening duration		0.98 ($p = .32$)
Pharyngeal residue		0.47 ($p = .49$)

Note. $R^2 = .765$
[a]Critical value for $F_{1,89} = 3.95$
[b]Critical value for $F_{1,88} = 3.95$

and fourth or below for the patient groups. Finally, duration of CPO or LAC rarely makes a significant contribution to OPSE once other variables are taken into account. The percent of OPSE variance explained by the significant explanatory variables ranges from 76.5% to 88.9% across the six groups.

Relating Impairment to OPSE

Finally, a qualitative analysis was done to relate the nature of impairment to the variables correlated with OPSE. Table 19 is a summary which combines the results of the intergroup comparisons of swallow variables with the intragroup multivariate correlations of these variables to OPSE. Each column gives the results for a single group. Rows represent individual variables. The number in the column is the rank of that variable in its correlation with OPSE, as determined by Tables 13 to 18. Beside the rank is the indication "lo" or "hi," depending on whether that variable was significantly lower or higher than normal (Tables 2–4, 6–11). An asterisk indicates that the variable contributes at

TABLE 18. Regression analysis of OPSE, normal volunteers.

Variables	Partial R^2	F (*p*-value) to Remove From 5 Variable Model[a]
In Model		
Oral transit time	.265	191.0 ($p < .0001$)
Pharyngeal delay time	.261	188.1 ($p < .0001$)
Pharyngeal response time	.214	154.4 ($p < .0001$)
Pharyngeal residue	.015	10.8 ($p = .001$)
Oral residue	.006	4.3 ($p = .04$)
		F (*p*-value) to Enter 5 Variable Model[b]
Not in Model		
Cricopharyngeal opening duration		2.47 ($p = .12$)
Laryngeal closure duration		1.04 ($p = .31$)

Note. $R^2 = .877$
[a]Critical value for $F_{1,89} = 3.95$
[b]Critical value for $F_{1,88} = 3.95$

TABLE 19. Summary of results.

Columns represent groups, rows represent variables.
The number in each column is that variable's rank order of importance in the multiple regression analysis (lower numbers are more important).
*means the variable explains at least 5% of the R^2 in the final regression model. Asterisked variables are more important determinants of OPSE than unasterisked variables.
hi = mean value for whole group is significantly higher than normal
lo = mean value for whole group is significantly lower than normal
ns = variable was not significant in regression model
N/A means that variable was not analyzed in that group.
R^2 = R^2 for model with all significant (i.e., all ranked) variables.
*R^2 = R^2 for model with asterisked variables only.

	OROPHARYNG. CANCER		LARYNGEAL CANCER			
	ANTERIOR	POSTERIOR	NON-FUNC.	FUNC.	STROKE	NORMAL
OTT	3* hi	3*	5	1*	1*	1*
PDT	4	4	6	2*	2*	2*
PRT	6	5	7	5*	ns	3*
CPO	5 lo	ns lo	ns	ns	ns	ns
LAC	ns	ns	ns	ns	4	ns
ORES	1* hi	1* hi	4*	4*	3*	5
PRES	2* hi	2* hi	2* hi	3*	ns	4
ASPB	N/A	N/A	3*	6*	N/A	N/A
ASPD	N/A	N/A	1* hi	ns	N/A	N/A
R^2	.868	.793	.870	.889	.765	.877
*R^2	.823	.758	.756	.889	.738	.845

least 5% to the variance of OPSE. An "ns" indicates that the variable was not significant in the stepwise regression. An "N/A" indicates that a variable was not included in the stepwise regression analysis for that group.

The following observations may be made from the results presented in Table 19. For the oropharyngeal cancer patients (anterior and posterior locus) and the non-functional laryngeal cancer patients, the most important correlates of OPSE are variables that, in these groups, are significantly elevated from normal (ORES, PRES and OTT in oropharyngeal cancer; ASPD and PRES in laryngeal cancer). Pharyngeal delay time and PRT are of secondary importance to OPSE while LAC and CPO duration are of little or no importance in these patients.

For the functional laryngeal cancer patients and the stroke patients, the most important correlates of OPSE are OTT and PDT. Residue is of secondary importance while LAC and CPO duration are of little or no importance. In these two groups, no variables exhibited differences from normal in contrast to the three groups of cancer patients described above.

Finally, in normal volunteers, the most important correlates of OPSE are OTT, PDT and PRT, the sum of which form the denominator of OPSE. ORES and PRES are of secondary importance. LAC and CPO duration are not important factors in OPSE in these subjects.

Discussion

Swallowing is a serially ordered sequence of motor events designed to direct food safely and efficiently from the mouth to the stomach. These events can be categorized into two major activities: (a) the functioning of valves to prevent food from entering inappropriate regions such as the nose (velopharyngeal valve) and the airway (laryngeal valve), and to direct food appropriately into the esophagus (cricopharyngeal valve), and (b) the functioning of pressure generators that exert pressure against the posterior end of the bolus to propel food efficiently from the mouth through the pharynx and esophagus into the stomach. Pressure generators include the oral tongue, tongue base, and pharyngeal walls. Thus, the two primary characteristics of the oropharyngeal swallow are safety and efficiency. Oropharyngeal swallow efficiency was designed as a global measure to represent the degree of safety and efficiency of a particular patient's swallow. Failure of any valve functions in the pharynx would result in some or all of the bolus failing to reach the esophagus, hence efficiency of the swallow would be reduced. Ineffective valve function at the velopharynx would result in food entering the nose and not being swallowed through the pharynx, thus reducing efficiency. Inadequate closure of the airway would result in aspiration and failure of aspirated material to be swallowed. Failure of the upper esophageal sphincter to open would result in residue above the sphincter, again with failure of material to enter the esophagus. If airway protection is impaired because laryngeal valve functioning is damaged, safety of the swallow is also reduced. These conditions would result in a reduction of the numerator of OPSE. Similarly, if pressure generation on the bolus is less than adequate, food will not be propelled rapidly and cleanly through the mouth and pharynx, resulting in residual food left in the mouth or pharynx. Such conditions would decrease the numerator (percent swallowed) and increase the denominator (transit times) of OPSE, again reducing efficiency. Thus, oropharyngeal swallow efficiency has been conceived as a global measure, potentially sensitive to both the degree of safety and the degree of clearance of food from the mouth and pharynx.

This study has demonstrated that OPSE is a statistically valid and representative measure of swallow function. When

no swallow impairment exists, the variables used to calculate OPSE explain 88% of the variance of OPSE, and the bolus transit times are the most significant correlates of OPSE. Residues, which are low or nonexistent in normal swallows, are minor correlates of OPSE.

In the four groups of oropharyngeal or laryngeal cancer patients, the component swallow measures explained between 79% and 89% of the variance of OPSE. In other words, the correlation coefficient (square root of R^2) between OPSE and the best linear function of transit times, amounts of bolus residue and amounts aspirated, has a value near .90 and above. Oropharyngeal swallow efficiency is a summary measure that statistically represents commonly measured swallow variables in the clinical radiographic assessment of oropharyngeal swallow.

The pattern of the importance that individual swallow measures have to OPSE differs across the four cancer patient groups. Oral and pharyngeal residue correlate most highly with OPSE in patients with anterior or posterior resections for oropharyngeal cancer. In both these groups, oral transit time is more important than pharyngeal transit times. The nonfunctional laryngeal cancer patients show significantly increased aspiration during swallow and pharyngeal residue, and these variables are, respectively, the first and second most important correlates of OPSE. In contrast, functional laryngeal cancer patients show oral transit time and pharyngeal delay time as the most important correlates. The functional patients as well as the stroke patients are close to the normal volunteers in terms of swallow function, and this is reflected in the similar patterns of strong correlates of OPSE.

The analyses presented assume a linear relationship among the variables. However, there are outliers, especially for oral transit time and OPSE. When analyses were repeated using a square root transformation on OTT and OPSE, the multivariate correlations with OPSE were stronger. The analyses of this study were done using the square root transformations on these two variables, since that tended to linearize the relationships.

The data analyzed in this study represent three bolus consistencies for all study groups. For each study group, analyzing deviations from consistency-specific means is equivalent to using a pooled within-consistency correlation matrix as the raw data. Pooling of multiple conditions was also done by Henderson, Fisher, Cohen, Waltzman, & Weber (1990) in the development of a composite score from a battery of 24 audiologic tests, measured at four time points.

The method of stepwise regression must be used with caution (Leigh, 1988). The incremental importance of an individual variable entering the regression model at a given step depends on the set of variables already in the model at that step. Moreover, to use the actual order of entry in a stepwise procedure as a measure of relative importance ignores the variability of selection. To protect ourselves from such variability, we used the F to remove from the final model (and corresponding partial R^2) as our measure of relative importance. In all our analyses, the ranking based on the F to remove and the actual order of selection were exactly the same. This was likely due to the distinctive statistical contribution of each variable within the groups.

The results of this investigation have implications both for the clinician as well as the researcher. The single measure OPSE which summarizes swallowing ability and takes into account several measures typically observed in videofluorographic studies can provide the clinician with a useful summary assessment of a patient's swallowing condition. The comprehensive assessment of a given swallow requires that multiple swallow measures of transit times, residues in the oral and pharyngeal phases as well as the amounts of aspiration be examined. We have demonstrated that oropharyngeal swallow efficiency represents these measures and that over 75% of its variance can be explained by them. We have further demonstrated in patients with swallowing impairment that variables that characterize the impairment are the strongest correlates of oropharyngeal swallow efficiency. The use of OPSE in swallowing-impaired patients will ensure an accurate assessment of their overall swallowing ability. Since OPSE is readily interpretable in that the lower the values, the more compromised the patient's swallow, we recommend oropharyngeal swallow efficiency as a general summary measure when simplification from multiple measures is required.

Acknowledgments

The authors acknowledge the following persons for their part in patient accession and data collection: Mary Ann Heiser, R.N., B.S.N., Salvatore Cardinale, M.S., Donald Shedd, M.D., Roswell Park Memorial Institute, Buffalo, N.Y.; Darlene Graner, M.A., Barbara Cook, M.A., Frank Milianti, Ph.D., Sharon Collins, M.D., Hines VA Hospital, Hines, Ill.; Quinter Beery, Ph.D., David Stein, Ph.D., Jonas Johnson, M.D., University of Pittsburgh; Jan Lewin, M.S., Shan Baker, M.D., University of Michigan, Ann Arbor; Julia Bowman, M.A., Helmuth Goepfert, M.D., M.D. Anderson Cancer Center, Houston; Cathy Lazarus, M.A., Northwestern University, Chicago; Joan Kuhn, M.S., Robert Toohill, M.D., Medical College of Wisconsin, Milwaukee; Terilyn Nitscke, M.A., Zablocki VA Hospital, Milwaukee; Paula Sullivan, M.A., Moffitt Cancer Center, Tampa, Fl. This research was funded by grants P01- CA-40007 and R01-NS-28525.

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Received April 27, 1993
Accepted November 15, 1993

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