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Respiratory Swallow Coordination in Healthy Individuals

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Abstract The coordination between swallowing and breathing is considered to be an essential element in the protection of the airway during eating/ drinking. A variety of age-related changes occur in the oral pharyngeal mechanism, with some affect on the coordination between swallowing and breathing. Hence the present study was planned to investigate the differences between respiratory swallow coordination if any in the healthy individuals. 800 participants in the age range of 18-40 yrs, 41-59 yrs, 60-75 yrs and 76 yrs and above participated in the study. The swallowing examinations were recorded on a Digital Swallowing Workstation (Model 7200; Kay Elemetrics Corporation) coupled to the swallowing signals lab. Nasal respiratory flow was captured by using a standard 7-ft nasal cannula coupled to the Swallow Signals Lab (Model 7120; Kay Elemetrics Corporation) module. Respiratory measures (inhalation/ exhalation) were recorded for all swallowing attempts. Swallow apnea duration was calculated from these measurements. Obtained data was analyzed statistically using MANOVA. Results revealed an increase in swallow apnea duration with the increase in age. Significant difference was observed between males and females. It was also observed that bolus consistency and volume did influence the swallowing physiology. This normative would serve as a base for comparisons against disordered respiratory swallow coordination in individuals with dysphagia.

Keywords *Digital Swallowing Workstation, Dysphagia, Oropharynx, Swallow Apnea*

1. Introduction

Respiration and swallowing are physiologically linked to each other to ensure effortless gas exchange during oronasal breathing and to prevent aspiration during swallowing process (1, 3). The contribution of discoordinated breathing and swallowing to the occurrence of aspiration pneumonia in patients with dysphagia is poorly studied. This lack of information has in part been owing to limitations in technology. But the emerging technology made the synchronous recording of breathing and swallowing possible, reliable, and clinically practical, leading to the establishment of normative data regarding this patterned coordination (3). Presently, there is overwhelming evidence that points to the coupling of swallowing with the exhalation phase of respiration using nasal airflow monitoring studies during swallowing (1, 3) i.e. swallowing always interrupts the breathing of humans, including premature infants (4).

This cessation of respiration during swallowing is known as swallowing apnea. This breathing-swallowing coordination is defined by the point in the respiratory phase cycle where swallowing apnea occurs. Swallowing apnea occurs at one of the following four stages in breathing: during expiration, during inspiration, at the transition between inspiration and expiration or between expiration and inspiration. However, in the past 30 decades, plenty of attempts have been taken to investigate the respiratory swallowing coordination in the normal (5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 17) and clinical population (15, 18). Yet, there appears to be no consistent pattern available for swallow apnea duration. Apart from the fact that swallow apnea occurs in the expiratory phase of respiration, temporal measures of respiratory swallow coordination such as swallow apnea duration revealed varied findings even in the normal participants. It is because of non-uniformity in instrumental procedures, the type, volume and consistency of bolus. Hence, there exists a need for systematic analysis of respiratory swallow coordination especially across the age and gender in the Indian population.

2. Materials and Methods

2.1. Participants

Human volunteers were used for this study. The study protocol was approved by the Institutional Review Board at Kasturba Medical College, Mangalore. Written, informed consent was obtained from each participant. Based on the sample size formula (n = Z21-$\propto$/2 σ2 /d2, where σ is the Standard deviation, d is the precision and 1- σ/2 is the desired confidence level), eight hundred non dysphagic individuals were recruited for the study. They were divided into four groups depending on their age. Group 1 consisted of 100 males and 100 females in the age range of 18 to 40 yrs. Group 2 consisted of 100 males and 100 females in the age of 41-59 yrs. Group 3 consisted of 100 males and 100 females in the age of 60-75 yrs. Group 4 consisted of 100 males and 100 females in the age of 75 yrs and above. The exclusion criteria considered were history of speech, language, neurological and swallowing disorders.

2.2. Procedure

The study followed the cross sectional control group design. Experiments were performed while each subject was seated on a comfortable chair. All swallowing measurements were conducted using the Kay Digital Swallowing Workstation and Swallowing Signals Laboratory (Model 7120; Kay PENTAX). The Kay Digital Swallowing Workstation with signals laboratory is a computer-integrated system of swallowing measurement facilities including cervical auscultation, surface electromyography (sEMG), nasal airflow monitoring and cervical auscultation. Nasal airflow monitoring was used to measure the apneic duration of swallowing associated with each preparation. Respiratory coordination for swallowing was measured using a nasal catheter positioned at the entrance of nares. A Nasal respiratory flow was captured by using a standard, 1.8 meter nasal cannula coupled to the workstation by using the Swallow Signals Lab hardware and software to create a digital display of the respiratory phase and apnea duration. The nasal cannula was calibrated between each individual to ensure accurate measures. Airflow direction was shown on the respiratory display with a green positive trace representing expiration and a red negative trace representing inspiration. The sampling rate for the respiratory tracing was set to 250 Hz.

The participants were requested to swallow the bolus in one complete action. Recording of the swallow commenced with the lip to cup contact. Recording ceased post swallow, after the laryngeal movement was visualized and the participant brought the cup back to resting position. The specific swallowing tasks were recorded for each individual.

A. Dry Swallow It is defined as a swallow involving no external food or liquid. The data was collected as the participants performed three dry swallows. Each swallow was separated by 30 sec. which was determined by the use of stop watch.

B. Thin Liquid Swallow It is defined as a swallow involving intake of water. Each measured quantity of water was passed on to the participants on a spoon. Three thin liquid swallows were elicited from each participant during the recording session. The time interval separating each swallow was maintained as 30 sec.

C. Thick Liquid Swallow It is defined as a swallow involving the ingestion of water mixed with the commercially available rice flakes. Three thick liquid swallows were elicited from each participant during the recording session. 30 sec time interval separating each swallow was maintained.

Three samples were recorded for each volume of boluses. Each participant swallowed the bolus in the following order: dry swallow, 5 ml and 10 ml of thin liquid, followed by 5 ml and 10 ml of thick liquid. The order of presentation of bolus was constant.

2.3. Analysis

Respiratory information (inhalation/ exhalation) displayed as a line tracing was recorded for all swallowing attempts. Respiration points were temporally related to the electro myographic activity. Respiration points included were (1) onset of inspiration, defined as a downward line tracing; (2) swallowing apnea, defined as a horizontal line on the respiratory tracing indicating absence of airflow; and (3) expiration onset, defined as the upward line tracing associated with an open glottic position. In the present study, swallow apnea as well as the respiratory phase where the swallow apnea occurred were measured for each volume and consistency of the bolus. Swallow apnea duration was calculated from these measurements. Swallow apnea duration, measured in seconds, reflects the duration of “non-breathing” during the swallow. Longer apnea durations may reflect more physiologic demands on the subject during swallowing. All these measurements were carried out for each bolus type and volume of food taken for the study.

Statistical Analysis performed is detailed below. The dependent variables included were amplitude and duration of each swallow event. Descriptive statistics were employed to describe all the parameters under consideration. The mean and standard deviation for each measure was obtained for age, gender, bolus type and volume. All statistical analysis was performed using SPSS 10.0 for windows. An alpha level of .01 was used for all statistical tests including the post hoc tests. For each of the dependent variables, 4 x 2 x 3 x 2 (Age x Gender x Bolus type x Volume) MANOVA was performed followed by the Bonferonis post hoc test for the comparison across the age group and various consistencies of food.

3. Results

The present study investigated the respiratory swallow coordination in adults and geriatric population. For this, the respiratory phase in which swallow apnea occurred was measured for each participant across various food consistencies and volume. Also, swallow apnea duration was measured for each participant across various food consistencies and volume. The results are as follows. The coding for various respiratory patterns during swallow apnea is shown below:

EX-EX – Expiration bracketing the swallow
EX-I – Midcusp between expiration and inspiration
I-I – Inspiration bracketing the swallow
I-EX – Midcusp between inspiration and expiration

***Table 1**: Respiratory Phase during Swallowing Apnea in Males*

Tasks	Group 1				Group 2			
	EX-EX	EX-I	I-I	I-EX	EX-EX	EX-I	I-I	I-EX
Dry	96.4%	3.6%	-	-	95.3%	4.6%	-	0.1%
Thick 5 ml	97.7%	2.3%	-	-	96.6%	3.4%	-	-
Thick 10 ml	97.3%	2.7%	-	-	96.3%	2.9%	-	0.8%
Thin 5 ml	97.5%	2.5%	-	-	95.5%	3.5%	-	1%
Thin 10 ml	95.6%	4.4%	-	-	96.9%	3%	0.1%	-

***Table 2:** Respiratory Phase during Swallowing Apnea in Males*

Tasks	Group 3				Group 4			
	EX-EX	EX-I	I-I	I-EX	EX-EX	EX-I	I-I	I-EX
Dry	85.5%	9.1%	3.4%	2 %	64.7 %	17.6 %	5.9 %	11.8 %
Thick 5 ml	83.9%	11.8%	4%	0.3 %	70.6 %	11.6 %	9.1%	8.7 %
Thick 10 ml	79.3%	10.8%	7.7%	2.2 %	67.6 %	13.6 %	7%	11.8 %
Thin 5 ml	81%	3.9%	6.1%	9.0 %	68.6 %	13.6%	11.8 %	6 %
Thin 10 ml	85.6%	8.1%	3%	3.3 %	66.5 %	11.8 %	10.1	11.6 %

***Table 3:** Respiratory Phase during Swallowing Apnea in Females*

Tasks	Group 1				Group 2			
	EX-EX	EX-I	I-I	I-EX	EX-EX	EX-I	I-I	I-EX
Dry	95.6 %	4.4%	-	-	96.3 %	3.7%	-	-
Thick 5 ml	97 %	3 %	-	-	96 %	3.7 %	-	0.3%
Thick 10 ml	96.3 %	3.7 %	-	-	94.1 %	5.5 %	0.1%	0.3%
Thin 5 ml	96.5 %	3.5%	-	-	94.5 %	3.5%	-	2 %
Thin 10 ml	94.6 %	6.1 %	-	0.3%	93.9 %	3 %	0.1%	3%

***Table 4:** Respiratory Phase during Swallowing Apnea in Females*

Tasks	Group 3				Group 4			
	EX-EX	EX-I	I-I	I-EX	EX-EX	EX-I	I-I	I-EX
Dry	83.5 %	9%	5.3 %	2.2 %	67.2%	13.6 %	11.9 %	7.8 %
Thick 5 ml	80.4 %	10.7 %	5.4%	3.5 %	69.5%	10.8 %	10.3%	9.4 %
Thick 10 ml	81.1 %	11. 0%	5.2 %	2.7 %	69.1 %	11.6 %	7%	12.3%
Thin 5 ml	84.0 %	6.9%	5.1%	4.0 %	63.7 %	12.3%	12.9%	11.1 %
Thin 10 ml	8 2.4%	7.8 %	5.5 %	4.3 %	59.3 %	12.2 %	14.3	14.2 %

From the tables 1, 2, 3 and 4, it is evident that EX-EX is the predominant respiratory phase pattern for The occurrence of swallow apnea in all the age groups and across the gender. However, it was seen that as the age increases, percentage of individuals exhibiting EX-EX pattern decreases and the other patterns such as EX-I, I-I, I-EX increases suggesting age related changes in respiratory swallow coordination. This was evident across various bolus consistencies and bolus volume.

Descriptive statistics employed to find out the mean and Standard Deviation (SD) for swallow apnea duration across the age, gender, bolus consistency and volume are shown in the table 5.

Table 5: *Mean and SD for Swallowing Apnea Duration across the Age, Gender, Bolus Consistency and Volume*

Group	Consistency	Volume	Males		Females	
			Mean	SD	Mean	SD
1	Dry	0 ml	1.08	0.15	1.11	0.17
	Thick liquid	5 ml	1.16	0.16	1.17	0.15
		10ml	1.22	0.17	1.24	0.20
	Thin liquids	5 ml	1.14	0.17	1.12	0.17
		10 ml	1.19	0.18	1.21	0.15
2	Dry	0 ml	1.30	0.15	1.37	0.18
	Thick liquid	5 ml	1.38	0.15	1.43	0.17
		10ml	1.53	0.15	1.48	0.17
	Thin liquid	5 ml	1.34	0.15	1.40	0.17
		10 ml	1.40	0.15	1.46	0.17
3	Dry	0 ml	2.09	0.30	2.22	0.23
	Thick liquid	5 ml	2.23	0.28	2.32	0.22
		10ml	2.31	0.28	2.41	0.25
	Thin liquid	5 ml	2.14	0.31	2.28	0.24
		10 ml	2.25	0.27	2.35	0.24
4	Dry	0 ml	2.68	0.32	2.72	0.24
	Thick liquid	5 ml	2.87	0.31	2.85	0.20
		10ml	2.96	0.33	2.96	0.21
	Thin liquid	5 ml	2.77	0.28	2.80	0.19
		10 ml	2.88	0.25	2.89	0.20

From the table 5, it is evident that as the age increases swallow apnea duration also increases. This was evident in both the genders with females exhibiting higher values than males. It was also found that as the thickness of the bolus increases, swallow apnea duration also increases with the thick liquid exhibiting higher swallow apnea duration in comparison to thin liquids. Bolus volume effect was also evident with increase in swallow apnea duration with increase in bolus volume. Results of MANOVA revealed significant main effect of age ($F=11803.45$, $p<0.05$) and gender ($F=51.92$, $p<0.05$) with the significant age and gender interaction ($F=10.755$, $p<0.05$). The results of Bonferronis post hoc analysis across the age revealed the following.

Table 6: *Results of Bonferronis Post Hoc Analysis for the Age Variable*

(I) AGE	(J) AGE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
18-40 yrs	41-59 yrs	-.2351(*)	.00976	.000	-.2609	-.2093
	60-75 yrs	-1.0948(*)	.00976	.000	-1.1206	-1.0690
	75+	-1.6726(*)	.00976	.000	-1.6983	-1.6468
41-59 yrs	18-40 yrs	.2351(*)	.00976	.000	.2093	.2609
	60-75 yrs	-.8597(*)	.00976	.000	-.8854	-.8339
	75+	-1.4375(*)	.00976	.000	-1.4632	-1.4117
60-75 yrs	18-40 yrs	1.0948(*)	.00976	.000	1.0690	1.1206
	41-59 yrs	.8597(*)	.00976	.000	.8339	.8854
	75+	-.5778(*)	.00976	.000	-.6035	-.5520
75+	18-40 yrs	1.6726(*)	.00976	.000	1.6468	1.6983
	41-59 yrs	1.4375(*)	.00976	.000	1.4117	1.4632
	60-75yrs	.5778(*)	.00976	.000	.5520	.6035

** The mean difference is significant at the .05 level*

From the table 6, it is evident that there was a significant difference between all the age groups at $p<0.05$. There was also a significant main effect observed for bolus consistency ($F=40.12$, $p<0.05$). The results of Bonferronis post hoc analysis for the consistency variable revealed the following.

Table 7: *Results of Bonferronis Post Hoc Analysis for the Consistency Variable*

(I) Consistency	(J) Consistency	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Dry	Thick	-.1418(*)	.00945	.000	-.1645	-.1192
	Thin	-.0930(*)	.00945	.000	-.1156	-.0703
Thick	Dry	.1418(*)	.00945	.000	.1192	.1645
	Thin	.0489(*)	.00771	.000	.0304	.0673
Thin	Dry	.0930(*)	.00945	.000	.0703	.1156
	Thick	-.0489(*)	.00771	.000	-.0673	-.0304

** The mean difference is significant at the .05 level*

From the table 7, it is evident that there was a significant difference between all the bolus consistencies considered for the study. There was a significant main effect of bolus volume ($F= 100.54$, $p<0.05$) observed with no interaction effect between bolus consistency and volume ($F=0.012$, $p>0.05$). There was no significant interaction observed between "within group variables and between group variables" at $p>0.05$.

4. Discussion

The one of the primary objectives of this study were to establish normative respiratory-phase patterns and to measure the swallow apnea duration in adults and healthy aged population. The Expiratory-Swallowing-Expiratory respiratory pattern was clearly the predominant phase pattern produced by

healthy adults. This finding supports the earlier work (1, 3, 7, 8, 9, 10, 11, and 12). However they used small numbers of subjects or indirect recording methods. These observations support the theory that exhalation is in some way the preferred respiratory phase that brackets oropharyngeal swallowing activity in adults. This expiratory phase of breathing is usually associated with a paramedian vocal fold position during the early and late stages of the pharyngeal swallow (16) but it was not assessed in the present study. Studies have reported that the paramedian position of the true vocal folds may facilitate the airway closure at the level of the laryngeal valves during the pharyngeal swallow. The paramedian posturing of the true vocal folds appears to place the airway in a protective position compared with the abducted vocal fold posturing characteristic of inhalation before or after swallowing (1, 16).

However, a higher occurrence of inhalation bracketing the swallow was observed in the current study in individuals older than 60 years i.e., in group 3 and 4. Inhalation with an abducted vocal fold position may facilitate entry of portions of the ingested material or saliva into the laryngeal inlet prior to or during the late stages of the pharyngeal swallow. This would be of particular concern in patients with impaired pulmonary defenses, such as suppressed cough or decrease in upper airway sensation. But these individuals who demonstrated the non-dominant phase pattern did not aspirate during the swallow attempts. However, videofluroscopy was not used in this present study to comment on silent aspiration. This altered age-related pattern may predispose the individuals to dysphagia, and aspiration in patients with age-related diseases such as stroke or progressive neurologic conditions. Given the predictions regarding the increases in age-related diseases known to be related to dysphagia and pneumonia, longitudinal studies are required to determine the relationship between abnormal swallowing physiology and respiratory swallowing discoordination, and morbid health outcomes. Hence the respiratory phase relationship during the swallowing activity would be of clinical significance and should be measured during the swallowing assessment.

Swallow apnea duration, like the phase pattern, changes with age. The results of the present study revealed that there was a significant difference between the means of swallow apnea duration across the age groups i.e., as the age advances, swallows apnea duration increases. The functional significance of the prolonged apnea duration is related to an overall increase in total swallow duration that has been shown in healthy aging adults without dysphagia. This is in agreement with the previous studies (19, 20, 21, 22, and 23). Increased apnea duration in the healthy aged population may be compensatory protective mechanism rather than the result of decreased muscle mobility or reaction time, and not indicative of impairment (23). This may be attributed to the plasticity at the cellular level and perhaps also at the supramedullary level with the advancement in age. However, this altered age-related pattern may predispose the individual to more severe dysphagia, and aspiration in patients with age-related diseases such as stroke or progressive neurologic conditions. It suggests the clinical usefulness in attempting to apply norms to the swallow apnea duration when the comparison against disordered swallowing is the need.

There was a significance difference observed across the gender for the swallow apnea duration. These results support the findings of (11) where significant differences were seen across the gender and contradicts the study by (2) where there was no significant difference observed between the genders. Significant main effect of volume was observed in the swallow apnea duration indicating that swallow apnea duration increases with increase in volume. As the volume increases, more demand is expected at the level of laryngeal valves to protect the airway during the pharyngeal swallow. This demand places the airway in a protective position for more duration compared to that during the 5 ml swallow. Hence there is an increase in the swallow apnea duration as the volume increases. This finding is in consonance with the previous findings in the literature (11, 12). The results of the present study did reveal the significant main effect of the consistency indicating that as the thickness decreases swallow apnea duration decreases. This finding could be attributed to the effect of gravity

while swallowing thick and thin liquids. Gravity plays a major role while swallowing thin liquids. As the thin liquids move towards the laryngeal level at the faster pace, duration of airway protection during the pharyngeal swallow decreases and hence there is decreased swallow apnea duration during the thin liquid swallow. However, the role of gravity in thick liquid swallow is not as much as seen with the thin liquids and hence it is expected that the duration of airway protection during the pharyngeal swallow is more.

These normative will be used for comparison against the disordered population i.e., the development of disordered models in patients with disturbed breathing and swallowing coordination. Early detection of swallowing impairment, including breathing and swallowing disco ordination that contributes to aspiration, may lead to prevention of pneumonia or to a cost-effective, expedited swallowing diagnosis and treatment plan. The establishment of a direct link between the abnormal breathing and swallowing patterns with aspiration pneumonia will be a challenge, given the multifaceted nature of aspiration pneumonia, and will require carefully controlled longitudinal investigations of the relationship between breathing and swallowing abnormalities and the occurrence of aspiration pneumonia. The findings of the current study represent an initial step toward this far-reaching objective that has high clinical relevance in the aging population.

5. Conclusion

The present study investigated the respiratory swallow coordination in the normal adults and geriatrics. Results revealed a trend showing increase in swallowing apnea duration with the increase in age. Significant difference was observed between males and females. It was also observed that bolus consistency and volume did influence the swallowing physiology. These normative values could be useful when assessing disordered swallowing leading to early detection of swallowing impairment, including breathing and swallowing disco-ordination that contributes to aspiration. The findings of the current study represent an initial step toward the objective of assessing respiratory swallow coordination. This would be of high clinical relevance in aging population as well in individuals with dysphagia.

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