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The Effect of Bolus Characteristics and Endoscope Position on the Whiteout During Fiberoptic Endoscopic Evaluation of Swallowing

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ABSTRACT

Background: During fiberoptic endoscopic evaluation of swallowing (FEES), the whiteout (WO) phenomenon arises when pharyngeal structures obscure the endoscopic view by contacting the tip of the endoscope during the pharyngeal phase of swallowing. The objective of this study was to investigate the influence of endoscope positioning, bolus volume, and bolus opacity on the duration and intensity of the WO observed with thin liquid boluses during FEES.

Methods: Thirty healthy volunteers undergoing nasoendoscopy performed 3 empty swallows with the endoscope positioned in the nasopharynx (NP), oropharynx (OP), and hypopharynx (HP). Bolus trials consisting of 5 mL and 10 mL portions of green-dyed 3% milk and water were administered in a randomized order. Whiteout duration (WOd) and WO intensity (WOi) were measured for all 11 swallowing trials. The WOd was calculated by a manual frame count and WOi was scored with a 5 point ordinal scale.

Results: Endoscope position significantly affected WOi, but not WOd. Mean WOi was 3.07 ± 1.2 for the NP, 3.3 ± 0.95 for the HP, and 3.67 ± 0.66 for the OP ($P = .039$, Friedman's test). The WOd was significantly longer for milk boluses than for water boluses (0.52 ± 0.13 seconds for water vs. 0.59 ± 0.17 seconds for milk, $P = .019$). The WOi was significantly weaker for milk boluses compared to water boluses (3.49 ± 0.43 for water compared to 3.32 ± 0.49 for milk, $P = .022$). No significant differences in either WOd or WOi were detected between 5 and 10 mL boluses.

Conclusion: The intensity and duration of the WO observed with thin liquid boluses are significantly influenced by both the bolus opacity and the endoscope's position, while the bolus volume has no significant effect.

Keywords: Deglutition, dysphagia, FEES, swallowing, whiteout

Introduction

Fiberoptic endoscopic evaluation of swallowing (FEES) is a highly valued and widely used instrumental assessment for oropharyngeal dysphagia, offering direct visualization of pharyngeal and laryngeal anatomy, sensation, and the ability to detect residue, penetration, and aspiration in real-time.[1,2] During FEES, a flexible endoscope is introduced transnasally and placed in the pharynx to visualize the pharyngeal phase of the swallowing mechanism.[1] First introduced by Langmore et al,[3] FEES provides an excellent visualization of the larynx and pharynx just before and immediately after the pharyngeal phase of the swallow. This allows for effective evaluation of swallowing pathophysiology, as well as resulting issues like penetration, aspiration, and pharyngeal residue.[4,5] The FEES does not capture the peak of the pharyngeal phase; instead, the screen goes white in an event known as the "whiteout"

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(WO). This happens because the endoscope tip makes contact with the rapidly moving structures (pharyngeal walls, base of tongue, velum) or the passing bolus itself, temporarily blocking the view.[6] Clinicians can score the WO based on both its duration (WOd)—the length of time it persists—and its intensity (WOi)—the brightness of the visual occlusion. Previous studies have shown that parameters measured during FEES, such as airway invasion or pharyngeal residue, might be affected by bolus characteristics, such as bolus volume, color, adhesiveness (indicated by a thin layer of residue lining the mucosa of the upper airway post-swallowing), and opacity (indicated by the degree of translucency of the liquid).[7-9] The effect of these characteristics has been studied mostly for liquid boluses.[7] Residue was detected more frequently with artificially colored liquid, and adhesiveness was shown to increase the ability to detect airway invasion.[7,10,11]

Several studies have examined whether WO parameters, i.e., WOd and WOi, correlate with residue or aspiration on FEES,[12-18] demonstrating a correlation between WOi and WOd and pharyngeal residue and aspiration, emphasizing the utility of the WO as a possible tool to predict dysphagia during flexible laryngoscopy. However, only a few studies addressed whether the WO is also affected by bolus characteristics. The effects of bolus volume and consistency on WOd have been assessed by Mozzanica et al.[13] Their findings indicated that the duration of the WO (WOd) was significantly affected by both the volume and the consistency of the bolus, meaning the WOd was shorter both for liquids compared to solids and for smaller compared to larger bolus volumes. It should be noted that the effect of bolus volume on WOd was observed only in semi-solids and not in liquids. The utility of WOi as a potential marker for dysphagia has been investigated in 2 studies thus far. The WOi as a marker for dysphagia was evaluated to date in 2 studies,[12,14] which examined the correlation between WOi and pathological swallowing outcomes, such as residue and dysphagia severity, and none of them evaluated whether WOi is affected by bolus characteristics. To the best of knowledge, the effect of thin liquid opacity on WOi or WOd during FEES has not been previously examined.

In addition to bolus characteristics, endoscope position might also affect the WO during FEES. The WO is elicited by contraction of different pharyngeal structures around the endoscope tip. Depending on the position of the endoscope's tip, the varying anatomical components of the nasopharynx (NP) (velum and superior constrictor), oropharynx (OP) (base of tongue and middle constrictor), and hypopharynx (HP) (epiglottis, arytenoids, and inferior constrictor) coming in contact with it might affect the WO.

The objective of this research was to assess the effect of the position of the endoscope as well as bolus volume and opacity on the duration and intensity of the WO for thin liquid boluses during FEES. The study hypotheses were that WO parameters would not be affected by thin liquid opacity or volume, and that endoscope position would significantly alter WOi and WOd.

MAIN POINTS

- *Bolus opacity affects both WO duration and intensity.*
- *Bolus volume did not affect the duration or intensity of the whiteout.*
- *Endoscope position affects whiteout*

Material and Methods

Study Design and Participants

The study was a cross-sectional study. Thirty healthy volunteers were recruited. Inclusion criteria were age above 18 years. Exclusion criteria were having a positive history for complaints of dysphagia, neurologic disorders, and/or head and neck malignancy, pregnancy, and allergy or intolerance to dairy products.

Each volunteer signed an informed consent. The study was approved by Kaplan Medical Center institutional review board (Approval No.: 0063-23-KMC, Date: April 24, 2023).

Test Protocol

Participants underwent a flexible nasolaryngoscopy with pre-set tasks: 3 "empty" swallows at different endoscope positions (NP, OP, HP), followed by 8 bolus challenges of either 5 mL or 10 mL of either 3% cow's milk or tap water, both dyed with green food coloring.

Participants maintained a natural sitting posture for the entire examination. A flexible fiberoptic endoscope, lightly coated at the tip with a local anesthetic (Ezracaine gel 2%), was inserted through 1 nostril. The endoscope was then positioned in 3 different locations where an empty saliva swallow was recorded: (1) NP—positioning of the endoscope above the uvula, with the soft palate visible in the lower part of the screen (Figure 1), (2) OP—positioning of the endoscope at the level of uvula, while ensuring the epiglottis and vallecula are fully visualized and the epiglottis does not take up more than 50% of the width of the screen (Figure 1), and (3) HP—positioning of the endoscope at the level of the epiglottis, i.e., the epiglottic tip is no longer visible and the glottis is in the center of the screen (Figure 1).

Following the 3 empty swallows, the endoscope was repositioned in the oropharyngeal position and 8 bolus challenges were presented to the participants: 2 boluses of 5 mL 3% cow's milk, 2 boluses of 10 mL 3% cow's milk, 2 boluses of 5 mL of room temperature tap water, and 10 mL of room temperature tap water. All boluses were presented in small cups and were dyed with green food coloring (Mendelberg Food Technologies LTD). Food coloring was performed by adding 3 drops of the food dye to 150 mL of either milk or water and stirring until the thin liquid was uniformly dyed. The volume of the bolus challenges was then measured by a syringe from the prepared colored thin liquids and placed in the smaller cups. The order of bolus presentation was simply randomized and the examining endoscopist was blinded to the volume being presented. Participants were instructed to swallow the entire bolus in 1 swallow. If piecemeal deglutition was observed, the same bolus was presented again.

To maintain consistency, all flexible endoscopies were performed by the same examiner (Y.S.G.), a laryngologist who possessed 8 years of experience performing and interpreting FEES. All exams were performed using the same endoscope (Olympus® ENF-VH, United States) using white light with the brightness level set at auto, after performing a white balance, and recorded with the same system (Orpheus-Medical system Software Version 11.0.70.2) at a video rate of 25 frames per second using the same workstation.

Whiteout Scoring

For all 11 swallows, both WOd and WOi were recorded. Raters were blinded to bolus volume and thin liquid type, but not to study aims.

Figure 1. Screen view of the 3 endoscope positions. NP, nasopharynx, the endoscope is positioned above the uvula, with the soft palate visible in the lower part of the screen; OP, oropharynx, the endoscope is positioned at the level of uvula, while ensuring the epiglottis and vallecula are fully visualized and the epiglottis does not take up more than 50% of the width of the screen; HP, hypopharynx, the endoscope is positioned at the level of the epiglottis, i.e. the epiglottic tip is no longer visible and the glottis is in the center of the screen.

The mean WOi score and mean WOd for each of the 2 identical bolus challenges (5, 10 mL of water and milk) were calculated. Those values were used for statistical analysis.

Whiteout Duration

The WOd was measured according to the method detailed by Mozzanica et al.[13] The process entailed manually counting the frames spanning from the onset of peak screen whiteness to the first frame where the laryngo-pharyngeal anatomy became visible again. By dividing the number of frames in the total 25 frames per second, the duration of the WO in seconds was calculated.

Whiteout Intensity

Whiteout intensity was scored according to Labeit et al's[12] proposed ordinal scoring method: First, the frame with the maximum white superimposition was selected. Then a score from 0 to 4 was assigned, based on the following criteria: (0) No WO, i.e., no frame with white superimposition, (1) less than one-third of the image is white, (2) more than one-third but less than two-thirds of the image is white, (3) more than two-thirds, but not the entire image is white, and (4) the frame is completely white (Figure 2).

Rater Training

Video recordings were scored by 2 independent researchers (H.R.B.—third year Otolaryngology resident, R.K.—sixth year medical student). Both raters reviewed and scored 3 exams with Y.S.G. (training laryngologist), during which training was performed by the laryngologist. Inter-rater reliability was established by having both raters evaluate a subset of 6 tests (20%), and calculations were performed for both WOd and WOi metrics.

Statistical Analysis

Continuous variables were presented using mean and standard deviation or median and interquartile range. Categorical variables were presented as frequencies and percentages. Categorical variables were compared using the Pearson Chi-square test. Another statistical

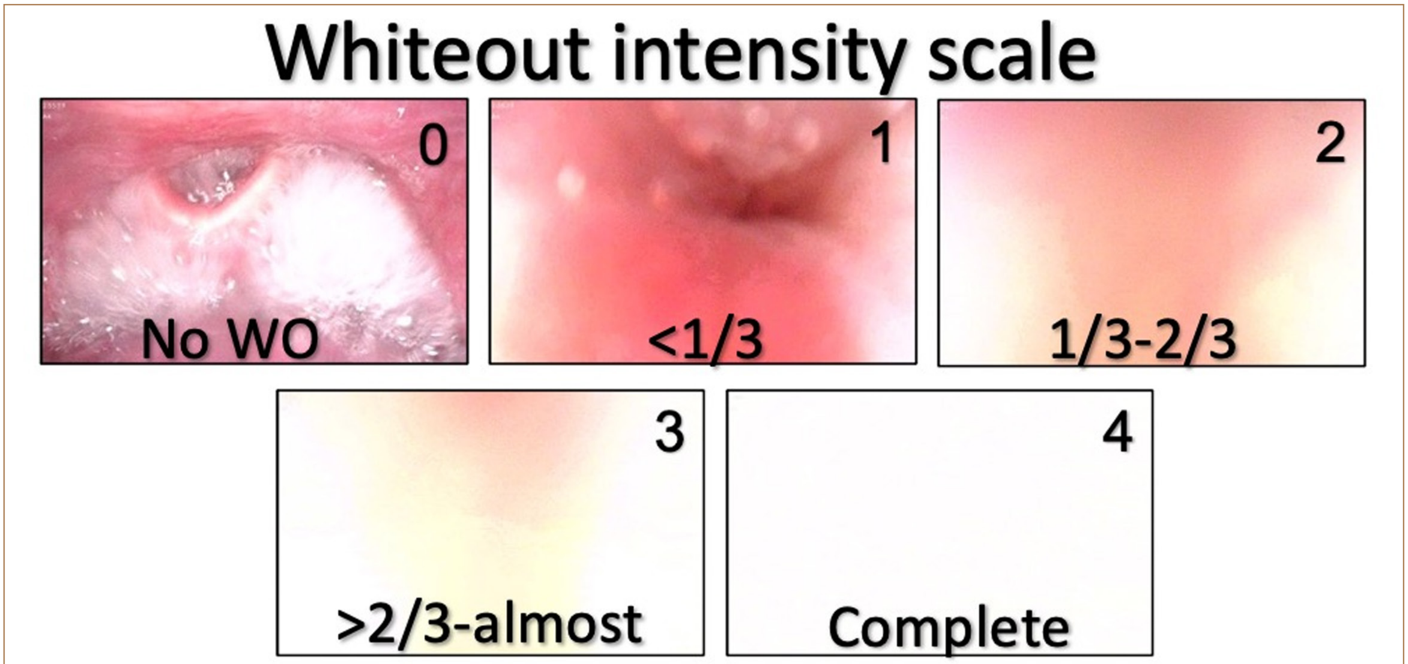

Figure 2. Whiteout intensity scale. The ordinal scale used for evaluation of whiteout (WO) intensity. 0 = no WO is observed, 1 = less than a third of the screen is white, 2 = more than 1/3 but less than 2/3 of the screen is white, 3 = more than 2/3 of the screen is white, but not all of it, 4 = the entire screen is white.

test, adjusted residuals, was calculated in order to define the exact significant categories.

Continuous variables were tested for normality using the Shapiro–Wilk test. Nonparametric tests, such as Mann–Whitney and Kruskal–Wallis, were performed to calculate differences between groups without a normal distribution. Nonparametric correlations, such as Spearman correlation, were performed between continuous variables that were not normally distributed. A reliability test—Cronbach α—was performed to examine the adjustment of different judges.

Results

A total of 30 patients were recruited, 18 of them were males. The mean age of the study cohort was 31.67 ± 6.1 years, range 19-52 years. The interrater reliability was high for both WOi and WOd (Interclass correlation coefficients 0.965-1.0, $P < .001$) for all of the 6 patients (66 swallows).

Endoscope position was found to significantly affect WOi. Mean WOi was 3.07 ± 1.2 for the NP, 3.3 ± 0.95 for the HP, and 3.67 ± 0.66 for the OP ($P = .039$, Friedman's test). However, when performing between-group comparisons, no significant difference was found between the groups (NP-HP, $P = .897$; NP-OP, $P = .071$; Oropharynx-Hypopharynx, $P = .093$).

Mean WOd was 0.62 ± 0.25, 0.61 ± 0.22, 0.68 ± 0.44 seconds for NP, OP, HP swallows, respectively. There was no significant difference found in WOd between the 3 endoscope positions. Table 1 details the mean WOi and WOd for each endoscope positions.

Table 2 and 3 present the mean WOi and WOd scores for all the bolus challenges. There were no statistically significant differences in WOi or WOd when comparing 5 mL and 10 mL boluses of milk (*P* values of .11 and .72, respectively) or water (*P* values of .789 and .523, respectively). Even when comparing all 5 mL boluses (milk and water) to all 10 mL boluses (milk and water), no significant differences were found ($P = .239$ for WOi, and $P = .497$ for WOd).

The WOd was significantly longer for milk boluses compared to water boluses (0.52 ± 0.13 seconds for water vs. 0.59 ± 0.17 for milk, $P = .019$). The WOi was significantly weaker for milk boluses compared to water boluses (3.49 ± 0.43 for water compared to 3.32 ± 0.49 for milk, $P = .022$).

Table 1. Whiteout Duration and Intensity for Different Endoscope Positions

	Mean WO Intensity Score (SD)	Mean WO Duration in Seconds (SD)
Nasopharynx	3.07 (±1.2)	0.62 (±0.25)
Oropharynx	3.67 (±0.66)	0.61 (±0.22)
Hypopharynx	3.3 (±0.95)	0.68 (±0.44)
P	.039	.488

Results presented are mean and standard deviation.
WO, whiteout.

Discussion

Whiteout intensity and duration during FEES are gathering interest in recent years as potential measurable metrics. However, to date, the information about factors affecting these WO parameters is scant. The study was the first to examine whether technical aspects of FEES such as endoscope position, bolus volume, and opacity affect WO intensity and duration. The results show that WO parameters are affected by bolus opacity and endoscope position. These are novel and yet unreported findings. These results partially support the initial hypothesis.

The effect of the endoscope position on the WO was manifested with weaker WOi when the endoscope is positioned in the NP compared to the more distal endoscope positions. A possible explanation for these findings is the different anatomical structures that create the WO in the NP, i.e., the superior constrictor and the soft palate, which are smaller than the medial and inferior constrictors and the tongue base, which would be the main contributors to the WO in the oro-HP, or "home position" that is usually chosen during FEES.[19,20] The WOd was not found to be affected by endoscope position. This finding could possibly be explained by the significant overlap in the timing

Table 2. Mean Whiteout (WO) Intensity for Different Bolus Volumes and Liquids

Comparison Type	Condition A	Condition B	WO Intensity A	WO Intensity B	*P*
Volume comparison (within liquid)	5 mL milk	10 mL milk	3.42 ± 0.51	3.22 ± 0.68	.11
	5 mL water	10 mL water	3.48 ± 0.50	3.50 ± 0.59	.78
Liquid comparison (within volume)	5 mL milk	5 mL water	3.42 ± 0.51	3.48 ± 0.50	.578
	10 mL milk	10 ml water	3.22 ± 0.68	3.50 ± 0.59	.081
Grouped comparison	All milk boluses (5 + 10 mL)	All water boluses (5 + 10 mL)	3.32 ± 0.49	3.49 ± 0.43	.022
	All 5 mL boluses (milk + water)	All 10 mL boluses (milk + water)	3.45 ± 0.42	3.36 ± 0.49	.239

Results are presented as mean ± standard deviation. mL, milliliters; WO, whiteout.

Table 3. Mean Whiteout (WO) Duration for Different Bolus Volumes and Liquids

Comparison Type	Condition A	Condition B	WO Duration A	WO Duration B	*P*
Volume comparison (within liquid)	5 mL milk	10 mL milk	0.58 ± 0.16	0.60 ± 0.22	.72
	5 mL water	10 mL water	0.50 ± 0.13	0.53 ± 0.19	.52
Liquid comparison (within volume)	5 mL milk	5 mL water	0.58 ± 0.16	0.50 ± 0.13	.023
	10 mL milk	10 mL water	0.60 ± 0.22	0.53 ± 0.19	.071
Grouped comparison	All milk boluses (5 + 10 mL)	All water boluses (5 + 10 mL)	0.59 ± 0.17	0.52 ± 0.13	.019
	All 5 mL boluses (milk + water)	All 10 mL boluses (milk + water)	0.54 ± 0.12	0.57 ± 0.18	.49

Results are presented as mean ± standard deviation. mL, milliliters; WO, whiteout.

of the different events during the pharyngeal phase of the swallow, all contributing to the Wod.[21]

The study results showed bolus volume did not affect WOd or WOi. These findings reinforce previously reported findings in the literature. Mozzanica et al[13] measured the effect of bolus volume on WOd by administering 5, 10, and 20 mL boluses in liquids and semi-solid consistencies to healthy subjects. Their results showed no significant difference in WOd for different bolus volumes when administered in liquid state. However, it should be noted that Mozzanica did find that bolus volume affected WOd in semi-solids, hinting at a potential effect in liquids as well that their study and the study were simply underpowered to uncover. However, another explanation for the lack of correlation between bolus volume and WOd might stem from the small bolus volumes chosen for this study (5 and 10 mL). The rationale for bolus volume choice was to ensure the entire bolus was swallowed in 1 swallow. However, these small volumes perhaps limited the demonstration of a possible correlation between bolus volume and WOd.

An interesting and unanticipated finding was the effect of bolus opacity on both WO intensity and WO duration. The WOi was stronger while WOd was shorter for transparent compared to opaque fluids. These are novel and yet unreported findings in the literature. The differences in WOd between water and milk might be explained by the protein and fat content of the milk adhering to the endoscope tip and obscuring the camera, thus prolonging the duration until a clear frame of the pharynx comes into view and artificially prolonging the measured WOd. Another possible explanation could stem from differences in pharyngeal dwell times between milk and water. Butler et al found that milk boluses tend to dwell longer in the pharynx compared to water, i.e., spill into the vallecula/pyriform sinuses prior to pharyngeal phase initiation.[19] It is possible that the movement of the opaque milk bolus might have obscured the endoscope tip prior to pharyngeal contraction, again causing artificial WOd prolongation.

The effects of bolus opacity on WO intensity were also statistically significant. The WOi was stronger for water compared to milk. A possible explanation for this finding might be the different refractive properties of milk compared to water. During the WO, light emitted from the tip of the endoscope hits the pharyngeal walls and is reflected back. When traveling through water, a transparent medium, a greater proportion of the reflected light waves are able to make their way back to the camera at the tip of the endoscope. However, when the light waves travel through milk, an opaque medium, more would get absorbed or diffracted, so that fewer light waves will be captured by the camera, manifesting as a weaker WO intensity. The superior reflective properties of water compared to milk might also manifest in reflection from the water-air interface adjacent to the tip of the endoscope.[20]

The study has several limitations. Its small sample size perhaps makes it underpowered to demonstrate some findings. In addition, the study was limited to thin liquid boluses in healthy adults, so the generalizability of its results is limited. Furthermore, the differences in WOi and WOd, while statistically significant, are small, and their clinical relevance and applicability are yet to be determined.

For thin liquid boluses during FEES, bolus opacity affects both WO duration and intensity, while endoscope position affects WO intensity. Bolus volume does not affect WO parameters for thin liquid boluses.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Kaplan Medical Center (Approval No: 0063-23-KMC, , Date: April 24, 2023).

Informed Consent: Written informed consent was obtained from the participants of the study.

Peer-review: Externally peer-reviewed.

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